SOILLESS CULTIVATION OF CUCUMBERS AND TOMATOES UNDER PROTECTION IN NATAL

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M.Sc. Agric. (Natal)

Submitted in partial fulfilment of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

in the

Department of Horticultural Science
Faculty of Agriculture
University of Natal
Pietermaritzburg

January, 1982

DECLARATION

I hereby certify that the research work reported in this dissertation is the result of my own original investigation, except where acknowledged.

SIGNED............................

(I. E. SMITH)

ACKNOWLEDGEMENTS

The author is grateful to Professor B.N. Wolstenholme for advice in the writing of the manuscript, and for helpful discussion during the period of the study.

Many thanks are due to Mr M.J. Savage, for his helpful co-operation and loan of equipment for meteorological measurements. Much of this work would have been less meaningful without his enthusiasm and expertise.

Several fourth year students in the Dept. of Horticultural Science were also involved in the running of the experiments as part of their final year studies. Thanks are due to Messrs. P. Whitfield, T. Richards, J. Cutting, G. Rose, P. Mills, W. Blackbeard, and Misses J. Glen and S. Duigan. Several Agrometeorology students were also involved in the taking of meteorological records. Their time and effort was appreciated.

Thanks also to Mr G.P.Y. Clarke and Mr D. Chalton of the Dept. of Biometry and Statistics for advice in planning experiments and using the computer.

Donations of equipment, fertilizers, and growing media were made by several companies. Thanks are due to:-

Bayer Agrochem (Johannesburg) for ® Lewatit
DRG Plastics (Cape Town) for plastic mulch
Gundle Plastics (Johannesburg) for ® Uvidek plastic
Gromor (Cato Ridge) for local peat, bark, mushroom compost and other media
Huletts (Durban) for milo and bagasse
Perlite Industries (Johannesburg) for perlite
Triomf Fertilizers (Durban) for phosphoric acid

Some financial support was provided by the University of Natal Research Fund.

Technical aid was provided by Mr M.E. Gough (Phytotron Senior Technician) and Mr R. Alcock and Miss D. Hansen of the Dept. of Horticultural Science, to whom thanks are due.

Many thanks to Mrs. D. Judkins for her expert typing and patience.

Special thanks, and sincere appreciation to Zula, my wife, for patience and back up, and to Alec, Robert and Donovan, who often wondered who 'Dad' was!

Finally, mention must also be made of Prof. E.W. Laubscher and Mr. P. Maree of the University of Stellenbosch, who established an Association for the Production of Vegetables under Protection in South Africa, and whose enthusiasm has resulted in a small, but now firmly based, and viable industry in this country. Our continuous contact, and trip overseas, have been rewarding experiences.

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INTRODUCTION

Plastic film-covered semi-circular shaped greenhouses for growing plants have been described by Anon. (1969), Roberts (1975), Nelson (1978) and many others in different parts of the world. Generally such structures are referred to as plastic covered greenhouses or film plastic greenhouses (Roberts, 1975; 1981; Nelson, 1978), or single span tunnels, or plastic tunnels (Anon., 1969; Allington, 1974). The last term is used by the author throughout this report when referring to such structures.

Most designs are based on that of Allen and Allington at Lee Valley Experimental Horticulture Station, U.K. (Allington, 1974), described in a Station leaflet (Anon., 1969). In South Africa, commercial units usually measure 30 to 50 m in length, 8 m in floor diameter and 3,2 m in height, and are covered with a single layer of clear polyethylene film (Anon., 1978). Typically the film is 150 µm thick and includes uv stabilisers. Depending on conditions the film lasts for about two years. Probably the first double layer tunnel (Roberts, 1975; Nelson, 1978) in South Africa has recently been erected at Pietermaritzburg.

As growers in South Africa demanded research back-up for their enterprises research was started in 1972 at the University of Stellenbosch, situated in a Mediterranean climatic area (Wolstenholme, 1977), with extremely high summer solar radiation intensities (Maree, 1979a). The University of Natal, Pietermaritzburg, situated in a cool subtropical summer-rainfall area (Wolstenholme, 1977) commenced research in this field in 1976. In both areas absolute winter minimum temperatures may reach -2 ^{o}C, with absolute maximum summer temperatures of $\pm$ 40 ^{o}C. In summer and winter, noon irradiance levels on cloudless days are typically 1 000 W m^{-2} and 600 W m^{-2} respectively (Savage & Smith, 1980). These levels are much higher than typical European summer conditions (Anon., 1980a). More detailed climatic data are presented in later sections. Tunnel climatic data have been accumulated locally at Stellenbosch (Maree & Laubscher 1976a; b; Maree, 1979a;b;c), Pretoria (Oosthuizen & Miller-Watt, 1978), and Pietermaritzburg (North, 1979; North, de Jager & Allan, 1978).

The first commercial growers used soil as the growing medium but soon encountered problems with nematodes, bacterial wilt, bacterial canker and *Fusarium*, and were forced into soilless culture systems. Originally commercial tunnel units were sold with vermiculite included as the growing medium. This was successful and vermiculite is still used by some growers. However, the cost, the high pH of the local product, and its compaction with use, limited its reusability, and have forced growers and researchers to look for alternatives (Smith, Whitfield, Savage & Cass, 1979; Maree, 1981a). The author (Smith *et al.*, 1979) has had success with local peat, perlite, and more recently with pinebark and sawdust. Maree (1979a;b;c; 1981a;b) reported good results with strawbales and rockwool, and recently with sawdust. A major objective of the research reported here was to develop a system for tomatoes and cucumbers using a locally obtainable, cheap, re-usable medium suited to local conditions.

At the same time an easy-to-use system of 'hydroponics' was required preferably without the expensive structures of a true hydroponic system (Harris, 1970). Hydroponics is usually defined as "the science of growing plants in a medium, other than soil, using mixtures of the essential plant elements dissolved in water" (Harris, 1970; Sholto-Douglas, 1975). According to Harris (1970), Ellis, Jensen, Larsen & Oebker (1974) and Cooper (1979) the term hydroponics is derived from the Greek words -'hydro' (water) and 'ponos' (labour) - and was coined by D.W.F. Gericke in California.

The terms hydroponics, water culture, sand culture, gravel culture, aquaculture, solution culture, mist culture, drip irrigation, soilless culture and vermiculture, are widely used to describe a particular system of applying plant nutrients to the roots of the plant. Each, in its own way, is a method of substituting some other medium for soil (Ellis *et al.*, 1974). All systems place nutrients in intimate contact with the plant roots. Ellis *et al.* have preferred the term 'nutriculture', and have used it to describe most systems. In their opinion the word hydroponics has popular appeal. The term 'hydroculture' has been used for the domestic application of hydroponics (Horsfall, 1980).

More recently the system has been further developed into the Nutrient Film Technique (NFT), which is by definition "a simple system of hydroponic culture in which plants have their roots in a shallow stream of recirculating water in which are dissolved all the elements required for growth" (Cooper, 1979). The stream of water is very shallow, and the upper surface of the root mat is in the air, thus ensuring a constant supply of oxygen. Israeli workers have recently produced a slight modification of the NFT system known as the Ein-Gedi system (Anon., 1981a).

Nutriculture systems differ in the type of media in which the roots grow (Ellis *et al.*, 1974). This may be a liquid medium (hence the name water culture or hydroponics) or a solid medium. Many forms of solid rooting media have been used and the general term 'aggregate culture' has evolved to cover them all (Ellis *et al.*, 1974; Cooper, 1979). With aggregate media the nutrient solution can be applied either in a closed system, or in open systems. In the latter nutrient solution is supplied to the aggregate, and any excess liquid drains to waste. Adamson (1977) described this as a wasting system. In closed systems the aggregate is moistened with the nutrient solution, and the draining liquid is collected and re-used (Harris, 1970; Ellis *et al.*, 1974; Cooper, 1979). This is also known as a recirculating system (Adamson, 1977).

For tomatoes and cucumbers under South African conditions a wasting or non-return system seemed most appropriate, as used in Ireland (Maher, 1972), U.S.A. (Ellis *et al.*, 1974; Jensen, 1975; 1980), United Kingdom (Wall, 1973; Bunt, 1976), Canada (Adamson, 1977; Anon., 1980b), Scotland (Wilson, 1981), Guernsey (Anon., undated a; Moorat, 1981), New Zealand (White, 1978), Holland (Klapwijk, 1981), Sweden (Jorgensen & Jonssen, 1978), Norway (Guttormsen, 1976) and other countries. A second objective of this project was therefore to research the suitability of non-return systems under South African conditions.

Different nutrient solutions are recommended world-wide, and research was also undertaken into this complex field. There are basically two distinct types of open system nutriculture. A complete, balanaced, nutrient solution can be fed to the plants at each watering, such that excess liquid just drains from the bottom of the container, as in Jensen's (1980) sand culture, and Adamson's (1977) sawdust culture. Examples of nutrient solutions recommended are shown in Table 3.3.

Alternatively, base fertilisation (Bunt, 1976) or 'pre-enrichment' (Anon., undated a; Moorat, 1981) of the medium in the container, or fertiliser pre-mixing (Maas & Adamson, 1980), takes place before planting. This is followed by watering with a solution containing N, P and K in the correct proportions. Examples of pre-enrichment recommendations for different media in various countries are given in Table 3.4, and suitable liquid feeds in Table 3.5.

Both these systems were included in the research for this thesis, and of necessity a broad approach was adopted. It was first established which media and nutrient solutions would perform satisfactorily, considering that many of the recommended chemicals were not available locally at the start of the study, and had to be substituted for in certain cases.

Thus the work reported here was aimed at establishing an infant industry on a firm scientific footing by adapting overseas expertise to local conditions, starting with the growing of the seedlings and taking them through to harvest.

Climatically, and especially in terms of radiation intensities, local conditions differ considerably from other countries where most of the research has been carried out. Thus it could be expected that fertilisation, water usage (Maree, 1981a), and physiological responses (Hammes, Beyers & Joubert, 1980) of tomatoes and cucumbers might differ. For this reason measurement of tunnel climate, its modification, and the plant's growth reponses, formed a major part of this study, as in other centres in South Africa. This is important since all the seed used is bred and multiplied under European conditions.

Generally, conditions here are more akin to those in Arizona than Europe. Thus much of the work was based on the recommendations of Ellis *et al.* (1974), and Jensen (1975; 1980). Of importance also, is that the price structure of the protected cultivation industry in South Africa differs considerably from overseas countries. Meyer (1978) and Kassier (1979) reported on the economics of plastic tunnel grown tomatoes in South Africa. The latter author concluded that there was zero profitability on a one hectare tomato plastic tunnel operation in the Stellenbosch area. The introduction of expensive cooling and heating systems to more precisely control the climate has generally not succeeded, mainly because growers in frost-free areas of the country can produce all year round without protection, and at low costs. The system to be researched had to take these facts into consideration.

The same argument is not however true for European ("hot-house") cucumbers, which must of necessity be grown under protection.

Overall therefore, the aim of this research was to establish recommendations for the growing of tomatoes and cucumbers under protection in Natal, starting from seed, through to harvest using soilless media and nutriculture systems. At the same time the plants' response to modified climate was investigated. Physiological studies did not form part of the research.

Van Bavel (1981) has noted the rapid expansion of the greenhouse industry in warmer areas, and in comparison to cooler areas has stated, "precedent and transferable technology are often lacking, and the research opportunities are in the innovative use of materials and of solar and of waste energy utilisation."

CHAPTER 1

CONTAINER SEEDLING PRODUCTION

1.1 LITERATURE REVIEW

The first step in tunnel production is the raising of the seedlings to a suitable size for transplanting into the tunnel. The fast increasing popularity of growing vegetable seedlings in container trays in South Africa, both by growers themselves, and by specialised nurserymen on a large scale, has necessitated research into this system of production under local conditions. The high cost of imported media has led to growers experimenting with cheap locally available media, often resulting in large scale losses and poor seedling growth due to lack of knowledge. These losses have not been recoverable as the advantages of an early crop during a high price period have been lost.

European and American greenhouse growers have traditionally grown tomato seedlings in 100-150 mm diameter pots to a stage when first flowers are visible (Anon., undated a; Wittwer & Honma, 1979; Moorat, 1981), before transplanting into beds or containers. Usually the objective is to grow the plant until the spring solar radiation levels are high enough to support good growth. Supplemental radiation may be provided for the seedlings.

Various types of peat blocks have been successfully used for other types of vegetables (Cox, McKee, Dearman & Kratky, 1978), as well as tomatoes (Gray, Steckel & Ward, 1980) and cucumbers (Wittwer & Honma, 1979). The size and shape of the block, and the time before transplanting can affect the subsequent growth and yield (Cox, 1979).

Re-usable seedling trays are also becoming popular locally with growers. If the trays are kept above ground, 'air pruning' of the roots takes place. Secondary root development then occurs resulting in a characteristic root plug, which holds together and allows for easy transplanting and a minimum of root disturbance (Anon., 1981b). The shape and size of each compartment can affect immediate and subsequent growth of the seedling (Glen, 1980).

Usually the inverted pyramid shape is preferred since the roots are forced to grow downwards, and no root circling occurs (Anon., 1973). Containers with round shaped compartments are, however, also used with equal success, provided that management of the seedlings is correct (Hartmann & Kester, 1975).

After selection of the container type, the actual growing of the seedling is largely dependent on the growing medium and the fertilisation applied. Most overseas systems are based on high quality, pre-enriched, sphagnum peat (Irish, Russian, Finnish or Canadian). This is usually mixed with vermiculite, polystyrene, perlite or other inert material (Baker, 1957; Boodley & Sheldrake, 1972; Bunt, 1976; Anon., 1981b). Speedling Inc., of Sun City, Florida use a mix of 45 per cent. Canadian peat, 45 per cent. American vermiculite, and 10 per cent. polystyrene beads (old ground up trays) (Roode, 1981).

Although most of these ingredients are available in South Africa, their cost and quality make them unsuitable. An important objective of the following study was to find a cheap, easy-to-use, locally available replacement for imported media. The only published work in South Africa is that of Zingel (1981), who obtained best results with tomato seedlings in a J. Arthur Bouwer medium, imported from Britain, and containing peat with sand and bark.

In most of the earlier work, local peat was used in many of the commercial mixes tested. Subsequently, however, the quality of the product deteriorated. The limited supply and large demand made it necessary to seek alternatives.

Apart from the medium, detailed aspects of which are reviewed in Chapter 3, the other critical factor in seedling production is nutrition. Nutriculture principles apply equally during this phase where seedlings are grown in soilless media in trays.

In Guernsey tomato seedlings are raised in pre-enriched peat, and watered with a solution containing 170 ppm N, 74 ppm P and 374 ppm K (N:P:K ratio = 2,3:1:5) (Anon., undated a). The Glasshouse Crops Research Institute, U.K., recommends a pre-enriched peat : sand medium for raising tomato seedlings as shown in Table 1.1 (Smith, 1973). The seed compost is used for germination, and the potting compost for growing the seedlings from pricking out to transplanting. At all times the seedlings are watered with a solution containing 150g ℓ^{-1} KNO_3 (105 ppm N and 280 ppm K; N:K ratio = 1:2,5).

TABLE 1.1 Pre-enrichment recommendations for tomato seedling composts according to Smith (1973)

Fertiliser	Amt fertiliser (g m^{-3})	
	Seed compost	Potting compost
$(NH_4)_2\ SO_4$	217	
Calcitic lime	1 734	1 300
Single supers	434	867
K_2SO_4	217	434
$(NH_4)_2\ NO_3$		108
Ureaformaldehyde		217
Dolomitic lime		1 300
FRIT		217

Wittwer & Honma (1979) state that high nitrogen and high phosphorous levels during early seedling stages are necessary to produce the maximum number of flowers and fruit in the first truss in tomatoes. In an experiment 400 ppm N and 30 ppm P resulted in the most flowers in the first truss. These authors recommend watering seedlings with 4 g ℓ^{-1} of a fertiliser containing 10 % N, 23 % P and 14 % K, which is equivalent to a solution containing 400 ppm N, 920 ppm P and 560 ppm K.

A more detailed discussion of pre-enrichment and nutrient solutions is presented in Chapter 3.

The primary objective of this part of the research, therefore, was to devise an acceptable nutriculture programme for growing cucumber and tomato seedlings, using commercially available nutrient solutions, and comparing these to overseas norms.

1.2 GENERAL PROCEDURES

All seedling research was carried out in a small plastic enclosed tunnel (15 m x 5 m), covered with ® Uvidek 620, a UV stabilised, 150 µm polyethylene film (for transmission properties see North (1979) and section 2.3).

All research, unless otherwise stipulated, was done with standard white polystyrene seedling trays manufactured locally by Roode-Lyon (Pty) Ltd. under licence from the parent company Speedling Inc., Sun City, Florida. Each tray had 24 inverted cone-shaped cavities 30 mm square at the top, 60 mm in depth and with a volume of 36 ml. Outside tray dimensions were 336 mm x 133 mm. Typically, a 24 compartment tray constituted a plot, with the three seedlings at each end constituting guard rows, i.e. 18 seedlings per tray were harvested as data plants.

The trays were were placed on 1 m high, level, metal racks covered with chicken wire. Watering was done by hand, using a watering can with a fine rose sprinkler, so that each tray received approximately the same amount of water or nutrient solution, according to requirement.

Once the largest seedlings had reached the assumed optimum size for transplanting, all seedlings were removed from the trays and washed thoroughly to remove all the rooting medium from the roots. The fresh and dry mass of the whole plant, roots, stem and leaves were then determined, as well as stem length and leaf area in certain cases.

Close correlations between plant fresh mass and dry mass, top fresh mass and dry mass, root fresh mass and dry mass and root/shoot ratios on a fresh mass and dry mass basis were found in tomatoes (App. Fig. 1) and cucumbers (App. Fig. 2). Thus only fresh mass results are shown and discussed in most instances.

Statistical Analysis

All experiments were designed according to the standard procedures of Cochran & Cox (1957) and Rayner (1967), and analysed on a Univac computer of the University of Natal, using the Genstat system of Rothamsted Experimental Station, U.K. Throughout the thesis the use of the words 'highly significant' refers to significance at P = 0,01 (**), and the word 'significant' refers to significance at the level P = 0,05 (*) (Rayner, 1967).

Most results are presented in Figure form and least significant differences (LSD's) are shown where significance was found. Where no LSD is shown differences were not significant.

1.3 EFFECT OF ® SPEEDLING COMPARTMENT SIZE (Experiment 1)

1.3.1 <u>Aim</u> - A wide range of ® Speedling trays is available commercially with different numbers of compartments per tray, and with various compartment depths, top measurements and volumes. From the onset it was important to test which would be the most suitable for tomato and cucumber seedling production.

1.3.2 <u>Procedure</u> Tomatoes (*Lycopersicon esculentum* Mill. cv. Heinz 1370) and cucumbers (*Cucumis sativus* L. cv. Ashley) were grown in three different sized compartments (Table 1.2) in a 1:1 Irish peat: vermiculite medium, and watered twice daily with a nutrient solution containing 2 g ℓ^{-1} ® Chemicult (a commercial, complete mixture-composition in Table 3.8). The plants were sampled at four, six and eight weeks after sowing (1980:03:01). The trial was a 2 x 3 factorial with three replications. One third of the number of seedlings per plot were harvested at each sampling.

TABLE 1.2 Sizes of the three different ® Speedling compartments used in Experiment 1

Tray Size (mm)	Number compartments per tray	Compartment Dimensions				
		Length (mm)	Top Dimensions Breadth (mm)	Area (mm^2)	Depth (mm)	Volume (ml)
675x343	228	28	28	784	60	22
"	128	30	30	900	60	36
"	72	50	50	2 500	100	110

1.3.3 <u>Results and Discussion</u> Tomato and cucumber seedlings grown in the largest compartment size were highly significantly larger than those grown in the smallest compartment size as soon as four weeks after sowing (Fig. 1.1). After a further two weeks these differences became greater, and by eight weeks the best tomato seedlings had a mean mass of 24 g plant^{-1} (72 compartment tray) as compared to 8 g plant^{-1} (228 compartment tray). Cucumber seedlings in the '72' trays had a mean mass of 16 g plant^{-1} as compared with 8 g plant^{-1} in the '228' trays. Both shoot mass and root mass were significantly greater in the

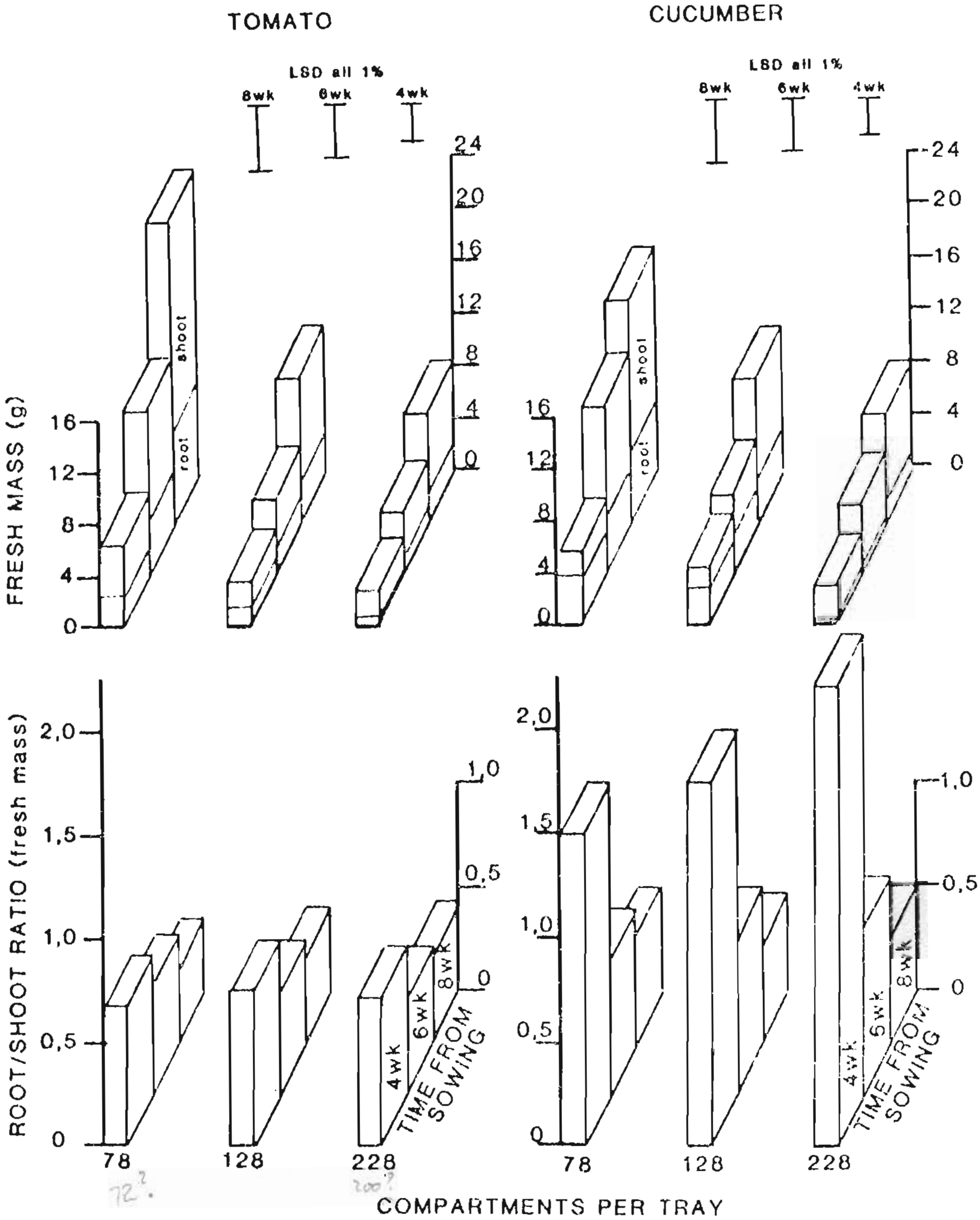


Fig. 1.1 Plant fresh mass and root/shoot ratio of tomato and cucumber seedlings grown in different sized compartments for different lengths of time

largest compartments (Fig. 1.1). Differences in mass were thus evident early on, and became more marked with time.

Measurements of plant height (Fig. 1.2) also showed that up to eight weeks from sowing the plants in the largest compartments had grown significantly better. The growth in height was significantly less in the '128' and '228' trays than in the '72' trays after four weeks. After six weeks a spacing (etiolation) effect began to show up causing the plants in the '228' tray to be slightly taller on average than those in the '128' tray (Fig. 1.2).

Leaf area (Fig. 1.2) showed a similar response to plant mass in that it was highly significantly greater in the '72' trays in both cucumbers and tomatoes. Despite the fact that tomatoes, especially, tended to grow taller in the '228' trays than the '128' trays, their mean leaf area was always smaller because of the etiolation effect.

The root/shoot ratio was usually always lowest in seedlings which had grown most vigorously, i.e. plants with the greatest mass usually had a smaller root system relative to their shoot mass (Fig. 1.1). In tomatoes and cucumbers the ratio decreased markedly between four and six weeks from sowing, from $\pm$ 0,75 to $\pm$ 0,5 in tomatoes, and from $\pm$ 2,0 to 0,75 in cucumbers. After eight weeks it was 0,35 in tomatoes and 0,5 in cucumbers, indicating that root growth declined in relation to shoot growth. In the smallest compartments shoot growth was more adversely affected and these seedlings therefore had a slightly higher root/shoot ratio (Fig. 1.1), although this effect was non-significant.

In a parallel trial with cabbage and lettuce (Glen, 1980), in which similar responses were recorded, the seedlings from the smaller compartments took longer to mature after transplanting and had lower final yields. The longer the seedlings were kept in the container the greater was the effect. Tomatoes and cucumbers are, however, long season crops and can recover from restrictions in the seedling stage to give similar final yields. Gray *et al.*, (1980) found that the size of the peat block and the time of transplanting (six weeks versus eight weeks) did not affect final field tomato yields, despite the fact that the plants differed considerably in size at transplanting.

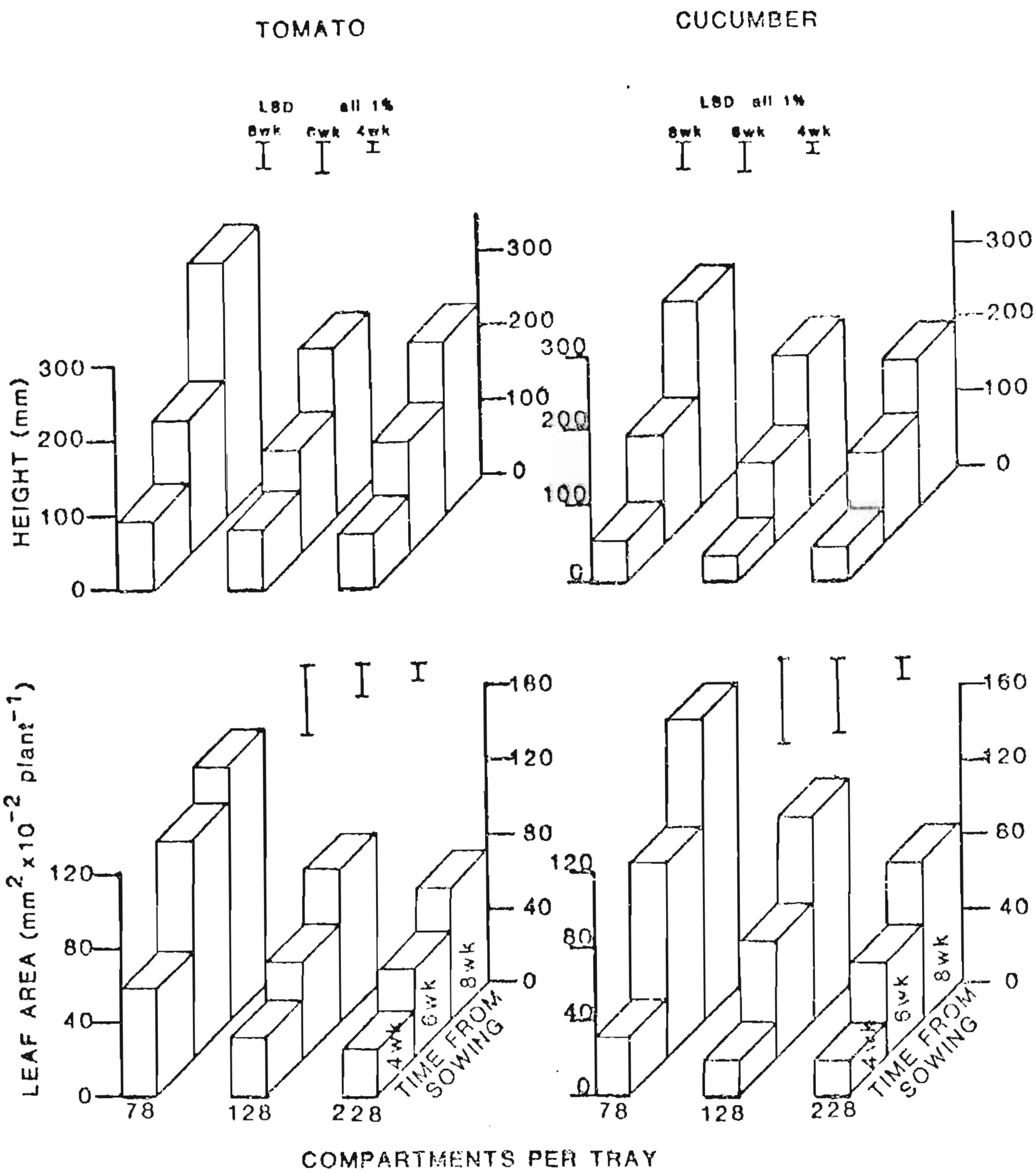


Fig. 1.2 Height and leaf area of tomato and cucumber seedlings grown in different sized compartments for different lengths of time

A recommendation on seedling compartment size must also consider costs. Large cavities require more growing medium per plant, have higher transport costs as there are few seedlings per tray, take a longer time for the root 'plug' to firm up, and must thus be managed for longer.

1.3.4 Conclusions

Noting seedling growth, and costs, the '128' trays are considered to be the most suitable. They have been recommended to, and are used by, most local growers.

1.4 EFFECT OF pH ADJUSTMENT IN THREE LOCAL MEDIA (Experiment 2)

1.4.1 Aim Growers initially used two local media for growing seedlings viz. vermiculite - the local product can have a pH up to 9,6 (Nelson, 1969), and local peat - rated at 6 on the von Post scale for measuring peat decomposition (Bunt, 1976), and with a pH 5-5,5. Problems were soon encountered and as a result this trial was set up to test whether an adjusted pH would not improve seedling growth. Similarly to Nelson (1969) the vermiculite pH was adjusted using acid or by mixing with peat, and that of peat by adding lime.

1.4.2 Procedure Tomatoes (cv. Heinz 1370) and cucumbers (cv. Ashley) were sown into either local peat, or vermiculite, or a local peat: vermiculite mixture. The $pH_{(H_2O)}$ of each medium was adjusted to approximately 5,5, 6,5, 7,5 (where possible) by adding sulphuric acid to the vermiculite, calcitic lime to the peat, and by varying the proportion of peat and vermiculite for the mixture (Table 1.3).

After germination all seedlings were watered twice daily with a nutrient solution of 2 g ℓ^{-1} ® Chemicult (Table 3.8) until normal transplanting size, when the final results were taken. The trial was a 2x3x3 factorial with 3 replications, and was carried out during April, 1980.

1.4.3 Results and Discussion Tomato and cucumber seedlings had a significantly greater plant mass at transplanting when grown at an initial pH of 6,5 as compared with 7,5 in all three media (Fig. 1.3). In most cases pH 5,5 resulted in an intermediate fresh mass. At any given pH the growth was always significantly better in the local peat medium. The peat/vermiculite mixture usually resulted in poorer growth than vermiculite only, but not significantly so.

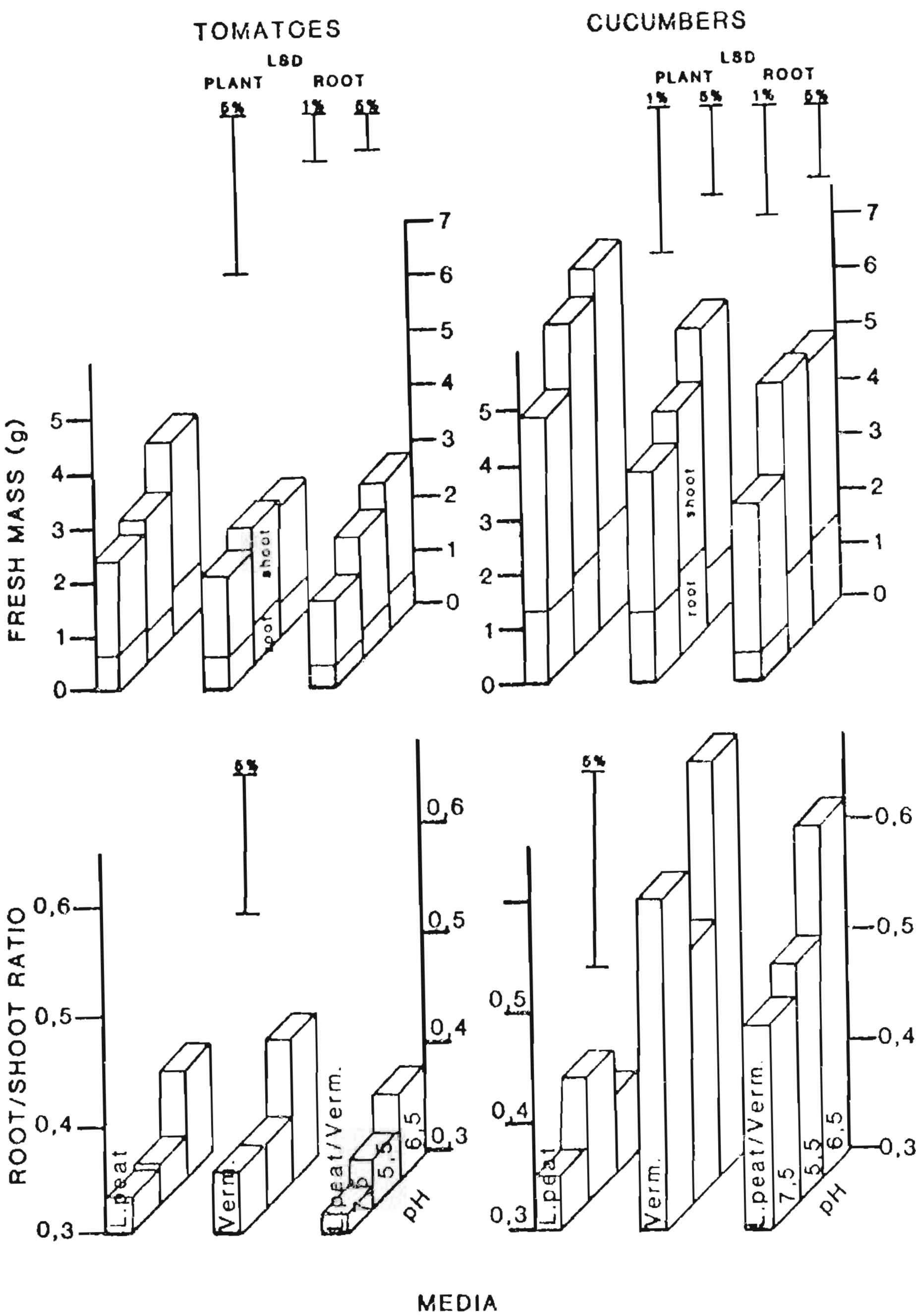


Fig. 1.3 Fresh mass and root/shoot ratio of tomato and cucumber seedlings grown in three media adjusted to three pH's

TABLE 1.3 Media combinations and pH's used in Experiment 2

Medium	TRT	Proportions in mix (by mass)	Initial pH (water)	Final pH (water)
Peat/Vermiculite	1	7:1	5,7	6,4
	2	1:2	6,6	7,1
	3	1:12	7,4	7,6
		mℓ 1N H_2SO_4 kg^{-1}		
Vermiculite	1	330	6,6	7,2
	2	115	6,8	7,6
	3	0	7,2	7,6
		g Calcitic lime kg^{-1}		
Local Peat	1	0	5,4	6,3
	2	2,85	6,3	6,7
	3	6,25	6,7	7,1

The response to pH in vermiculite was variable (Fig. 1.3). This was probably because the final pH's in the three vermiculite treatments were similar (pH 7,2 - 7,6, Table 1.3), all of which were detrimental to good growth.

The significantly best treatment was local peat limed to pH 6,5.

In cucumbers a signicantly greater mean root mass was produced by plants grown in local peat at pH 6,5 than in most other treatments (Fig. 1.3). In tomatoes most treatments resulted in a similar mean root mass and the plants in local peat (pH 6,5) only had a significantly greater root mass than those in peat/vermiculite (pH 7,5) (Fig. 1.3). Generally the largest plants had the biggest root systems, with the notable exception of the tomatoes and cucumbers in vermiculite (pH 6,5), which had relatively smaller root systems than other plants at the same pH.

As in the previous trial, root/shoot ratios (Fig. 1.3) tended to be highest in those treatments which resulted in the poorest growth. Thus vermiculite, as a medium, and at pH 7,5, tended to result in plants with a relatively large root system in relation to its shoot sytem, with a ratio of ± 0,6 and 0,4 in cucumbers and tomatoes respectively. Cucumbers and tomatoes in local peat had root/shoot ratios of ± 0,35.

Although these responses have been attributed to pH it is important to note that other properties of the media may have influenced growth eg. Ca content, Mg content (South African vermiculite has a high Mg content)(Table 3.1), and aeration. Physical properties of the two media, eg. water retention and total air porosity are, however, similar (Mastalerz, 1977) (Table 3.10).

The final pH's of the different media were mostly higher than at the start, probably due to the fact that the water used had a pH above 7, and the ® Chemicult solution had a pH 6,5 (Fig. 3.5, Chapter 3). Vermiculite especially, tends to take on the pH of the applied nutrient solution, and thus the three pH treatments in this medium ended up the same. Nelson (1969) reported a similar finding.

1.4.4 Conclusions Local peat, adjusted to pH 6,5 with lime, proved a suitable medium, and resulted in better growth than a peat/vermiculite medium.

1.5 COMPARISON OF SIX COMMERCIAL AND GROWER-FORMULATED MEDIA (Experiment 3)

1.5.1 Aim The aim of this experiment was to compare several different media which were being used commercially with imported peat and other local products.

1.5.2 Procedure Tomatoes (cv. Heinz 1370) and cucumbers (cv. Ashley) were grown in various commercial and grower-formulated media. The composition of the six media was as follows:-

1. ® Finnpeat (a pre-enriched, pH stablised, high quality, imported Finnish peat, sold as ® FINNPEAT ST 400 by Starke-Ayres, P.O. Box 304, Eppindust 7475, South Africa).

2. Local peat (a poor quality sphagnum peat mined near Johannesburg, and classified on the von Post scale for measuring peat decomposition as H6 (Bunt, 1976), with lime added according to Experiment 2.

3. Newcastle peat (a poor quality sphagnum peat mined near Newcastle, Natal and classified as H5 on the von Post scale).

4. Amberglo medium (formulated for use in ® Speedling trays by Amberglo seedlings, P.O., Merrivale, Natal, and consisting of local peat, fine sand and a well matured compost).

5. Roode-Lyon medium (formulated and previously sold commercially by Roode-Lyon (Pty) Ltd., P.O. Box 3323, Pretoria, and consisting of local peat, fine sand and a well matured compost).

6. Biggs' medium (a very well composted pine bark, with a relatively small particle size).

Only the Finnpeat was pre-enriched.

Seedlings were watered twice daily, until ready for transplanting, with a nutrient solution containing 2 g ℓ^{-1} ® Chemicult. The trial was a 2x6 factorial with six replications, and was started in September, 1980.

1.5.3 <u>Results and Discussion</u>

In both tomatoes and cucumbers plant mass and plant height were highly significantly greatest in ® Finnpeat (Fig. 1.4). Cucumber and tomato seedlings had a mean mass of 7 g plant^{-1} and 4 g plant^{-1} respectively at harvest when grown in ® Finnpeat, as compared with 5,5 g plant^{-1} and 2,5 g plant^{-1} in the next best (Amberglo) medium. There was no significant difference in the fresh mass of seedlings in the remaining media (Fig. 1.4).

The best tomato and cucumber seedlings reached 120 mm in height at harvest (® Finnpeat) which was significantly better than the seedlings in other media (Fig. 1.4). Plant height was significantly less in local peat and Roode-Lyon's medium than in the other media.

Generally root mass was greatest where plant growth was best (Fig. 1.6). Plants in ® Finnpeat produced the greatest mass of roots (P0,01), and plants in local peat and Roode-Lyon's medium had the lowest root mass.

The tendency for the root/shoot ratio to be the highest in the smallest plants was also recorded here (Fig. 1.4). Thus root growth was proportionately greater in the Roode-Lyon medium in tomatoes and cucumbers, and least in the ® Finnpeat for tomatoes, and the Amberglo medium for cucumbers.

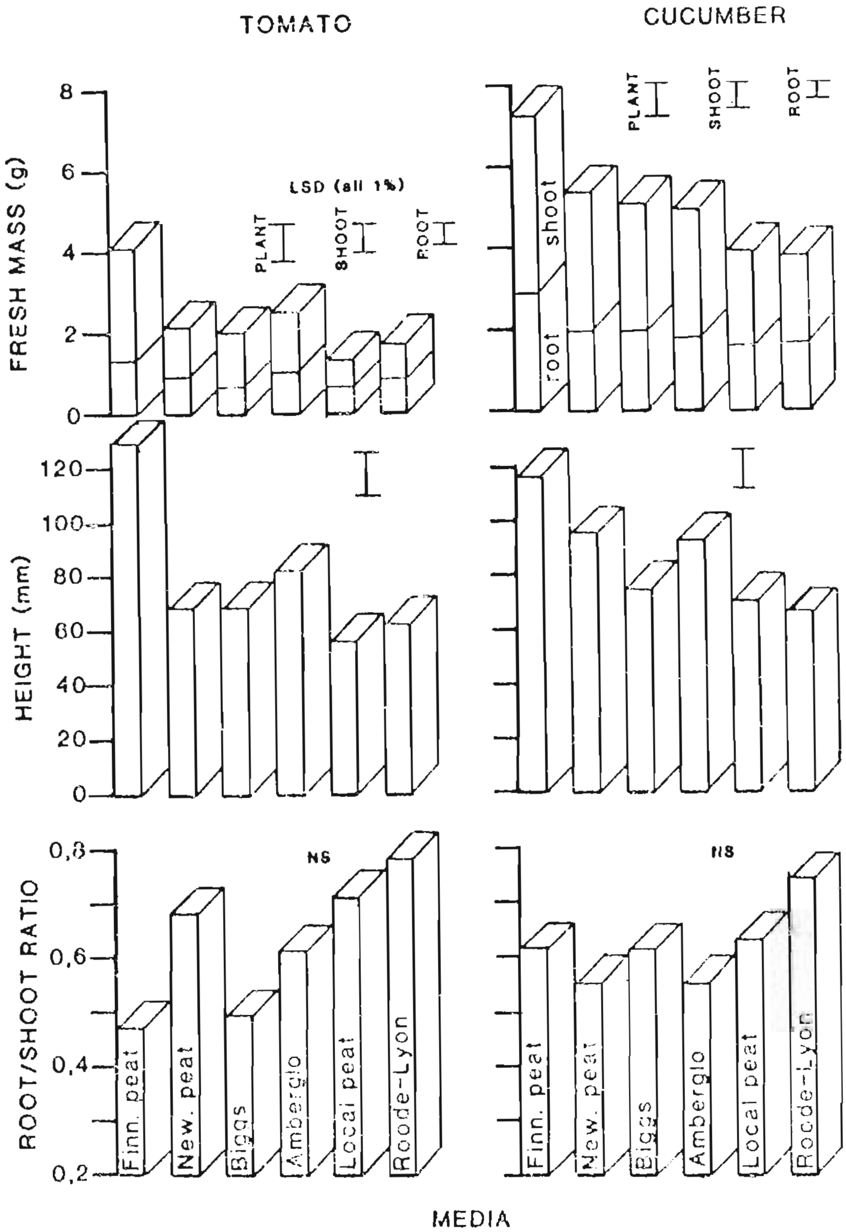


Fig. 1.4 Fresh mass, height and root/shoot ratio of tomato and cucumber seedlings grown in six different media

The better growth in ® Finnpeat was probably mainly due to its slow release nutrient content due to pre-enrichment. Apart from lime added to the local peat none of the other media were thus treated.

1.5.4 Conclusions Better seedling growth was obtained in imported pre-enriched peat than in any other locally used medium. It was apparent that in any medium pre-enrichment would be beneficial in growing seedlings, in spite of regular nutrient solution application. In order to avoid the high cost of imported ® Finnpeat a local pre-enriched medium would have potential and should be developed.

1.6 COMPARISIONS OF VARIOUS COMMERCIAL NUTRIENT SOLUTIONS, AND LOCAL AND IMPORTED MEDIA (Experiment 4)

1.6.1 Aim Several commercially formulated nutrient solutions were compared at the manufacturers recommendations with the aim of determining which provided for best seedling growth in conjunction with imported peats and other local media.

1.6.2 Procedure Tomatoes (cv. Heinz 1370) and cucumbers (cv. Ashley) were grown in the following five media:-

1. ® Finnpeat (see Experiment 3).

2. Canadian peat (a pH stabilised, pre-enriched, high quality sphagnum peat imported from Canada under the trade name ® HECO 1, and distributed in South Africa by the National Plant Food Co. (Pty) Ltd., P.O. Box 89, Cato Ridge, Natal.

3. Local peat and lime (see Experiment 3).

4. Pine bark - stripped by a debarking machine at a pulp mill from logs of *Pinus elliottii*, *Pinus taeda* and *Pinus patula*, milled through a 15 mm screen, and used when approximately 10 weeks old.

5. Roode-Lyon mixture (see Experiment 3).

The seedlings in each medium were watered twice daily with one of four commercially available nutrient solutions (see App. Table 1 for percentage nutrient composition) as follows:-

A. ® Aquapon - formulated and sold by Agrilab Laboratories, Pretoria. ® Aquapon is sold as two concentrated solutions, ® Aquapon 1 and ® Aquapon 2, which are diluted according to recommendation, as in Table 1.4.

B. ® Chemicult (see Experiment 3), at the rate shown in Table 1.4.

C. '® Chemicult Plus' - ® Chemicult at the recommended rate, but with an increased level of N, Ca and Mg (Table 1.4).

D. ® Speedling mix - formulated and sold by Roode-Lyon, Pretoria and used at the rate shown in Table 1.4.

The trial, which was designed as a 2 x 5 x 4 factorial with three replications, was started during November, 1980.

TABLE 1.4 Different commercial nutrient solutions used with the five media in Experiment 4. Calculated from percentage composition supplied by manufacturer and shown in App. Table 1

Element	ppm of each element at the given rates			
	® Aquapon 2,5 mℓ ℓ$^{-1}$ A1 +2,5 mℓ ℓ$^{-1}$ A2	® Speedling 1 g ℓ$^{-1}$	® Chemicult 1 g ℓ$^{-1}$	'® Chemicult Plus' 1 g ℓ$^{-1}$ Chemicult +1 g ℓ$^{-1}$ $CaNO_3$ + 0,25 g ℓ$^{-1}$ $MgSO_4$
N	183	91	65	184
P	50	26	27	27
K	280	122	130	130
Ca	180	96	75	244
Mg	48	26	25	49
S	98	44	70	70
Fe	5,0	3	1,5	1,5
Mn	2,0	1,2	0,24	0,24
B	2,0	1,0	0,24	0,24
Cu	0,1	0,05	0,02	0,02
Zn	0,45	0,27	0,05	0,05
Mo	0,1	0,1	0,01	0,01

1.6.3 Results and Discussion Media Tomato seedlings, and especially cucumber seedlings, grew to a highly significantly larger size (total fress mass) in the two imported, pre-enriched peats as compared with the other media tested (Fig. 1.5). Canadian peat and ® Finnpeat gave equally good results. There were highly significant differences (P = 0,01) in the root mass produced by seedlings in the different media, with similar trends to total fresh mass.

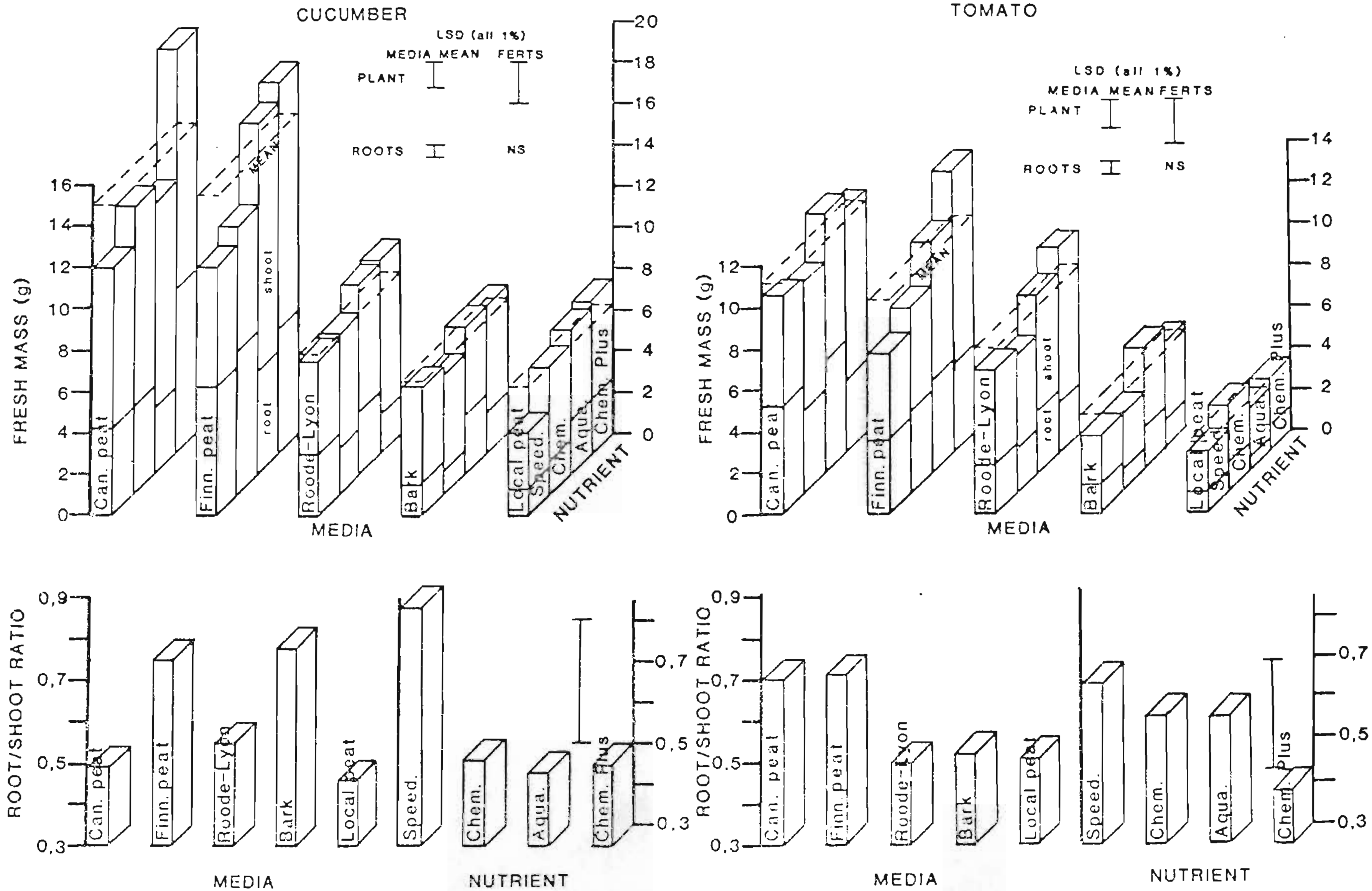


Fig. 1.5 Fresh mass and root/shoot ratio of tomato and cucumber seedlings grown in five media and watered

The results for pine bark (Fig. 1.5) in the trial were disappointing. The smaller seedlings at harvest were the result of delayed germination. This was attributed to the bark having too large a particle size so that the top layers dried out excessively. These seedlings grew well after germinating but did not catch up to the best seedlings by the time of harvest. There was an indication, however, that bark with a smaller particle size distribution might produce good results in future research. In contrast to earlier trials no significant differences were found between the mean root/shoot ratios of seedlings in the different media, although in tomatoes the Canadian and Finnish peat had the highest mean ratios (Fig. 1.5). This was attributed to a more even growth due to better overall nutrition as compared with earlier experiments.

Fertilisation Seedling fresh mass differences between the four different nutrient solutions tested were highly significant in all media (Fig. 1.5). In all cases except tomatoes in bark and local peat, '® Chemicult Plus' gave best results, especially for cucumbers in Canadian and Finnish peat, and for tomatoes in ® Finnpeat and ® Roode-Lyon mix. In a few treatment combinations viz. tomatoes in Canadian peat and bark; and cucumbers in ® Roode-Lyon mix, and bark, ® Aquapon was equally good. In the media tested ® Chemicult and ® Speedling used at the recommended rate resulted in significantly smaller seedlings.

The root/shoot ratios were again highest (P = 0,05) in the treatments which gave rise to the smallest seedlings (Fig. 1.5). Then ® Speedling mix resulted in relatively more root growth, especially in cucumbers.

Growth differences in response to the different nutrient solutions can be discussed in terms of the elemental composition of each solution, as shown in Table 1.4. ® Aquapon and '® Chemicult Plus' supplied twice as much N (184 ppm versus 91 ppm (® Speedling) and 65 ppm (® Chemicult), and a larger amount of Ca and Mg than ® Speedling and ® Chemicult at the rate used.

In most instances '® Chemicult Plus' was better than, or equally as good as, ® Aquapon at the rate used, using total growth as the criterion. These solutions contained equal levels of N, but '® Chemicult Plus' had more Ca, and less P and K. This balance of nutrients was therefore the best of those tested, i.e. a 1,4 : 1(N:K) ratio. In ® Aquapon this ratio was 1:1,5 (N:K). In comparison the Guernsey recommendation is 170 ppm with a N:K ratio of 1:2 (Anon., undated a), the U.K. recommendation 105 ppm N with a N:K ratio of 1:2,5 (Smith, 1973) and that of Wittwer & Honma (1979) 400 ppm N with an N:K ratio of 1:1,5.

1.6.4 Conclusions Any of the nutrient solutions tested could have performed equally well, if the rate per litre was adjusted so that the nutrient balance in solution was as close as possible to '® Chemicult Plus' solution. The costs of the different treatments are presented in detail in Chapter 3.

Further research is now required using straight chemicals to determine the optimum N, P, K, Ca and Mg levels in the nutrient solution.

1.7 TOWARDS A COMMERCIALLY AVAILABLE LOCAL MEDIUM : A COMPARISON OF MEDIA WITH DIFFERENT METHODS OF NUTRIENT APPLICATION (Experiment 5)

1.7.1 Aim The aim of this experiment was to determine whether pre-enrichment of locally available media would give as good results as imported peat, using a recommendation for bark in Scotland (Wilson, 1981), and a new slow release fertiliser (Anon., 1980c). The necessity for watering a pre-enriched medium with nutrient solution was also investigated.

1.7.2 Procedure Tomatoes (cv. Heinz 1370) and cucumbers (cv. Marketer) were grown in nine different media, some of which were pre-enriched with fertilisers according to Wilson (1981), as in Table 3.4 (+ nutrients). Others were pre-enriched with a resin-based, slow release, complete fertiliser named ® LEWATIT HD5, supplied by Bayer Industrial Chemicals Division, P.O. Box 1366, Johannesburg. This was applied at 36 $\ell\ m^{-3}$ and supplied 225, 110 and 449 g N, P, K m^{-3}.

The nine different media and pre-enrichment combinations were as follows:-

1. Amberglo medium (see Experiment 3).

2. Pinebark (as in Experiment 4 but seived through an 8 mm screen to achieve a smaller particle size distribution).

3. Bark (as in 2) + nutrients (Table 3.4 - Chapter 3).

4. Bark (as in 2) + ® Lewatit.

5. ® Gromor medium (formulated and sold by the National Plant Food Co. (Pty) Ltd., Cato Ridge, Natal and consisting of local peat, compost, bark and charcoal).

6. Canadian peat (see Experiment 4).

7. Local peat + lime (see Experiment 2).

8. Local peat + nutrients (Table 3.4).
9. Local peat + ® Lewatit.

All media received either tap water only, or the '® Chemicult Plus' nutrient solution (Table 1.3, Experiment 4), twice daily until the best seedlings had reached transplanting size.

The trial was a 9(media) x 2(nutrient solution) factorial with three replications and was started in March, 1981.

1.7.3 Results and Discussion

Media Germination was quickest (3 days) in the bark, bark + ® Lewatit and local peat media. There was a delayed germination (± 11 days) in ® Gromor and Canadian peat. All other media resulted in an intermediate time to germination.

Fig. 1.6 shows that tomato fresh mass was highly significantly better in the bark and bark + ® Lewatit media than all other media except bark + nutrients, where it was significantly better . In cucumbers bark alone was significantly better than bark + nutrients, and highly significantly better than all other media (Fig. 1.7). In both cases Canadian peat and ® Gromor resulted in the smallest seedlings. Canadian peat results were in contrast to previous findings, and were due to the poor and late germination of seeds because of over-watering. Initial overwetting of sphagnum peats is also a problem with growers and requires careful attention. Although these plants improved with time they had not caught up by harvest. The ® Gromor mixture resulted in poor germination and poor growth.

The greatest root mass recorded in tomatoes was in bark + ® Lewatit, while in cucumbers all three bark treatments and local peat gave rise to good root systems (Figs 1.6 and 1.7).

Tomato seedling height was greatest in bark + nutrients, bark + ® Lewatit and local peat, with no significant differences between these three media (Fig. 1.6). These were significantly better than bark, which was significantly better than all other treatments. The response to medium was similar in cucumbers but with a significant interaction with fertilisation.

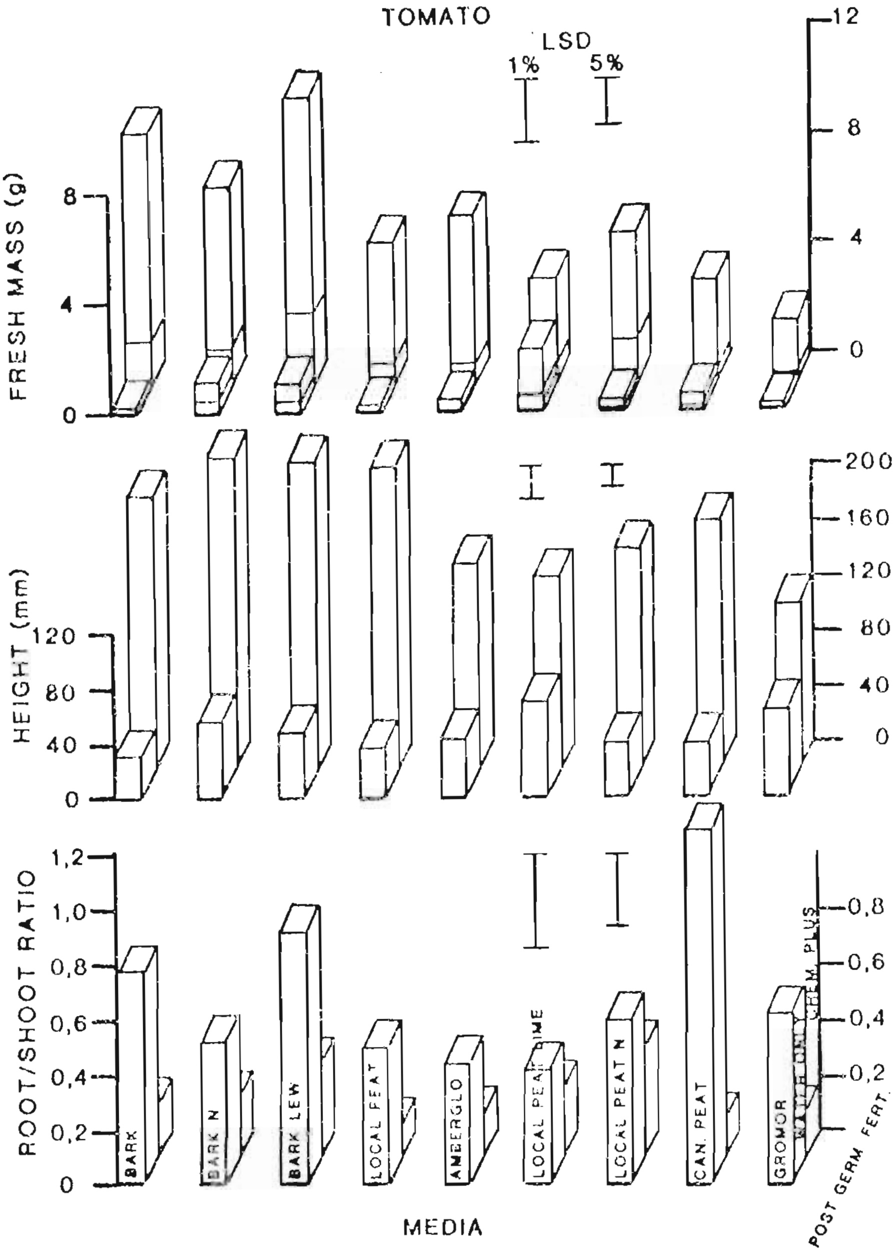


Fig. 1.6 Fresh mass, height and root/shoot ratio of tomato seedlings grown in nine media, some of which were pre-enriched, and watered with nutrient solution or water only after germination

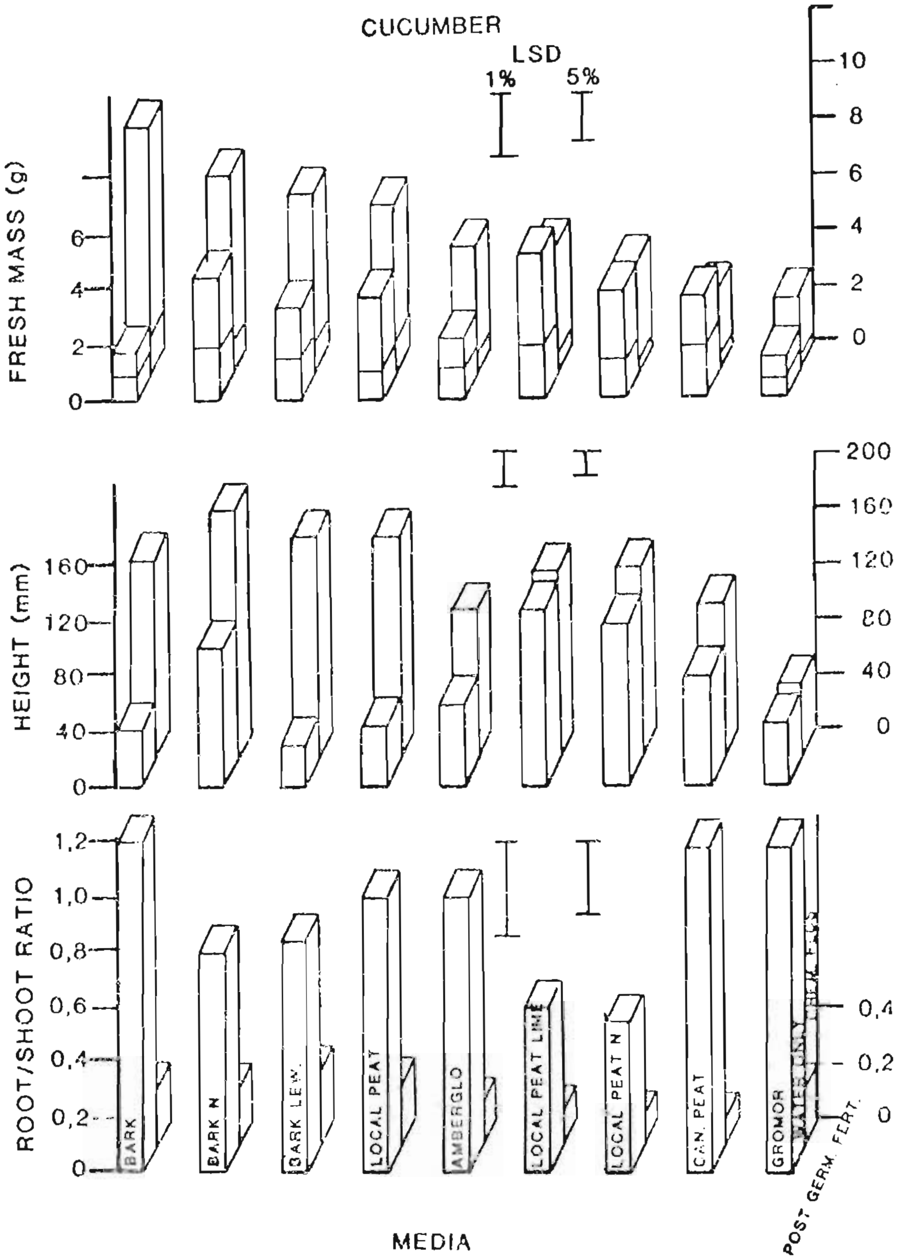


Fig. 1.7 Fresh mass, height and root/shoot ratio of cucumber seedlings grown in nine media, some of which were pre-enriched, and watered with nutrient solution or water only after germination

Bark and local peat + nutrients, which only received water after sowing, resulted in a relatively good plant height (Fig. 1.7). It was noticeable that although plant height in tomatoes and cucumbers was greatest in the bark + nutrients medium, this did not result in the greatest fresh mass. Thus plants grown in bark had the greatest fresh mass and were slightly shorter. In future research the growth of the seedlings after transplanting must be followed up to determine which type of seedling grows better and yields earlier.

Further it must be determined whether height and fresh mass is the best criterion of transplantability. It could be that a moderately high root:shoot ratio (as in a hardened plant) is a buffer against adverse conditions, and "sets the scene" for rapid regrowth (provided basic nutrition etc. is not a limiting factor).

As in earlier experiments, the highest root/shoot ratios (Figs. 1.6 and 1.7) were recorded in the media in which seedling growth was poorest, i.e. Canadian peat and ® Gromor which received water only. Amongst the better treatments in terms of overall growth, the highest root/shoot ratios were recorded where ® Lewatit was added to the bark in both tomatoes and cucumbers. This slow release fertiliser obviously favoured root growth, usually considered to be a favourable response.

<u>Post-emergence fertilisation</u> Using water only i.e. no nutrient addition after sowing, resulted in extremely poor growth in tomatoes, even where media had been pre-enriched. Mean seedling fresh mass in the best such treatment was only 2 g plant^{-1}, as compared to 10 g plant^{-1} where '® Chemicult Plus' nutrient solution was used with every watering (Fig. 1.6). Similarly mean tomato seedling heights were ± 40 mm as compared with 200 mm for water or nutrient solution respectively. These poor seedlings had root/shoot ratios of between 0,4 and 1,0 as compared with 0,1 to 0,4 for seedlings receiving nutrient solution. Thus adding base fertilisers to the medium did not compensate entirely for daily watering with a nutrient solution. Regular watering appeared to result in severe leaching of the pre-enrichment fertilisers in most media. Slower release pre-enrichment fertilisers could help overcome this problem and must be evaluated in future trials.

In cucumbers (Fig. 1.7) the same was not strictly true in that local peat pre-enriched with nutrients or ® Lewatit, gave equally good growth whether water or nutrient solution was used. Plant heights were equally good, and root/shoot ratios were lower (Fig. 1.7). The best treatments in cucumbers were, however, where nutrient solution was used at every watering.

1.7.4 Conclusions One of the best treatments in tomatoes and cucumbers was non-enriched pine bark with daily nutrient solution watering. The addition of ® Lewatit gave slightly better growth and root mass in tomatoes, but not in cucumbers. Bark itself contains appreciable amounts of K, Ca, Mg and trace elements (Table 3.1), and Gartner & Williams (1978) and Gartner (1981) do not recommend addition of Ca to hardwood barks.

According to recent findings in Europe (Allen, 1980; Winsor, 1980) cucumbers require 30 per cent. less total nutrients in solution than tomatoes. The reduced growth where nutrients were added to the medium may have been due to too high a salt concentration in the medium. A medium and leachate analysis would be required to confirm this.

Although ® Lewatit gave good results the cost is prohibitive (R250 m^{-3} at the rate used here). Further work with different rates of application may be rewarding. Other slow release fertilisers should also be tested to overcome the severe leaching which occurs with frequent watering in seedling trays.

1.8 DETERMINATION OF OPTIMUM RATE AND TIME OF NUTRIENT APPLICATION FOR PRE-ENRICHED PINE BARK (Experiment 6)

1.8.1 Aim Some alternative to daily nutrient solution application would simplify management for growers. The objective was firstly to test the application of the same total amount of nutrients a) once daily, b) once every second day, or c) once a week.

Three different rates of nutrient application were also tested to confirm earlier findings, and to determine whether a higher rate would compensate for loss of leached nutrients where water was applied on occasions.

1.8.2 Procedure Tomato (cv. Heinz 1370), lettuce (cv. Great Lakes) and cabbage (cv. Gloria Osena) seedlings were grown in pre-enriched (Table 3.4) pine bark milled through and 8 mm screen. Only the results for tomatoes will be reported here.

Three different rates of ® Chemicult with added $Ca(NO_3)_2$ were applied in solution or as a solid.

In solution they were applied either:

(a) once per day (200 mls/tray), with water once per day, (b) once every second day with water at other times. Each plot received the same total amount of fertiliser. These two treatments were compared with (c) applying the same total amount of ® Chemicult once per week, sprinkled over the medium in solid form and watered in.

The three rates of ® Chemicult and $Ca(NO_3)_2$ used, and the total amounts of each element applied are shown in Table 1.5. For treatment (b) a double strength solution was used once every second day. For treatment (c) 0,7 g $Ca(NO_3)_2$ + 0,7 g ® Chemicult were applied per tray once a week at the lowest rate, 1,4 g $Ca(NO_3)_2$ + 1,4 g ® Chemicult at the intermediate rate, and 2,1 g $Ca(NO_3)_2$ + 2,1 g ® Chemicult at the highest rate. At all other times these trays received tap water only.

The trial was a 3x3x3 factorial with 3 replications.

1.8.3 Results and discussion On average, the best treatment (fresh mass) was where nutrient solution was applied every day at the highest rate (Fig. 1.8). This was significantly better than weekly application but not significantly better than the same rate applied once every second day (Fig. 1.8). Using solid fertilisers did not cause as good growth, and the best treatment was significantly worse than the daily application at 0,5 g ℓ^{-1}.

There were no significant differences in the root mass of seedlings in the different treatments (Fig. 1.8). In all treatments root/shoot ratios were ± 0,3, and only at the 1,5 g ℓ^{-1} rate applied every second day was this ratio significantly lower.

1.8.4 Conclusions Results showed that a daily application of the medium strength solution, containing 184, 27 and 130 ppm of N, P and K respectively, gave rise to good seedling growth. There was no significant difference between applying this once per day or once every second day. The latter method makes management easier and results in cost savings.

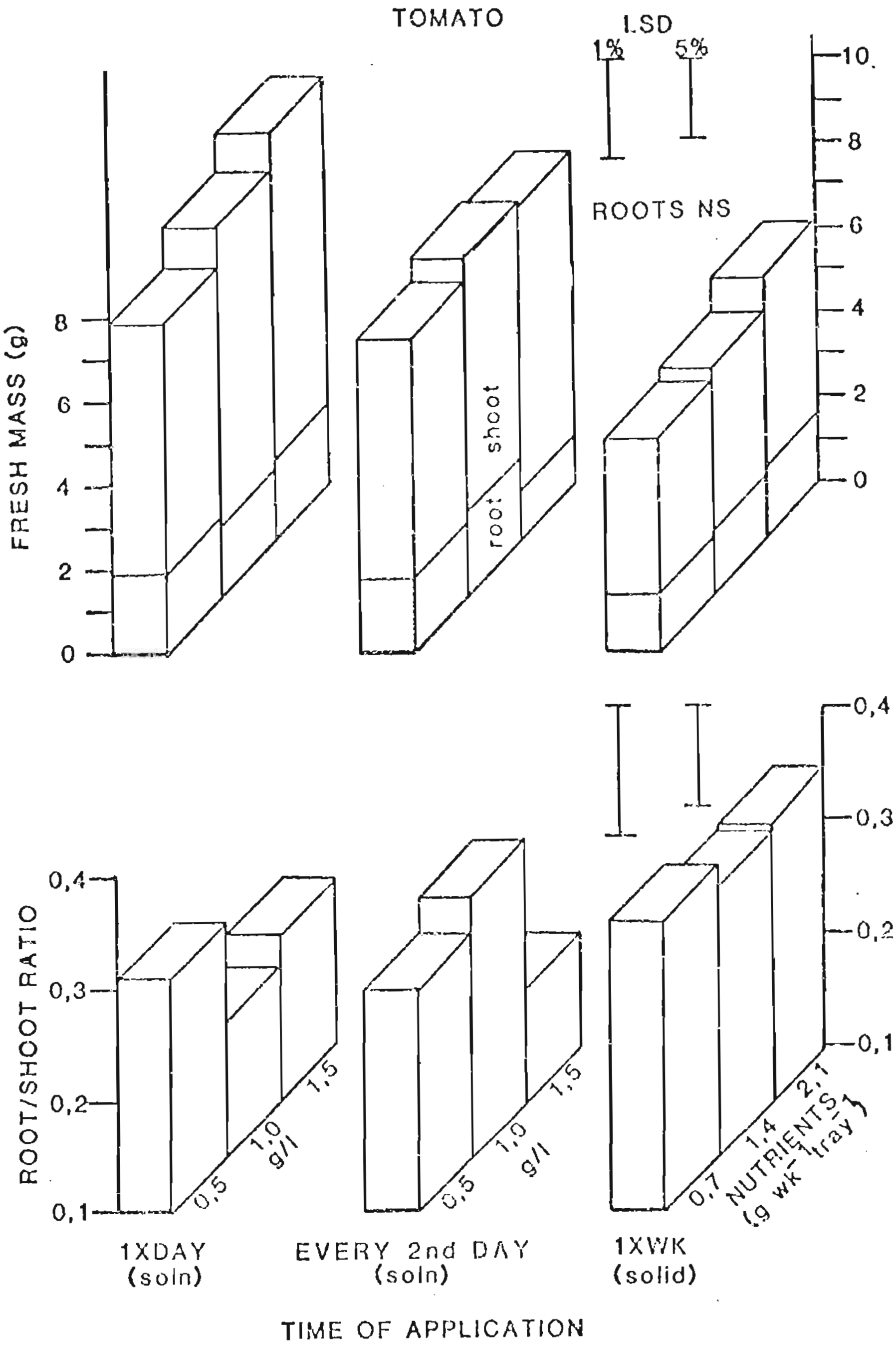


Fig. 1.8 Fresh mass and root/shoot ratio of tomato seedlings grown in bark and receiving different levels of nutrients at different times

TABLE 1.5 Elemental concentration in solutions containing different amounts of ® Chemicult and $Ca(NO_3)_2$, and total amount of nutrient applied to seedlings in Experiment 6. Calculated from percentage composition in App. Table 1

	1. Nutrient conc. in soln. containing x g ℓ^{-1} ® Chemicult + x g ℓ^{-1} $Ca(NO_3)_2$ (mg ℓ^{-1})			2. Amount nutrient (mg $plant^{-1}$ wk^{-1}) from 200 ml per tray (24 plants) per day of solns. in 1		
	x = 0,5	x = 1,0	x = 1,5	0,5	1,0	1,5
N	92	184	276	5,4	10,7	16,1
P	13,5	27	40,5	0,8	1,6	2,4
K	65	130	195	3,8	7,6	11,3
Ca	122	244	366	7,1	14,2	21,3
Mg	12,5	25	37,5	0,75	1,5	2,19
S	35	70	105	2,05	4,1	6,1
Fe	0,75	1,5	2,25	0,045	0,09	0,13
Mn	0,12	0,24	0,36	0,07	0,14	0,02
B	0,12	0,24	0,36	0,07	0,14	0,02
Cu	0,01	0,02	0,03	0,0006	0,0012	0,002
Zn	0,025	0,05	0,075	0,0015	0,0029	0,004
Mo	0,005	0,01	0,015	0,0003	0,0006	0,009

The good growth of the seedlings also confirmed the suitability of pine bark as a growing medium for seedlings.

1.9 GENERAL DISCUSSION AND CONCLUSIONS (Chapter 1)

The research reported here has shown that by using pine bark, of which large continuous supplies are available locally, at a reasonable price, growers can get repeatably good results, provided that their nutritional management is correct.

The particle size distribution in the bark is important. For seedling trays, a bark which has been milled through an 8 mm screen has given the best results. Bark milled through a 16 mm screen resulted in poorer germination, dried out more quickly, and gave rise to a loosely packed compartment in which the centre did not wet properly. Larger bark particles also have a lower moisture retention (Gartner, Still & Klett, 1973), and form a loose plug which tends to fall apart at transplanting

Sieving a milled bark through a mesh smaller than 8 mm results in too fine a product which tends to pack, and gives rise to poorer drainage and aeration (Gartner *et al.*, 1973; Nixon, 1981). Pokorny (1973; 1975) suggested that pine bark material having 70 to 80 per cent. of the particles in the 0,6 to 6,35 mm range and 20 to 30 per cent. less than 0,6 mm in size was most suitable as a general medium. Detailed discussion on particle size distribution is presented in Chapter 3.

The author has also noted that pine bark from mature trees produces a better product than that from young trees, as the latter is more fibrous and does not mill as easily.

In the first trials the best results were obtained with Canadian peat and ® Finnpeat, but subsequently equally good results were obtained with pine bark. In comparison with imported peats, bark has similar water retention and total porosity properties (Table 3.10) (Mastalerz, 1977), but is better drained. Some germination problems have resulted in imported peats which were too wet at the start, especially in cooler weather, but with bark this has not been a problem.

The bark medium in the latest trials has also always been better than local peat or local peat mixtures, which have usually contained a fine sand to improve drainage. Addition of sand, however, is not recommended as it makes a full seedling tray heavy to handle, and decreases the porosity and aeration (Gartner *et al.*, 1973; Mastalerz, 1977). With bark this is unnecessary.

The nutritional studies reported here have confirmed that a nutrient solution with a high N:K ratio (1,5:1) has given the best results in terms of total growth. In addition, it has been shown that continuous nutrient feeding is superior to alternate feeding and watering, and to the application of a solid topdressing at intervals. Recommendations from Speedling Inc. in America (Roode, 1981) indicate that a hardening off period prior to transplanting is advantageous. This is carried out by reducing the N content of the nutrient solution, such that, in proportion, the P level is higher. A N:P:K ratio of 1:½:1 during this stage may then be more suitable. This would reduce aerial growth, thereby proportionally favouring the roots (increased root/shoot ratio).

Further research on the liquid feeding programme is required to determine the optimum levels of N:P and K, and how and when the levels should be changed during the growth period (keeping economic factors in mind). The timing of the first nutrient solution application after germination, or at germination, should also be investigated, especially with a view to reducing costs. For a detailed cost analysis see Chapter 3.

The necessity for watering with trace elements, as well as having them in the FRIT form in a pre-enriched medium should also be examined. Management would be simplified and costs reduced if a simple N, P and K solution was used. Speedling Inc. use a pre-enriched peat with vermiculite and polystyrene and recommend a nutrient solution containing NH_4NO_3, $Ca(NO_3)_2$ and KNO_3 only (Anon., 1973).

In bark, pre-enrichment of the medium was beneficial in tomatoes, but not with cucumbers where a complete liquid feed was used. More basic research is required using chemical analysis of the media and plant material. Such facilities were not available at the time of this study but must be included to make future research more meaningful.

Frequent watering results in heavy nutrient losses through leaching. Attempts to provide the total nutritional requirement through pre-enrichment have so far been unsuccessful. Considering the ease of management in such a system further research in this direction is justified, and tests with new slow release fertilisers could be useful.

According to Bunt (1976) water soluble fertilisers create two types of problems in soilless media. They can result in high salinity values or they can be easily removed by leaching. These problems have been approached experimentally by the use of resins with ion exchange properties. Nutrients are released from the resin by exchange with other ions in the irrigation water.

® Lewatit, tested in these experiments, is such a resin, and although it did not always result in the best seedling growth further research into different rates of application could be rewarding. Even though the cost may be higher the convenience in management terms could be worthwhile.

Other slow release fertilisers would also be less susceptible to leaching (Kofranek & Lunt, 1966; Bunt, 1976) and may hold an advantage for pre-enrichment, but also may not release their nutrients at a fast enough rate for vigorous seedling growth.

Further research is also required on the effect of the root/shoot ratio on recovery after transplanting i.e. the biggest seedlings, with a low root/shoot ratio, may not be the best in the long term. Subsequent growth, earliness of flowering and yield must also be examined, especially since these variables may be affected by the size of compartment, nutrient solution, medium and length of growing period in the container (Glen, 1980). Hardening off before transplanting should increase the root/shoot ratio and may result in better recovery, especially under stress conditions. These effects need to be examined more closely.

In conclusion, the stage has been reached where pine bark, of the correct particle size distribution, can be recommended locally for tomato and cucumber seedling production. At the present time best results have been where this medium was watered as required with a total nutrient solution containing an N:P:K ratio of 5:1:3 plus Ca, Mg and trace elements. Some refinement is necessary, under South African conditions, of the levels of nutrients applied both in pre-enrichment, and in the nutrient solution.

While the author's results have given valuable leads, the underlying explanations of the responses obtained have been difficult to unravel. Further research must be backed by continuous salinity monitoring, eg. with a direct-reading conductivity meter, and by medium and tissue analysis. Lack of equipment, facilities and time precluded this in the above investigation.

CHAPTER 2

ECOLOGICAL ASPECTS OF TOMATO AND CUCUMBER GROWTH AND YIELD IN PLASTIC TUNNELS

2.1 LITERATURE REVIEW

South African plastic tunnel growers have to rely on imported tomato and cucumber cultivars, bred and selected under European conditions with controlled greenhouse temperatures and relatively low irradiance levels. Such cultivars are expected to perform well under the variable and often extremely high summer air temperatures in South Africa, using structures which offer only limited forms of climate control. Therefore a knowledge of the ecology of the crop, and of the tunnel environment, is an important consideration where climate modification is to be practised.

The work reported here investigated the plant's response to local tunnel environments and to various other factors including spacing, rooting medium volume and shading.

2.1.1 Tunnel Environment The environment inside a naturally ventilated, plastic covered tunnel in South Africa has been studied at Pietermaritzburg (North *et al.*, 1978; North, 1979; Savage, 1980a; Savage & Smith, 1980; Smith & Richards, 1980); Pretoria (Oosthuizen & Millar-Watt, 1978; Hammes *et al.*, 1980) and Stellenbosch (Maree & Laubscher, 1976a; b; Maree 1979a; b; c).

Transmission properties for clear, ultra-violet (uv) light-stabilised plastic sheeting have been given by Dubois (1978), and the effect of a water film by Savage (1980a). Commercial plastic in South Africa generally reduces incoming irradiance (see 2.2) by ± 10 per cent. when new, increasing to ± 30 per cent. after two years exposure (North *et al.*, 1978; Savage & Smith, 1980).

Generally temperature profiles under plastic with natural ventilation only are characterised by an up to 10 ^{o}C higher maximum day time temperature in summer, and a 1 to 3 ^{o}C higher minimum night temperature in winter. Savage (1980a) has given detailed air temperature profiles. The extremes in temperature can be reduced by using shadecloth, or whitewash (Maree 1979a; b). The maximum temperature then seldom rises above ambient, and the minimum remains 5 to 7 ^{o}C higher than under plastic alone, or 8 to 10 ^{o}C above ambient.

Similar night temperature effects are caused by thermal screens, the subject of much recent study for energy saving in heated greenhouses in Europe and the U.S.A. (Allen, 1980; O'Flaherty & Maher, 1981; Roberts, Mears, Simpkins & Cipolletti, 1981).

Good daytime ventilation helps control excessively high temperatures and lowers relative humidity (North, 1979; Savage, 1980a).

The 'roll-up' sides tunnel used by the author (Anon., 1978) provided for efficient ventilation. With the lower sides rolled up, maximum daytime temperatures were not higher than ambient. In other types of tunnels ventilation is supplied by opening the doors as well as the gaps at the joins in the plastic strips covering the tunnel.

2.1.2 Tomato Ecology The native habitat of the tomato is the western coastal plain of northern South America, stretching from Ecuador, through Peru, into Chile. Over the six months of the growing season the air temperature changes are small. During the growing season the minimum night temperature is 15 ^{o}C, and the absolute maximum day temperature is 19,4 ^{o}C. The daylength ranges from approximately 11,5 hours to 12,5 hours. The relative humidity is high, varying from 65 to 85 per cent. Heavy mists are common reducing the radiation intensity considerably (Cooper, 1971).

In commercial tomato growing optimum temperatures are in the range 21 to 24 ^{o}C, with a mean monthly minimum of not less than 18 ^{o}C, and a mean monthly maximum of not greater than 27 ^{o}C (Rick, 1978).

According to Williams (1973) seed germination is fastest at 18 ^{o}C day/night. He recommended the same temperature for the first two weeks after germination, followed by 18 ^{o}C day/15,5 ^{o}C night until the first truss buds were visible. Guernsey recommendations (Anon., undated a) are that early seedling growth should be at 18 ^{o}C day/night changing to 18/16,5 ^{o}C day/night after 17 days until first flowering. Wittwer & Honma (1979) advise that tomato seedlings should be grown at 15-18 ^{o}C, with a 10 day cold treatment of 11-13 ^{o}C starting at cotyledon expansion to induce flowering at a lower leaf node, and more flowers per truss.

In tomato seedlings the number of leaves formed before the first truss and the number of flowers in that truss vary with season, and are temperature dependent (Lawrence, 1954; Calvert, 1973). First truss initiation, however, takes place at a constant plant fresh mass

(Klapwijk & de Lint, 1975; Klapwijk, 1981). Under cooler conditions with reduced radiation intensities the plant produced more, smaller leaves before the first truss. In warmer, higher radiation conditions fewer, larger leaves were formed to the same stage. Early phosphate nutrition may also play a role (Menary & van Staden, 1976).

During the bearing period, recent day/night air temperature recommendations in the N. hemisphere are 18/15,5 °C (Anon., undated a); 18/17 °C (Williams, 1973), 21-26 °C/16-19 °C (Moore, 1975), 18-23/15-18 °C (Wittwer & Honma, 1979), 21-24/17 °C (Anon., 1980a), 21-24/16-18 °C (Anon., 1981c).

Latest research aims at lower night temperatures to reduce heating costs (Swatton, 1978; Hurd, 1981). Selection of cultivars which yield better at lower temperatures has also been carried out in the U.K. (Allen, 1980) and at higher temperatures in Israel (Elhamadi, 1977), and in South Africa (Smith, 1980).

Large diurnal fluctuations in temperature cause leaf curling and 'beaking' on fruit (Moorat, 1981), symptoms often seen in South Africa.

Cooper (1973b) reviewed the effect of root temperature on growth. Recent interest in NFT has resulted in more research into these effects.

Winsor, Hurd & Price (1979) recommended that the NFT solution be kept at 23 °C. Heating the solution to 25 °C in a greenhouse at 20/18 °C or 20/13 °C did not improve overall yields. Although there was an increase in fruit size, fewer fruits were produced at the higher night temperature (Maher, 1978). Hurd (1981) tested root temperatures of 17, 22 and 27 °C combined with night air temperatures of 8, 12 and 16 °C. Higher root temperatures with lower air temperatures resulted in a later first harvest as a result of excessive vegetative growth. At optimum air temperatures, increased root temperatures resulted in increased total yields but with poorer fruit quality, mainly due to boxy and hollow fruit. At less than 15 °C root temperature, deficiency problems were encountered through poor nutrient uptake.

According to Allen (1980) any root temperature less than 16 °C causes a growth check. Root growth is restored at 23 °C. In South Africa, Savage & Smith (1980) have reported potting medium temperatures fluctuating between 4 ° and 24 °C in plastic tunnels in winter.

Fretz (1971) measured media temperatures of 45 °C in polyethylene containers. Exterior colours had a significant influence on medium temperatures. Yellow, silver and white containers significantly reduced media temperatures. None of the soilless media tested reduced the temperature.

Pollination is also temperature dependent. Pollen formation is abnormal above 32 °C and below 13 °C (Calvert, 1964; 1973; Wittwer & Honma, 1979; Anon., 1981c). Stevens & Rudich (1978) have shown that even four hours at high temperatures five to nine days before the flowers open, reduced pollination. They also noted stigma exsertion at high temperatures.

At ambient temperatures below 13 °C and above 27 °C pollen germination and pollen tube growth may also be abnormal (Calvert, 1964; 1973). Generally, exposure of most cultivars to 26/20 °C (day/night) results in severe blossom drop, while 30/20 °C prevents fruit set (Stevens & Rudich, 1978). Rick (1978) states that exposure to 42 °C for a short period results in no fruit set taking place for one week or more afterwards. Considering that the outside/inside temperature difference in inadequately ventilated tunnels in South Africa may reach 14 °C at high irradiance levels (1 000 W m^{-2}) (North *et al.*, 1978; Maree, 1979c), fruit set problems can be expected and do occur, eg. Oosthuizen & Millar-Watt (1978), and experiments reported in Chapter 3.

Being a C_3 plant (Salisbury & Ross, 1978), individual leaves of the tomato are saturated at relatively low irradiance levels (Calvert, 1973) (less than one third summer irradiance levels in South Africa). In America and Europe irradiation becomes a limiting factor in greenhouse tomato production at times (Wittwer, 1949; Hemphill & Murneek, 1950; Marr & Hillyer, 1968; Sheard, 1972; Calvert, 1973; Maas & Adamson, 1980), and prevents winter production. Rodriguez & Lambeth (1975) working in Missouri, U.S.A., found that supplementing the natural light in winter with top lights resulted in an 89 per cent. yield increase in tomato plants.

Kinet (1977) and Klapwijk (1981) showed that daylength, as well as radiation intensity, affect the growth of greenhouse tomato plants. The growth rate was greater at higher irradiation intensities, but at the same irradiance level, growth was faster at longer daylengths.

Artificial lighting in greenhouse tomato growing is usually not economical (Moore, 1975). Growers in European countries, however, take measures to make more efficient use of the available irradiance by laying a white reflective plastic on the floor, which also acts to isolate growing bags from the soil (Moorat, 1981).

Whilst total radiant density is not a problem in tunnels in South Africa it could become one through wrong spacing practices. This study (Savage & Smith, 1980; Smith & Richards, 1980) has shown that decreasing the in-row spacing from 400 mm to 200 mm lowered the yield by 0,5 kg per plant. Similarly, in America, Rodriguez & Lambeth (1975) recorded 1 kg plant^{-1} more fruit at a spacing of 500 x 480 mm as compared with 410 x 380 mm, which in turn yielded 1 kg more than at 410 x 250 mm spacing. In Georgia (U.S.A.) Harper, Pallas, Bruce & Jones (1979) found that in 2 m tall plants 15-25 per cent. of available solar radiation was transmitted to the floor surface at a spacing of 450 x 450 mm (2,5 plants m^{-2}). They subsequently increased their plant populations to 3,3 plants m^{-2} with a far better radiation interception pattern.

Recommendations for plant spacing in tunnel tomatoes vary from 2,5 to 3,3 plants m^{-2} (Table 2.1). The final recommendation must balance yield ha^{-1} with costs, management and fruit quality (Wittwer & Honma, 1979).

TABLE 2.1 Recommended spacing practices for greenhouse tomatoes in different growing areas

Author	Plants ha^{-1}	Plants m^{-2}	m^{2} plant^{-1}	Spacing arrangement (mm) Double rows	
				Between row	In row
Anon. (undated a)	23 350	2,3	0,43	500	480
Kingham (1973)	33 358	3,3	0,30	500	380
Wittwer & Honma (1979)	22 239	2,75	0,36	790	480 (fall
	24 710	2,47	0,40	790	450 (summ
Anon. (1980b)	27 000	2,7	0,37	500	400
Maas & Adamson (1980)	38 000	3,8	0,26	300	380
Smith & Richards (1980)	27 000	2,7	0,37	500	400
Marec (1981b)	25 000	2,5	0,40	600	400

Irradiance and daylength can also affect flowering and fruit set in tomato. Kinet (1977) found that high irradiance levels and short days gave rise to earlier and better flower development than long days and low irradiance. Mostly, however, the age at anthesis is less in long daylengths (Sheard, 1962). Wittwer (1963), Calvert (1973) and Kinet (1977) agree that the tomato is a qualitative short-day plant in respect of flowering.

Calvert (1964) in a review of factors affecting pollination, concluded that flower abscission may occur at low irradiance levels. This is mainly due to the formation of non-viable pollen, and stylar exsertion (Rodriguez & Lambeth, 1975).

Increasing the CO_2 concentration can result in increased photosynthesis rates in greenhouse tomatoes, and hence increased yields (Anon., undated a; Calvert, 1972; 1973; Calvert & Slack, 1975; 1976; Wittwer & Honma, 1979; Anon., 1980b). There is a strong interaction between CO_2 enrichment and temperature, and irradiance. Higher temperatures and irradiance levels result in a greater response to CO_2 enrichment (Calvert, 1972; 1973; Calvert & Slack, 1975; Salisbury & Ross, 1978; White, 1978). The recommended level of CO_2 in greenhouses is 1 000 ppm.

Conditions in South Africa could result in good responses to higher CO_2 levels, but the structures used and higher temperatures inside the tunnels present problems. Continuous ventilation is essential, making CO_2 enrichment difficult. In badly ventilated tunnels North *et al.* (1978) have shown that CO_2 levels are often below ambient, and therefore limiting.

High CO_2 levels also cause partial stomatal closure in several crops, which can result in a reduced water usage, without affecting production (Bierhuizen & Slatyer, 1965; Tinus, 1974; Enoch, Rylski & Spiegelman, 1976; Wiebe, 1981).

The response of the tomato plant to different times of planting has been described by Cooper (1964) and Klapwijk (1981). Crop specifications have been made for many countries eg. U.K. (Kingham,1973), U.S.A. (Wittwer & Honma, 1979), Canada (Anon.,1980b, Anon., 1981c) and Guernsey (Anon., undated a).

In South Africa Oosthuizen & Millar-Watt (1978) found that fruit of an acceptable size was harvested in tunnels during May, June and July (autumn/ winter). During August (late winter) there was a decline in fruit size, continuing through September and October, with some improvement in November and December. Small fruit size was related to poor pollination in flowers whose time of anthesis was from mid-April to mid-September, during which time the minimum temperature was often below 10 ^{0}C. Similar effects have been recorded by Maree & Laubscher (1976a) in Stellenbosch and Smith & Richards (1980) in Pietermaritzburg. Pollination problems have also been recorded in mid-summer due to excessively high temperatures.

Reducing the irradiance with shadecloth or whitewash paint has been effective in reducing summer tunnel temperatures to ambient (Maree, 1979b). Too heavy shading (60 per cent.), however, caused yield and fruit size reductions in tomatoes on the South African highveld in summer (Hammes *et al.*, 1980). In this study the plastic covering of the tunnel reduced the photosynthetic photon flux density to 80 per cent. of that outside (2 000 $\mu E\ m^{-2}\ s^{-1}$). With 20 per cent. shade cloth this was reduced to 1 200 $\mu E\ m^{-2}\ s^{-1}$.

The volume of growing medium in modules in Europe is 42 ℓ, allowing 14 ℓ plant^{-1} (Allen, 1980; Moorat, 1981; Wilson, 1981). In Canada (Anon., 1981c) slightly less is recommended (10 ℓ) in plastic bags with single plants. In sand beds Jensen (1975; 1980) (Arizona) suggests a bed width of 600-750 mm, with a depth of 300 mm. Theoretically, a bed with dimensions 100 m x 0,6 m x 0,3 m would contain 18 m^3 (18 000 ℓ) of sand. At a plant spacing of 450 mm in the row (Table 2.1) a double row of plants would number 444, resulting in 40,5 ℓ of sand per plant.

Guttormsen (1974) recorded optimum yields in 28-30 dm^3 of peat per plant. Adamson & Maas (1976) conducted extensive studies into bed size and volume of medium and concluded that small volumes of medium will produce good crops of greenhouse tomatoes. They recommended a two plant bag containing 18,4 ℓ of sawdust i.e. 9,2 ℓ plant^{-1}.

2.1.3 <u>Cucumber Ecology</u> The cucumber is probably a native of Asia and Africa, and there is evidence that it has been cultivated in Western Asia for at least 3 000 years (Whitaker & Davis, 1962; Ware & McCollum, 1975). Greenhouse cucumbers differ from field cucumbers in that they have thinner, softer skins and are seedless. They are a warm-season crop, seriously damaged by frost. Generally, mean daily temperatures of 18-24 °C are most favourable for growth (Ware & McCollum, 1975), but heat is not as essential for cucumbers as it is for other cucurbits.

For germination of greenhouse cucumbers Bauerle (1975) and Adamson (1977) recommended that seeds should be pre-sprouted by placing them between moist towels at 25-30 °C for 48 h. Sprouted seedlings should then be placed into the growing medium and kept at 25 °C for the next few days, followed by 24/18 °C day/night until transplanting. Anon. (1981c) suggests germination at 21-25 °C in seedling flats.

Recommended greenhouse growing temperatures after transplanting are 26 °C on sunny days and 24 °C on overcast days, with night temperatures not below 18 °C (Bauerle, 1975). Wittwer & Honma (1979) recommended a day temperature of 28 °C with minimum temperatures not below 21 °C. Anon. (1980b) and Anon. (1981c) suggest 20-23 °C on sunny days or 18-20 °C on cloudy days, with a night temperature of 18 °C. European growers are advised to use 21/19 °C for the first 45 days, followed by 19/17 °C thereafter (Anon., 1980a).

Slack, Hand & Hurd (1978) compared cucumber growth and yield at four night temperatures (14, 17, 20 and 23 °C) with a constant day temperature of 20 °C for up to eight weeks after first harvest, and then 20/17 °C for the rest of the season. The highest night temperature improved the early yield, but in the long run the 20 °C night temperature produced the highest yield and gross monetary return.

Slack & Hand (1979; 1980) subsequently tested different day temperatures (16, 19, 22, 25 °C) up to six weeks after the first harvest, followed by 19/17 °C for the rest of the season. Early yields, and nett profit in the long run were highest at 22 °C.

Milthorpe (1959) found that field cucumbers required an optimum temperature of 24 °C for both assimilatory activity (NAR), and the expansion of assimilating surface (RCGR). Challa (1976), in extensive growth studies with greenhouse cucumbers considered 25 °C the optimum growth temperature, and showed that the CO_2 uptake of five leaf plants was still increasing at that temperature at an irradiance of 200 W m^{-2}, the maximum level tested.

Recently the use of thermal screens to save energy in cold climates has received much attention (O'Flaherty, 1974; Allen, 1980; Roberts *et al.*, 1981). In most cases in Europe the use of the screen has resulted in reduced yields, attributable to shading from the folded screen in the day (Moorat, 1981). However, Allen (1980) has noted that in cucumbers the relationship between leaf temperature and air temperature is critical. Apparently the thermal screen decreases yields in cucumbers because the leaf temperature remains higher in the evenings, with the screen in place. The plant's metabolism is not suited to removing carbohydrates accumulated during the day under such conditions. It is thus recommended that the screen should only be closed after sunset, once leaf temperature has decreased.

Greenhouse cucumber root growth temperatures should not be below 18 ^{0}C (Bauerle, 1975). In studies with young cucumber plants grown with different soil, but uniform air temperatures ($\pm$ 23 ^{0}C) the shoot and root growth was increased by higher soil temperatures up to 30 ^{0}C (Gohler, 1975). In an early crop (Spring in Europe) the early yield was highest where soil heating was used. Inadequate soil temperatures resulted in severe chlorosis, poor root formation and lower early yield. Chermnykh, Chugunova & Kosobrukhov (1975) recorded that in greenhouse cucumbers the maximum volume of photosynthetic tissue (leaf area and thickness) was found under conditions of optimal root temperature and normal irradiance (not stipulated). Higher and lower temperatures than optimum resulted in a decrease in the leaf surface area, and a reduced leaf thickness. At the same time chlorophyll a and b content in the leaf decreased. Shading of the plants caused a decrease in chlorophyll content, increase in leaf area, and decrease in leaf thickness.

Ludwig & Withers (1978) measured the 24 h CO_2 exchange of the first leaf of cucumber seedlings. The measurements were made in an environment of 50 W m^{-2} PAR for 10 h, 2 g m^{-3} CO_2, 20 ^{0}C day/night and a vapour pressure deficit of 0,7 kPa. As the leaf developed the net rate of photosynthesis per unit leaf area steadily increased and the rate of dark respiration declined. As a result, over the 24 h period, the net gain of carbon per unit leaf area by CO_2 exchange steadily increased from 2,2 g C m^{-2} for the young leaf to 5,6 g C m^{-2} for the fully expanded leaf. Comparable figures for the net gain of carbon per leaf over 24 h were 5,1 mg C for the young leaf to 71,1 mg C for the fully expanded leaf. In the young leaf about 28 per cent. of the net carbon fixed during the 10 h light period was respired during the following 14 h of darkness. This proportion steadily decreased as the leaf developed, and was about 8 per cent. in the fully expanded leaf.

Measured transpiration rates were low at all stages of leaf development and stomatal resistance to CO_2 transfer was high. However, the plants were grown in a high CO_2 concentration (2 g m^{-3}) and at this level stomatal resistance did not significantly limit photosynthesis (Ludwig & Withers, 1978).

CO_2 levels in greenhouses in Europe and America are kept at 900 to 1 000 ppm for cucumbers, as for tomatoes (Bauerle, 1975; Slack & Hand, 1979; Wittwer & Honma, 1979; Anon., 1980a; b). CO_2 enrichment of Israeli field cucumbers to 3 000 vpm increased early side shoot development. As the side shoots had a higher proportion of female flowers the number of fruits per plant was increased (Enoch *et al.*, 1976). The cucumber, like the tomato, is a C_3 plant and individual leaves are saturated at relatively low irradiance levels. Sale (1977) recorded maximum net CO_2 uptake rates at about 600 to 800 W m^{-2} in field cucumbers.

Under high radiation dry summer conditions in South Africa (800-1 000 W m^{-2}) Maree (1979b) found that cucumbers still yielded well under 60 per cent. shadecloth over plastic at $\pm$ 300 lumens wk^{-1}, as compared to $\pm$ 750 lumens wk^{-1} under plastic alone. Under shade maximum temperatures were up to 10 ^{o}C lower, and minimum temperatures were up to 5 ^{o}C higher. This work was conducted at Stellenbosch (34 ^{o}S lat.), with dry summers and relatively long days.

Spacing may also affect irradiance levels in the crop canopy, and too close spacing can reduce yields. Maree & Laubscher (1976b) showed that at Stellenbosch an in-row spacing of 600 mm resulted in higher per plant yields, but lower per hectare yields as compared with 400 mm. Spacing recommendations worldwide for greenhouse cucumbers are summarised in Table 2.2.

In a container system the volume of growth medium is also of importance. European growers have had success with cucumbers grown in traditional tomato bags with 42 ℓ of medium for 3 plants i.e. 14 ℓ $plant^{-1}$. Allen (1980), however, feels that the module size should be increased to 0,056 m^3 (56 ℓ) or 18,7 ℓ $plant^{-1}$.

TABLE 2.2 Recommended spacing practices for greenhouse cucumbers according to different authors

Author	Plants ha^{-1}	Plants m^{-2}	m^2 $plant^{-1}$	Spacing arrangement in a double row (mm)	
				Between rows	In rows
Bauerle (1975)	15 200 (fall)	1,52	0,65		
	17 600(spring)	1,76	0,56		
Anon. (1980a)	15 400	1,54-1,19	0,65-0,84		
Anon. (1980b)	14 700	1,47	0,68	500	450
Anon. (1981c)	10 000	1,0	1,0		
				Single	rows
Wittwer & Honma (1979)	13 000	1,3	0,76	1 500	500
Maree (1981c)	16 600-13 800	1,6-1,4	0,63-0,71	1 200	500-600

Adamson (1977) and Anon. (1981c) recommend that where plants are grown in wooden-sided beds or plastic bags there should be at least 0,028 m^3 (28 ℓ) of medium per plant, in this case sawdust. Maree (1981c) found 14 ℓ $plant^{-1}$ to be superior to 9 ℓ $plant^{-1}$, and in recent trials has used 20 ℓ of sawdust per plant.

2.2 GENERAL PROCEDURES

2.2.1 <u>Structures</u> Early work (section 2.3.1 and 2.4.1) was carried out in a small (15 x 8 m) plastic tunnel, orientated E-W, as described in Section 1.2 with environmental features given in 2.3.3. The effect of shading on cucumbers (2.6) was studied in a 30 m x 8 m x 3,5 m high ® Gundle 'roll-up sides' tunnel (Anon., 1978) orientated N-S, and covered with 150 μm thickness ® Uvidek 602 greenhouse sheeting, a uv stabilised clear polyethylene. The transmission properties of the plastic were reported by North (1979), and Maree (1979a; b; c) and are discussed later. Fruit growth studies were carried out in a fully air conditioned, temperature controlled glasshouse, part of the phytotron complex at the Faculty of Agriculture, Pietermaritzburg. Temperature control to ± 2 °C was possible, but daylength was not controlled.

2.2.2 Growing Methods Cucumbers and tomatoes were grown in individual black plastic bags with 13 ℓ or 10 ℓ of medium respectively, unless otherwise stated. The medium was usually a 3:1 mixture of local peat and Umgeni river sand (a coarse grit). In some later experiments (where stated) the medium was pine bark milled through a 16 mm screen.

The tunnel floor was covered with a black plastic mulch, and the pots were arranged in furrows on top of the plastic in double rows at a spacing of 500 mm x 500 mm, unless otherwise stated. The plants were watered three times daily by a gravity feed system, via polythene pipes and microtubes, from an asbestos tank containing a solution of 2 g ℓ^{-1} ® Chemicult (see App. Table 1 and Table 1.3).

The plants were grown to a single stem, and trained up a polypropylene string, attached to an overhead wire at 2,7 m height. In cucumbers first fruiting was only allowed to take place at the eighth node, usually ± 600 mm above pot level. Routine fungicide and insecticide sprays were applied weekly.

2.2.3 Climate Terminology and Measurement

Irradiance or radiant flux density (W m^{-2}) is the total (short wave and long wave) radiant energy received per unit area per unit time (Savage, 1978; 1979a; b).

Total radiant density (J m^{-2}) is the radiant energy received per unit area. Over a given day the total radiant density is defined as $\int_D I dt$, where I is the irradiance, t is the time and $\int_D$ indicates an integration over the days length D (Savage 1978; 1979a; b).

Short wave radiation is a term used for radiation wavelengths between 300 and 3 000 nm (Rosenberg, 1974). Long wave radiation refers to radiation with wavelengths between 3 000 and 60 000 nm.

Photosynthetically active radiation (PAR) is that radiation with wavelengths between about 380 and 720 nm which produces a photosynthetic response.

Incoming shortwave solar radiation was measured using a ® Weather Measure line pyranometer, commonly referred to as a tube solarimeter. The copper-constantan thermopile of the pyranometer is 200 mm long, with the entire detector assembly housed in a glass tube. This was ideal for the measurement of short wavelengths as the glass is opaque to long wavelength radiation (Kubin, 1971; Dubois, 1978). The instrument was factory calibrated against a source traceable to an American National Standard. A microvoltmeter was used to measure the voltage output from the pyranometer.

Photosynthetically active radiation (PAR) was measured using a ® Li-Cor quantum sensor, also factory calibrated.

Radiation profiles were obtained by placing the instruments at different heights in the canopy, in the centre of a central double row of plants. Usually this was done at hourly intervals on several clear days during the trial.

Temperature of the potting media was measured using three wire resistance thermometers (Savage, 1980b). These were inserted into the sides of pots 100 mm from the surface, and connected to a constant recorder.

Leaf resistance to water vapour movement was measured using a ®Lambda diffusion porometer. The porometer was calibrated at six temperatures between 14 and 36 °C using calibration plates supplied by the manufacturers. From the slope and intercept values of these curves, a temperature coefficient converting all time values (time taken to move from 20 to 60 per cent. relative humidity) to those at 25 °C, was obtained. The humidity sensing element was shielded from radiation using an aluminium foil covering. *In situ*, the sensing element was housed in a desiccator. The abaxial leaf resistance of four leaves per plant was measured, usually at hourly intervals, on selected representative days.

Leaf temperatures were recorded with a ® BAT-4 (Bailey Amplifying Thermocouple) clip thermometer, which was attached to the abaxial surface of four leaves per plant at one recording time. The thermometer was shielded from direct radiation.

Air temperatures were measured using sheltered resistance thermometers connected to a constant recorder. On occasions an ® Assman psychrometer, placed at a standard height (1,4 m) was also used to measure temperature and relative humidity.

2.2.4 Growth Analysis At each sampling the medium was carefully and thoroughly washed from the roots, keeping the roots as intact as possible. The fresh and dry mass of roots, leaves, stems and fruits of each plant were determined. Leaf area was measured using a

®Li-Cor leaf area meter. The following growth analysis formulae were used (Hunt, 1978):

1. LAR (leaf area ratio) $= \frac{\text{leaf area}}{\text{plant mass}}$ $(m^2\ g^{-1})$

2. SLA (specific leaf area) $= \frac{\text{leaf area}}{\text{leaf mass}}$ $(m^2\ g^{-1})$

3. CGR (crop growth rate) $= \frac{w_2 - w_1}{t_2 - t_1}$ $(g\ plant^{-1}\ day^{-1})$

4. RGR (relative growth rate) $= \frac{\log_e w_2 - \log_e w_1}{t_2 - t_1}$ $(g\ day^{-1})$

5. NAR (net assimilation rate) $= \frac{w_2 - w_1}{t_2 - t_1} \times \frac{\log_e LA_2 - \log_e LA_1}{LA_2 - LA_1}$ $(g\ m^{-2}\ day^{-1})$

where w_2 is the mass (g) at current week t_2
w_1 is the mass of previous week t_1
and LA_1 and LA_2 the leaf area (m^2) at times t_1 and t_2.

2.2.5 Statistical Analysis See 1.2

2.3 TOMATOES - EFFECT OF SPACING AND VOLUME OF MEDIUM ON ENVIRONMENT, GROWTH AND YIELD (Experiment 7)

2.3.1 Aim To quantify the radiation environment and measure the yield of tomatoes in a tunnel, growing in different volumes of medium and at different spacings.

2.3.2 Procedure Tomato (cv. Angela) seed was sown on 1979:02:25 in local peat in ® Speedling trays and transplanted into the pots in the small tunnel (2.2) on 1979:03:13. General procedures were as described in 2.2.

The trial was laid out as a 2x2 factorial with split plots and three replications, with 4 plants per sub-plot. Each replicate consisted of one double row of plants running the length of the tunnel. There were two between-row spacings (600 mm/300mm) and two in-row spacings (400 and 200 mm) as the whole plot factors, with four volumes of medium (17 ℓ, 13 ℓ, 10 ℓ and 7 ℓ) as the sub-plot factor. The four spacing arrangements were therefore : 300 x 400, 600 x 400, 300 x 200, 600 x 200 mm, hereafter referred to as A, B, C, D, respectively.

Records included plant height, number of nodes to first truss, height of first truss, and the mass and number of fruit per truss. Any fruit with a mass less than 30 g was not included in the yield figures. The number of flowers per truss was recorded in Rep. 2. Radiation profiles were recorded in the centre double row of plants.

2.3.3 Results and Discussion

The radiation environment

a) Irradiance profiles Three-dimensional graphs of the irradiance at different heights above pot level at different times of the day are shown for the 300 x 400 mm and 600 x 400 mm spacings on 1979.05.16 and 1979.05.02 respectively (Fig. 2.1). The crop height at the time of measurement was 1,5 m and 1,2 m above pot level respectively.

Irradiance levels at midday above the crop canopy, but inside the plastic, were typically 600 W m^{-2}, reducing down to very low levels at pot height ($\pm$ 50 W m^{-2}) in the close between-row spacing (Fig. 2.1a). At the wider between-row spacings more irradiance (100 - 200 W m^{-2}) reached the lower levels of the canopy at midday (Fig. 2.1b). In closely spaced rows (Fig. 2.1a) maximum irradiance did not occur at solar noon, but an hour before and after. The diurnal radiation profile was thus M shaped as more irradiance was intercepted by the crop when the sun was directly overhead.

In the wider spaced rows (Fig. 2.1b), where the leaf canopy was not as dense, maximum irradiance in all layers of the canopy was generally at solar noon.

b) Radiant density profiles The daily radiant density was calculated by integrating the irradiance curves from 8h00 to 16h00 for each treatment, at different heights in the canopy. Fig. 2.2 shows the daily radiant energy absorbed by each layer on four different days. In the close spacings (300 x 200 mm) the upper layers absorbed most of the radiant energy, this occurring to a lesser extent in the 300 x 400 mm spacing. At the widest spacing a more even amount of energy was absorbed by each canopy layer, indicating that more energy was reaching the lower levels of the canopy.

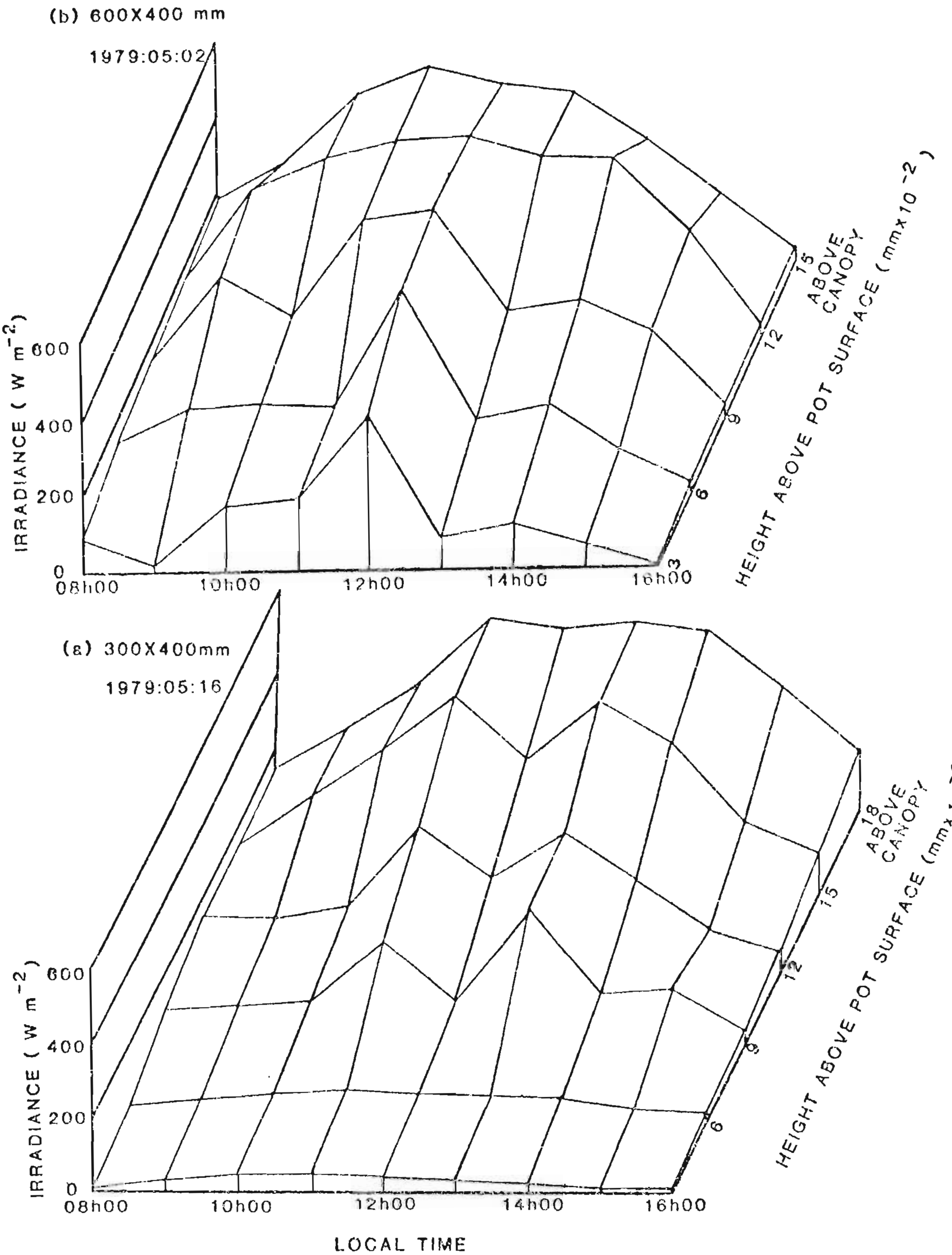


Fig. 2.1 Irradiance as a function of local time in different layers in the canopy of tomatoes at different spacings

a) 300 x 400 mm

b) 600 x 400 mm

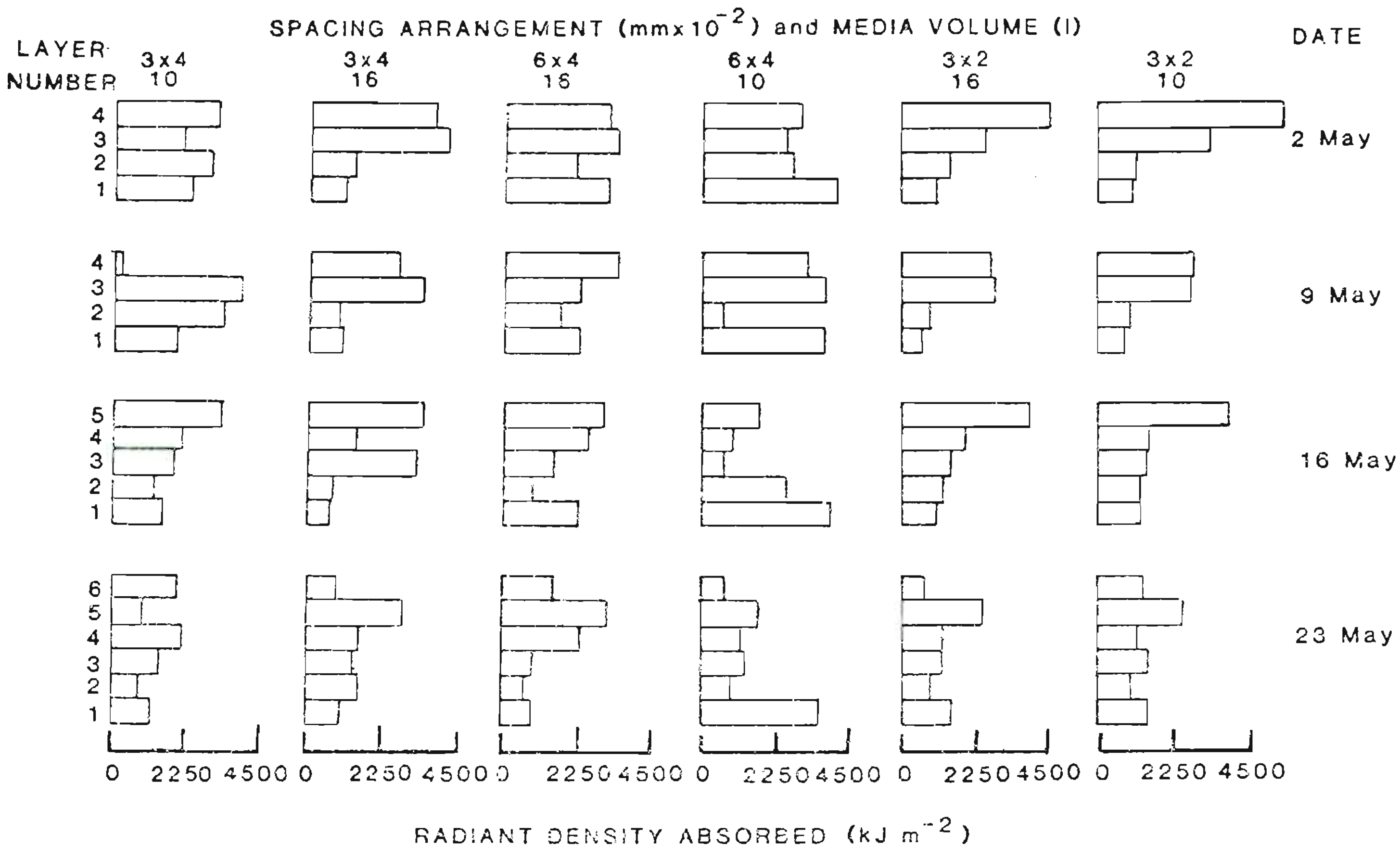


Fig. 2.2 Radiant density absorbed by different layers in tomatoes at different spacing arrangements on successive weeks

The percentage of total daily radiant energy available in the different layers in the crop (Fig. 2.3) shows that the top 300 mm layer of the crop had 70 per cent. available radiant energy in the widest spacing, compared with 50 per cent. in the close spacing. In the middle layer of leaves there was 45 per cent. energy available in the wide spacings, but only 20 per cent. in the close spacing. At the lowest canopy level nearly 30 per cent. remained in the wide spacing, compared with only 10 per cent. in close spacings.

Growth and yield

a) Growth rate Plant height measurements (Fig. 2.4) showed that the wider in-row spacing (400 mm) resulted in a slower increase in height than the close in-row spacing. The between-row spacing had little effect. Although there was no significant difference in growth rates between plants in different pot volumes it was evident that the plants in the small pots were spindly, with longer internodes, thin stems and a smaller leaf area - all indications of an etiolation effect.

b) Position of the first truss The number of nodes to the first truss varied from 8 to 10 with no significant differences between treatments.

The height to the first truss was significantly greater in the close in-row spacing than the wide in-row spacing. Between-row spacing had no effect on this parameter (Fig. 2.5).

Pot volume also significantly affected the height to first truss, this being higher as the pot volume decreased. This was especially the case at closer in-row spacings (Fig. 2.5).

c) Yield Fig. 2.6 shows the main effects of spacing and pot volume on plant yields. The 400 mm in-row spacing produced a significantly greater mass of fruit per plant than the 200 mm in-row spacing. Varying the between-row spacing had little effect on yield.

Pot volumes from 10 ℓ upwards gave significantly higher yields than the 7 ℓ pot volume. The best volume tested, however, appeared to be 10 ℓ, with a slight reduction in yield at 13 ℓ (NS) and 17 ℓ (significant at 5 %) (Fig. 2.6). The interaction between the different spacings and pot volumes (Fig. 2.7) showed that the highest yield at any spacing was with 10 ℓ of growing medium. It was significant that

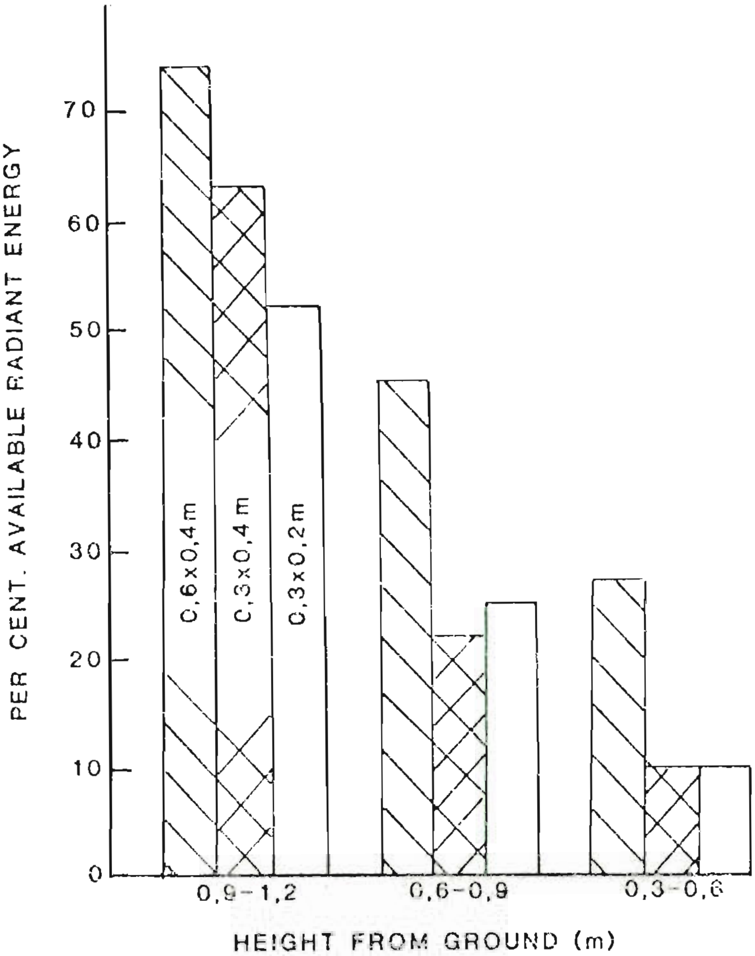
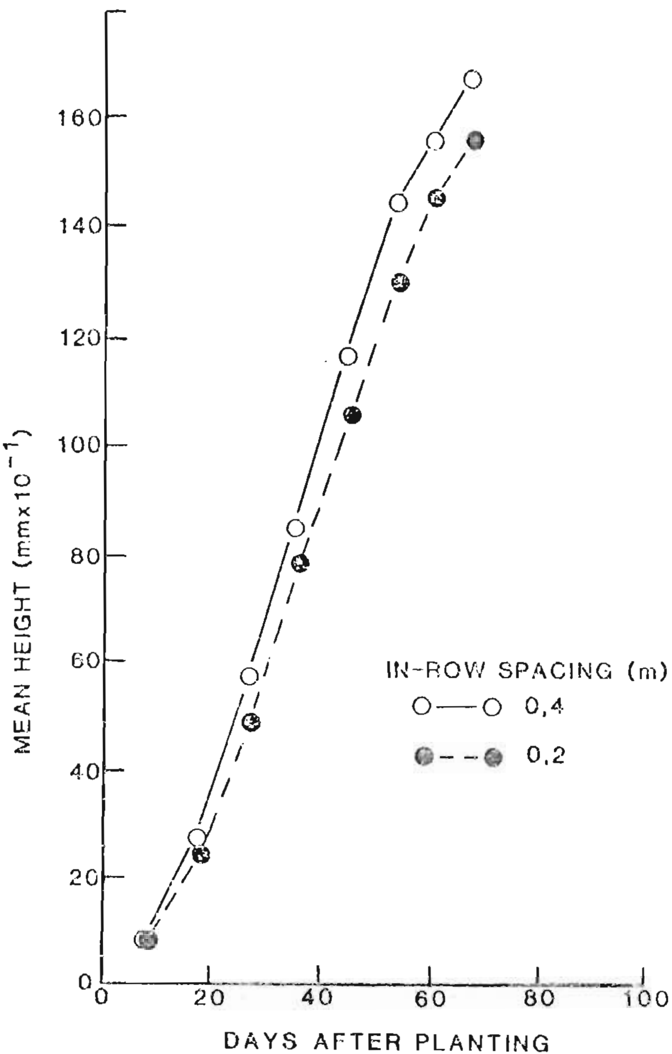


Fig. 2.3 Percentage radiant energy available at different heights in the centre of double rows of tomatoes at different spacings



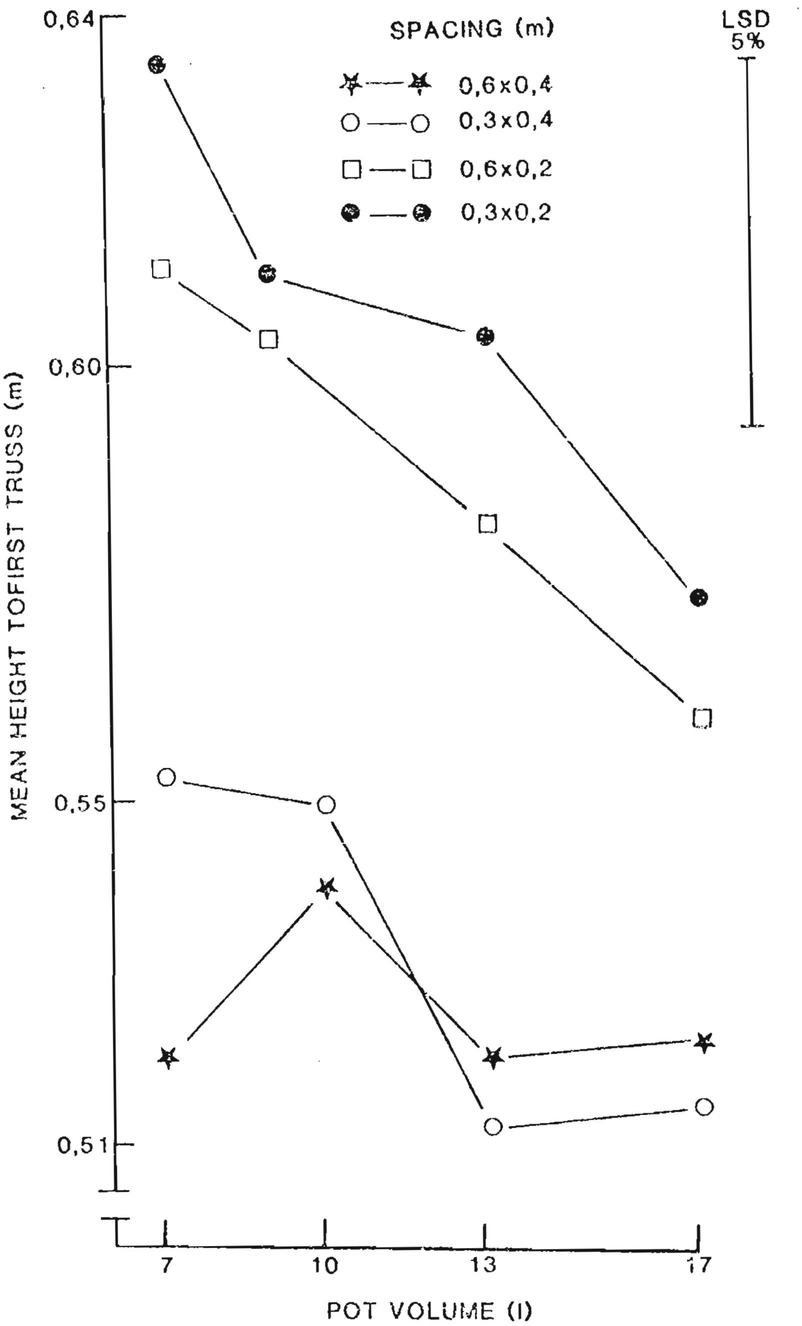


Fig. 2.5 Mean height to first truss on tomato plants at different spacings and in different pot volumes

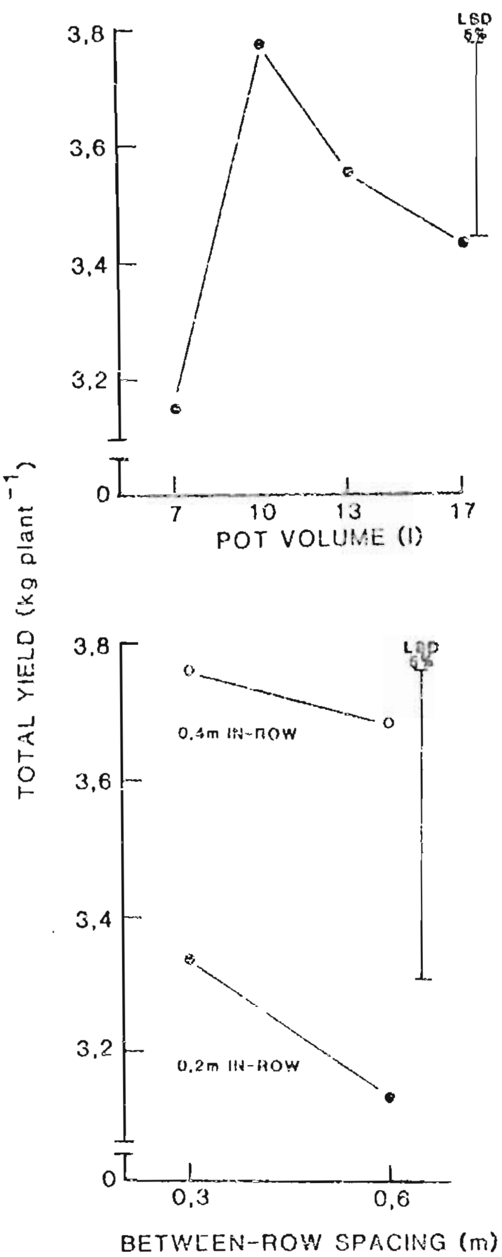


Fig. 2.6 Main effects of pot volume and spacing on the total yield of tomato plants

at close in-row spacings plants in the largest pots performed badly, and therefore at those spacings there was a disadvantage in using a large volume of medium. At the wider in-row spacing plants in larger volumes of medium yielded equally well as those in 10 ℓ.

In comparison to quoted yields these were not high due to the limited size of the tunnel. The time of planting also resulted in poor pollination in the higher trusses which set during cooler winter weather.

The lowest yield in the largest volume tested may have been related to a watering problem whereby a single microtube did not wet all the medium efficiently. Adamson (1977) and Maree (1981c) recommend two microtubes per pot.

d) Total number of fruit per plant Plants in the 300 x 400 mm spacing produced significantly more fruit than plants in the other spacing combinations (Fig. 2.8a), with the wider in-row spacing resulting in an average of 5 fruit per plant more than the close in-row spacing. Between-row spacing did not significantly affect the number of fruit produced per plant.

The smallest volume of medium tested resulted in significantly fewer fruit per plant than the other volumes (Fig. 2.8b). The average plant, topped at the overhead wire, produced ± 48 fruit from 7 trusses.

e) Mean fruit mass There was no significant difference between treatments in the overall mean fruit mass per plant, which averaged 76 g.

f) Yield components of the individual trusses There was a decline in the yield per truss up the plant (Fig. 2.9a), and this occurred in all treatments. The lowest yield per truss was always in the 7 ℓ pots at close spacing, with little difference between the other volumes. The spacing effect, however, was notable, and is important. Fig. 2.9a shows that the yields tended to be better at higher trusses where the in-row spacing was wider.

As with the yield per truss, there was also a decline in the number of fruit per truss up the plant in all treatments (Fig. 2.9b). Again, it was significant that at the wider in-row spacing the plants tended to produce a greater number of fruit per truss on the higher trusses.

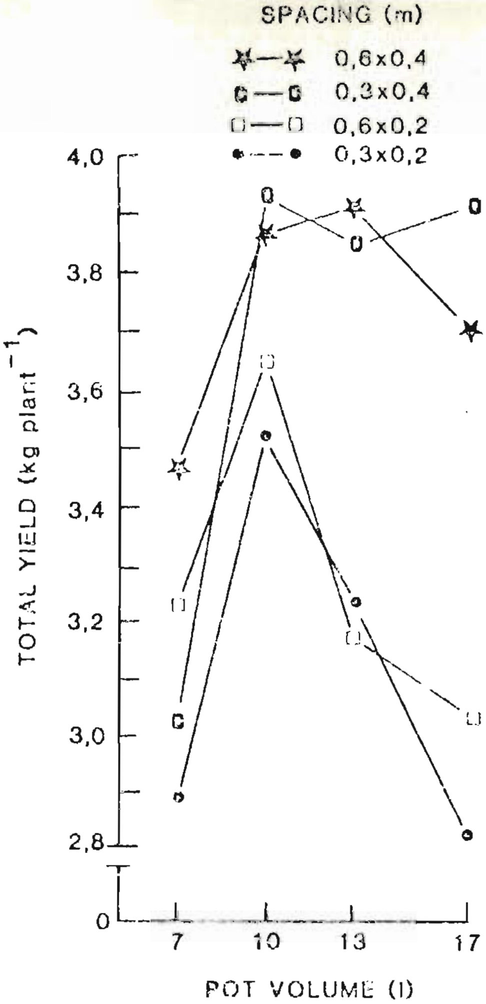


Fig. 2.7 Effect of spacing and pot volume on tomato plant yields

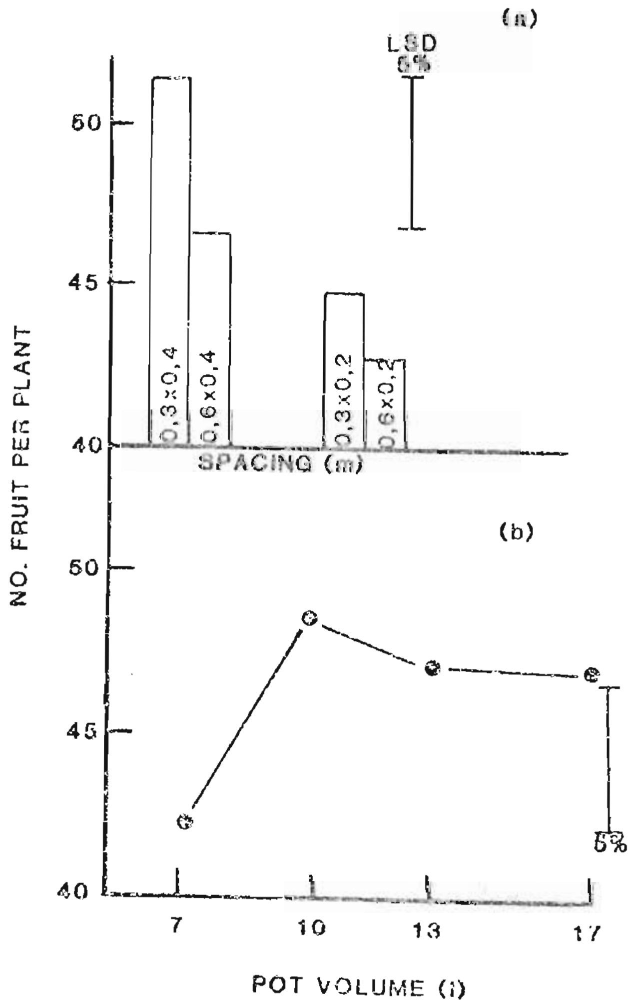


Fig. 2.8 Effect of (a) spacing and (b) pot volume on total number

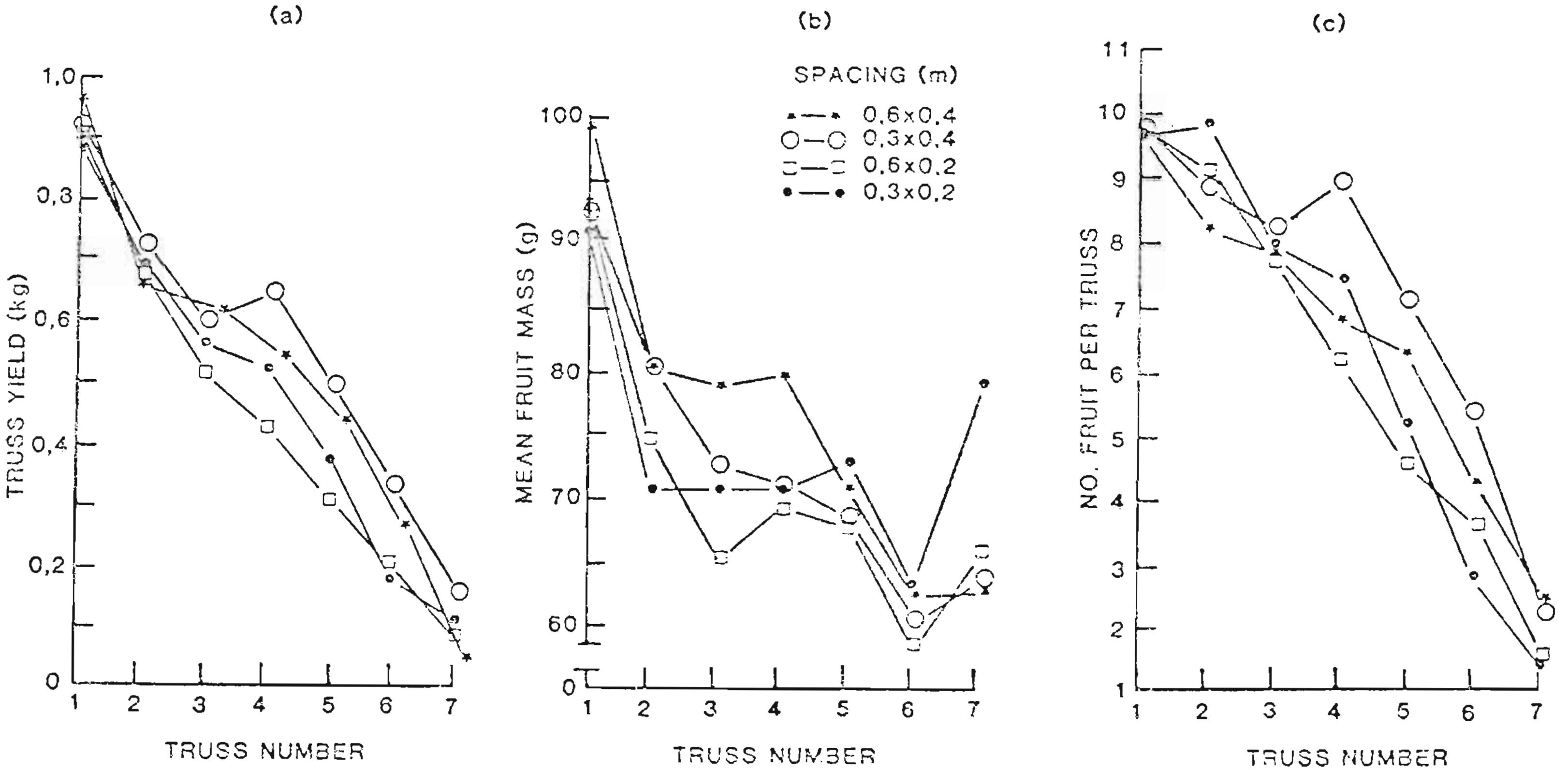


Fig. 2.9 Yield (a) mean fruit mass (b) and no. fruit (c) on different trusses on tomato plants at different spacings

The mean fruit mass of each consecutive truss (Fig. 2.9c) decreased until the sixth truss, with a slight increase at the seventh truss. The average size of fruit on each truss was greater in the 400 mm in-row spacing, especially on the third and fourth trusses. At higher trusses the close spacing treatments, which had the least number of fruit tended to produce slightly larger sized fruit.

The decreasing yields and fruit size per truss are typical for this time of planting in this region. As reported by Oosthuizen & Millar-Watt (1978) this occurs on trusses set in mid-winter when little pollination takes place due to minimum temperatures being too low for viable pollen formation (Calvert, 1964;1973). The slightly improved fruit mass on truss 7 resulted from these flowers developing in spring during warmer weather.

As this period is a high price period for tomatoes, any horticultural practice (such as a wider in-row spacing) which results in higher yields of fruit deserves attention.

f) Flower numbers and fruit set These counts were only made in Rep. 2 and therefore could not be analysed. The number of flowers per truss varied considerably and trends were hard to define. In some treatments the fourth truss tended to produce the most flowers. The percentage of flowers which set and produced a marketable fruit (Fig. 2.10) decreased with increasing truss number, and was generally higher at the wider in-row spacing.

Generally, although the wider spacing did not increase the number of flowers per truss, yield was increased due to higher fruit set and larger fruit size as compared with close spacings. This difference was especially evident for the upper trusses.

2.3.4 Conclusions

A wider in-row spacing of 400 mm resulted in a slower increase in plant height due to a reduced internode length. At close spacings the faster increase in plant height appeared to result from competition for radiation with the plants having a spindly growth habit, especially for 7 ℓ pot volumes. The reduced radiant energy recorded within close spacings in this trial was also found by Harper *et al.* (1979). Kedar & Retig (1968) and Klapwijk (1982) also found that decreased irradiance levels increased the internode length in tomatoes.

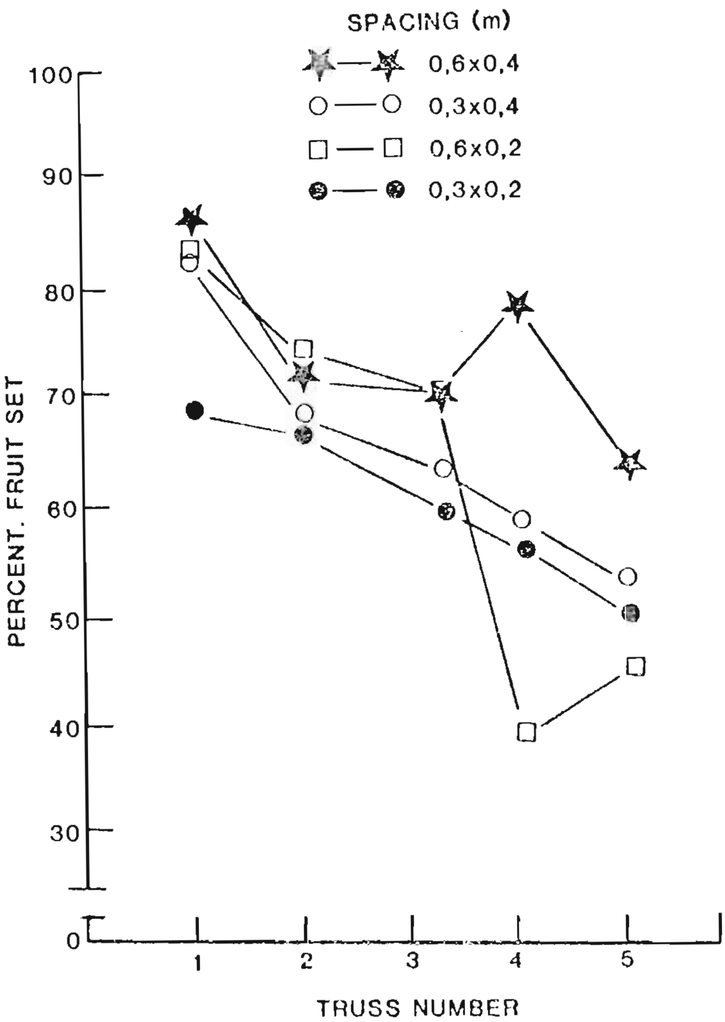


Fig. 2.10 Effect of spacing on per cent. fruit set per truss

Rodriguez & Lambeth (1975) recorded the highest per plant yield at a spacing of 510 x 410 mm, with a yield reduction as the in-row spacing was reduced. In the present trial the highest per plant yield was at the 300 x 400 mm spacing, although this was not significantly greater than the other combinations. The higher yields of plants at wider in-row spacings, suggest that in-row spacing was a critical factor. At wider in-row spacings there was a more even distribution of radiant energy through the canopy (Fig. 2.2), whereas in the close in-row spacing more energy was intercepted by the upper layers.

With respect to pot volumes the highest per plant yield was recorded in the 10 ℓ volume of medium, with apparently (but not significant) lower yields at greater pot volumes, especially at close spacings. It would seem that under our environmental conditions the more restricted root volume in 10 ℓ of medium gave rise to a better balanced plant in terms of vegetative growth and fruiting. A possible reason for the lower yield in larger volumes of medium was that the plant became too vegetative to the detriment of yield.

The 10 ℓ volume of medium is lower than that recommended for peat (Allen, 1980; Moorat,1981; Wilson,1981) and for sand (Jensen, 1980) but is similar to Canadian recommendations for sawdust (Adamson & Maas, 1976; Anon., 1981c). In general smaller volumes of medium require better watering management. The system chosen must balance cost with ease of management and yield. In spacing work it is not the optimum yield per plant that is important, rather the total yield per tunnel area, in conjunction with the required quality of product (Wittwer & Honma, 1979). Table 2.3 shows the yields of the different spacing arrangements tested. Obviously at the closer in-row spacing there would be twice as many plants per tunnel so the yields per unit area were far higher. Note that the yield was not double, as the per plant yields were lower at the close spacing. At close spacing pest and disease management under Natal conditions are also a problem.

Considering all factors it would seem that an intermediate plant population would be best. This could be achieved by either:

a) Using a 300-350 mm in-row spacing on a 4 double row system to give 746-640 plants per tunnel or 3,1 - 2,7 plants m^{-2} respectively, or

TABLE 2.3 Total number of plants and projected yield in a 30 x 8 m tunnel with 1 m door space at each end using yields from Experiment 7

Spacing (mm) Between row	In row	Total No. plants	Plants m^{-2}	m^2 $plant^{-1}$	Yield (kg m^{-2})	Total yield per tunnel (kg) 6 trusses $plant^{-1}$	Yield (tonnes ha^{-1})
300 x	400	520	2,2	0,45	8,20	1963	82,0
600 x	400	520	2,2	0,45	7,98	1914	79,8
300 x	200	1040	4,3	0,23	14,45	3468	144,5
600 x	200	1040	4,3	0,23	13,56	3254	135,6

b) By using the 300 x 400 mm spacing but including an extra single row of plants on each side of the tunnel to give a population of 640 plants per tunnel (2,7 m^{-2}). Alternatively a five double row system could be used, which would reduce the cost of the irrigation system slightly.

It has already been noted (Table 2.1) that worldwide spacing recommendations result in a plant population varying from 2,3 - 3,8 plants m^{-2}. The results of this experiment support these recommendations for Natal conditions.

2.4 TOMATOES - DIURNAL TEMPERATURE VARIATION IN A PLASTIC TUNNEL, AND IN DIFFERENT SOILLESS MEDIA (Experiment 8)

2.4.1 Aim To measure air and potting medium temperatures in a plastic tunnel with tomatoes planted in different media in black plastic bags.

2.4.2 Procedure An experiment comparing the growth and yield of tomatoes in eight different media (Table 2.4) in the small tunnel (2.2.1) was carried out during February to September, 1978 (autumn/winter/spring). Full details of the procedure and the different media are given in 3.3. Pot temperatures in each medium were measured (2.2.3) in the central double row of three double rows of tomatoes in the tunnel during June and July. Temperatures were also recorded in 3 pots on the northern row of plants in the E-W orientated tunnel i.e. 3 pots on the exposed sunny side of the tunnel, in direct solar radiation for the major portion of the day (No. 9, 10, 11 in Table 2.4).

The plants (cv. Hotset) were grown in 10 ℓ black plastic bags according to normal procedures.

2.4.3 Results and Discussion Table 2.4 shows the minimum and maximum medium temperatures in the various pots for the period 78.06.15 to 78.07.14. In the centre row, the 1:3 peat and sand mixture had the highest medium temperatures during the day. The next highest day temperatures were recorded for peat and vermiculite (1:1). Sand also had high day temperatures. In the northern row of pots, maximum temperatures were up to 10 °C higher than the centre row.

TABLE 2.4 Mean daily maximum and minimum and mean pot temperatures for the period 78.06.15 to 78.07.14, together with yield data. The pot number is indicated to the left of the pot media type

Pot media	Mean of daily maximum (°C)	Mean of daily minimum (°C)	Mean (°C)	Plant yield (kg)
1. Peat and sand (1:2)	13,4	6,4	9,9	2,27
2. Sand	14,1	6,1	10,1	2,02
3. Peat and vermiculite (1:1)	13,6	7,5	10,6	2,54
4. Polystyrene and peat (1:1)	13,3	6,1	9,7	1,65
5. Peat and sand (1:3)	14,7	6,2	10,5	3,16
6. Perlite	13,6	6,4	10,0	2,98
7. Vermiculite	13,2	7,0	10,1	2,43
8. Peat and perlite (1:1)	12,3	6,4	9,4	2,73
9. Perlite	18,6	7,6	13,1	3,29
10. Peat and sand (1:3)	23,5	6,2	14,9	3,86
11. Peat and vermiculite (1:1)	20,9	7,3	14,1	5,59

The 1:1 peat and perlite mixture had the lowest mean temperature of all media (Table 2.4).

Minimum temperature differences were smaller. Peat and sand (1:3) experienced relatively low temperatures, but the peat and vermiculite (1:1) mixture had higher minimum temperatures. In fact, both the vermiculite and peat : vermiculite media appeared to retain more heat energy than most of the other media during the night. Polystyrene and peat (1:1) and sand, experienced the lowest night time temperatures. The peat and sand (1:3) medium generally had the highest day pot temperatures, the greatest diurnal pot temperature range, and the highest mean temperatures.

The diurnal air and pot temperatures of the different mixtures are shown for a 24 h period in two different weather situations:

a) A sunny clear day and the following night (Fig. 2.11).

For the period shown, outside air temperatures were close to 0 ^{O}C at 06h00, and reached a maximum of 20 ^{O}C at 14h00. The temperature climbed sharply between 08h00 and 10h00 and decreased more gradually between 16h00 and 20h00.

The air temperatures inside the tunnel rose sharply with the increase in outside air temperatures, but climbed to a higher maximum of 24 ^{O}C. The tunnel cooled faster than the outside air in the afternoon (15h00 to 18h00), but thereafter the rate of cooling slowed down so that the tunnel was a few degrees warmer during the coldest time of the day (06h00).

Pots with vermiculite tended to remain the warmest at night, which is indicative of the insulative character of vermiculite. Thus the peat:vermiculite mixture did not heat up to the highest temperature during the day, but was warmest at night. The peat:sand (1:3) mixture became warmest during the day (15 ^{O}C), but cooled to a greater extent at night. For some unexplained reason the peat:polystyrene mixture became very cool at night.

b) A cloudy night and the following day.

Under cloudy night conditions less radiational cooling takes place. Thus the air and pot temperatures remained relatively warmer at night under these conditions (Fig. 2.12).

It was, however, still noticeable that the peat:vermiculite mixture remained the warmest during the night period and peat:polystyrene the coldest. All other media had temperatures between these two extremes.

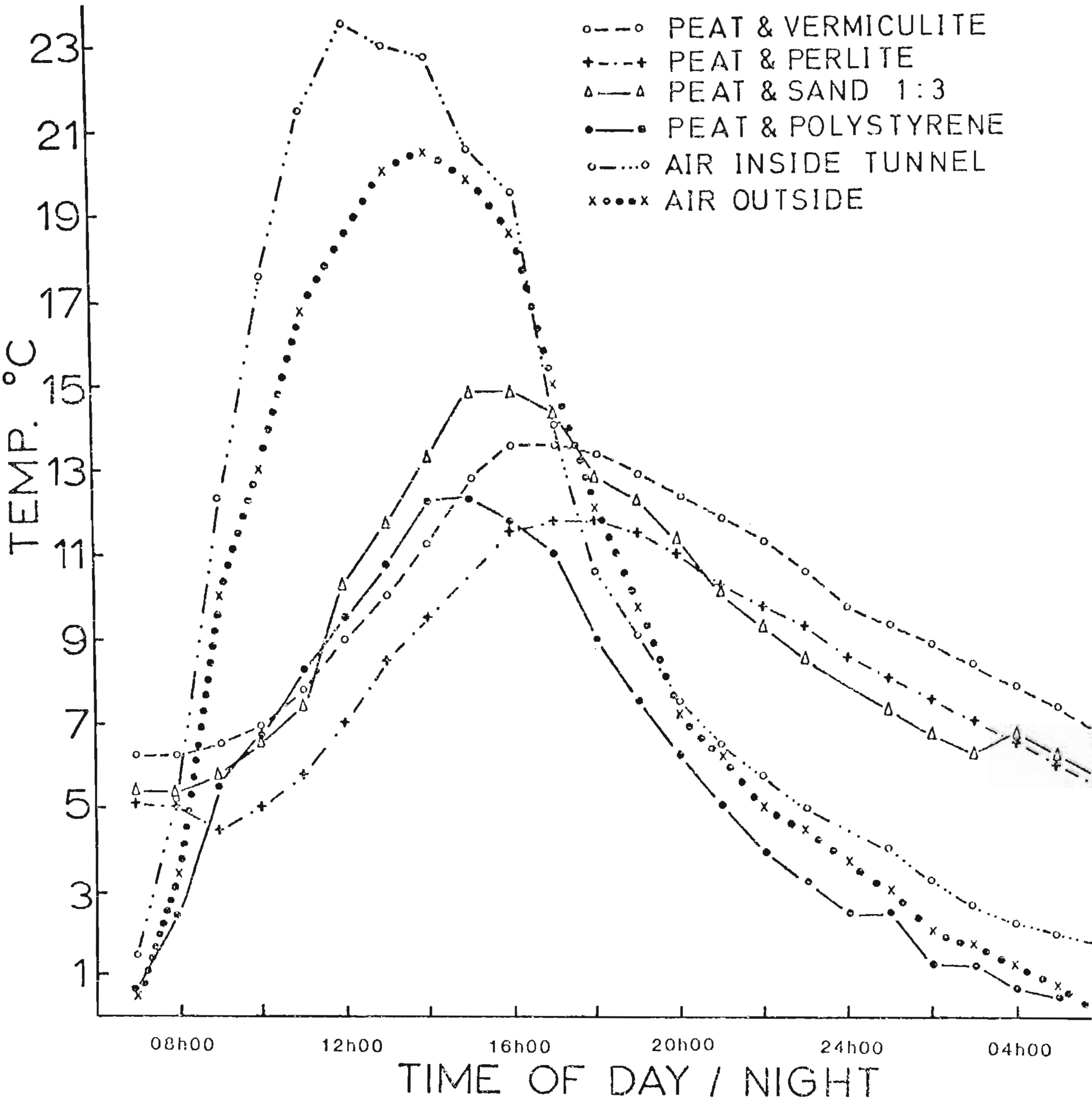


Fig. 2.11 Potting mixture and air temperatures during a sunny day and the following night

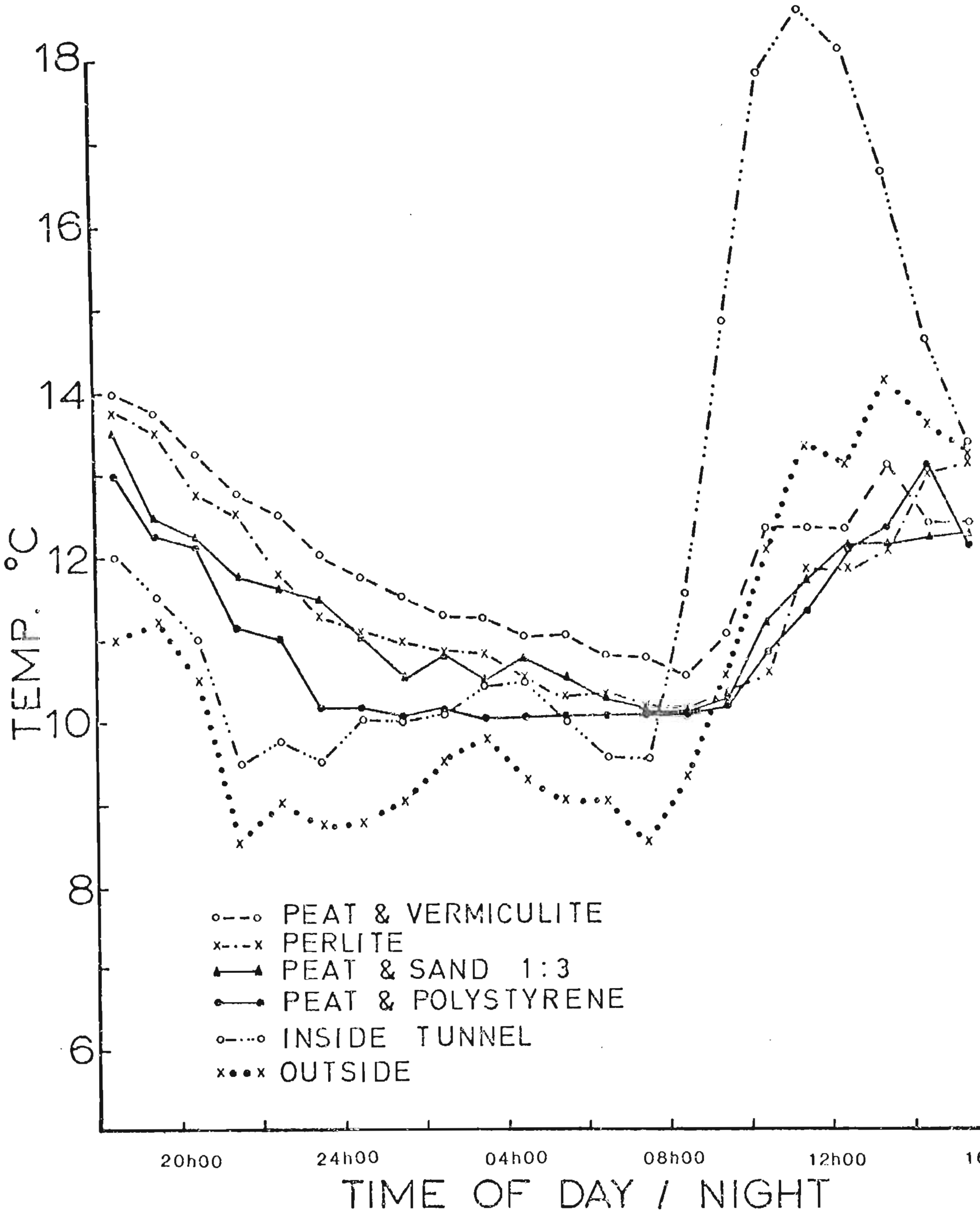


Fig. 2.12 Potting mixture and air temperatures during a cloudy night and the following day

An examination of individual plant yields in the pots measured (Table 2.4) shows that the two highest yielding plants tended to have the highest pot temperatures.

Treatments 10 and 11 (Table 2.4) were on the northern side of the tunnel and can be compared with treatments 3 and 5 which were the same medium but in the centre double row. Fig. 2.13 shows that on a sunny clear day the maximum temperature in peat:sand on the outer row was 24 ^{o}C as compared with 15,7 ^{o}C in the centre row. For peat: vermiculite the temperatures were 21 ^{o}C and 13 ^{o}C respectively. Table 2.4 shows this pot temperature difference between the corresponding treatments over a period of one month. In both cases the yield per plant in the same medium was higher with a higher pot temperature (Table 2.4).

Considering that the optimum root temperature for tomatoes is 23 ^{o}C (Winsor *et al.*, 1979), and should not fall below 16 ^{o}C (Allen, 1980) it is surprising that the plants yielded relatively well. Vegetative growth was reasonable and no deficiency symptoms were evident. In summer the author has measured potting medium temperatures up to 35 ^{o}C, as compared with Fretz (1971) who measured up to 45 ^{o}C in nursery containers. In South Africa, if tunnels are orientated E-W then the pots on the north side should be protected in summer. The author has successfully used white paint. Generally, however, growers are advised to erect their tunnels N-S to overcome this problem and for improved light relations.

The pot temperature profiles shown in Table 2.4 and Figs. 2.11, 2.12 and 2.13 may be explained by comparing the air filled porosity (θ_a) values given by Mastalerz (1977), in volume per cent (Table 3.10). The thermal conductivity will depend mainly upon θ_a.

The greater the thermal conductivity the greater the daily range in pot temperature. θ_a is greater than 30 per cent. for perlite whereas for peat and sand (1:3) θa is 10 per cent. (Mastalerz, 1977). Hence perlite will have a smaller thermal conductivity than peat and sand. Sand, and peat and sand both have $\theta a \pm 10$ per cent. and had higher pot temperatures. For vermiculite $\theta a > 25$ per cent., and hence a small thermal conductivity, and relatively lower pot temperatures.

Moisture retention in the different media (Table 3.10) will also affect the temperature fluctuation due to the high specific heat of water.

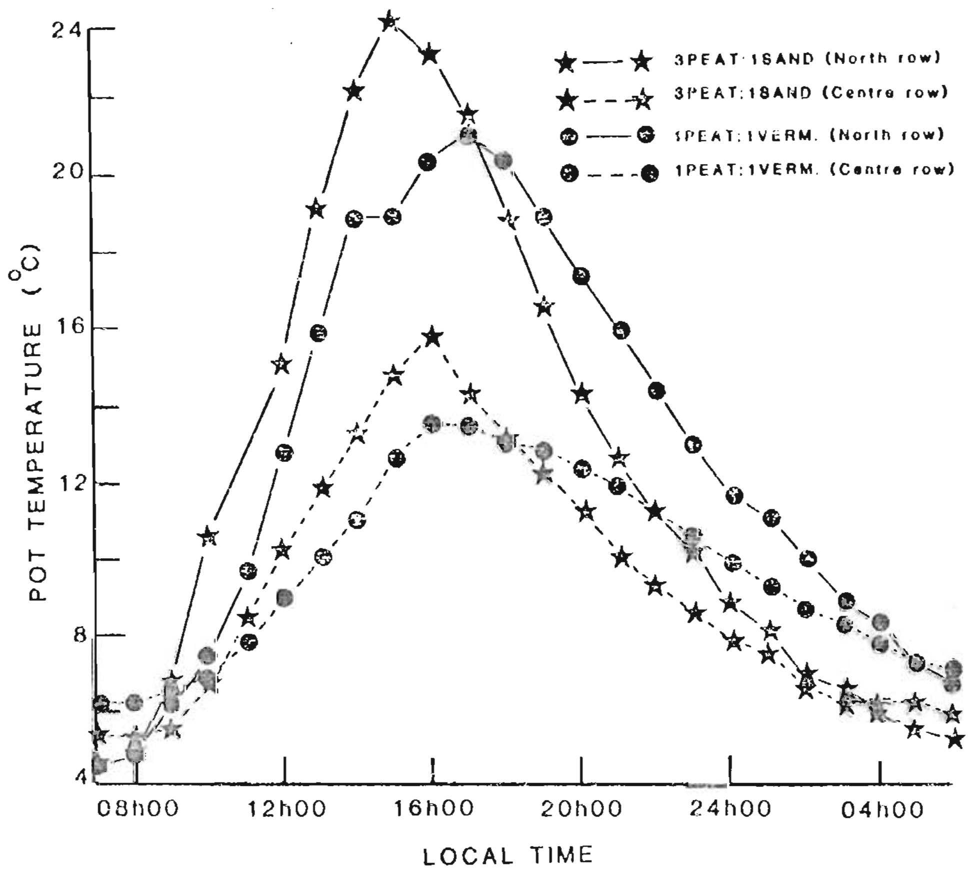


Fig. 2.13 Comparison of between row pot temperatures (for 1978:06:26, a hot day) with two pots in the centre row and two on the northern (sunny) side

2.4.4 Conclusions Day/night potting medium temperatures fluctuated between ± 24 °C and ± 6 °C depending on the type of potting medium and the position of the pot in the tunnel. Sand:peat mixtures had the highest day temperatures and the highest diurnal range in temperatures compared with vermiculite in which the diurnal range was smaller. Generally the plants grew and yielded relatively well considering that the recommended root temperature for tomatoes is 23 °C.

2.5 CUCUMBERS - EFFECT OF TEMPERATURE AND LEAF : FRUIT RATIOS ON FRUIT GROWTH (Experiment 9)

2.5.1 Aim Fruit abortion is often a problem under local conditions in tunnel cucumbers. This experiment was designed to measure the effect of temperature and leaf area on fruit growth.

2.5.2 Procedure Cucumbers (cv. Pepinex) were grown during summer, 1980 in plastic bags containing 15 ℓ milled pine bark, in a controlled temperature glasshouse at 2 temperature regimes viz. 22/17 °C and 18/15 °C day/night. The length and diameter of 10 developing fruits for each treatment were measured at regular intervals.

At the start of each set of measurements a record of total leaf area was made by measuring the length of all leaves on the plant. Leaf length was related to leaf area using North's (1979) correlation whereby 10 mm of leaf length was equivalent to 1 750 mm^2 of leaf area.

At the lower temperature regime fruit growth was compared in plants with a full leaf complement, and with half the leaf area; as well as between plants with two as compared to one developing fruit. A comparison was also made between fruit growth on old plants (± 4 m stem length) and young plants (± 2 m stem length). At both temperature regimes the total leaf length of each plant was from 0,3 to 0,4 m. At 22/17 °C this was adjusted to 0,37 m on all plants at the start of measuring, and at 18/15 °C to 0,3 m or 0,15 m according to treatment. This resulted in a leaf area of 0,6475 m^2, 0,5250 m^2 and 0,2625 m^2 in the three treatments respectively.

2.5.3 Results and Discussion

Fig. 2.14 shows that cucumber fruit growth curves were typically sigmoid shaped, similar to most fruit (Leopold & Kriedemann, 1975). The shape of the curve varied with temperature, leaf area and the number of competitive fruit.

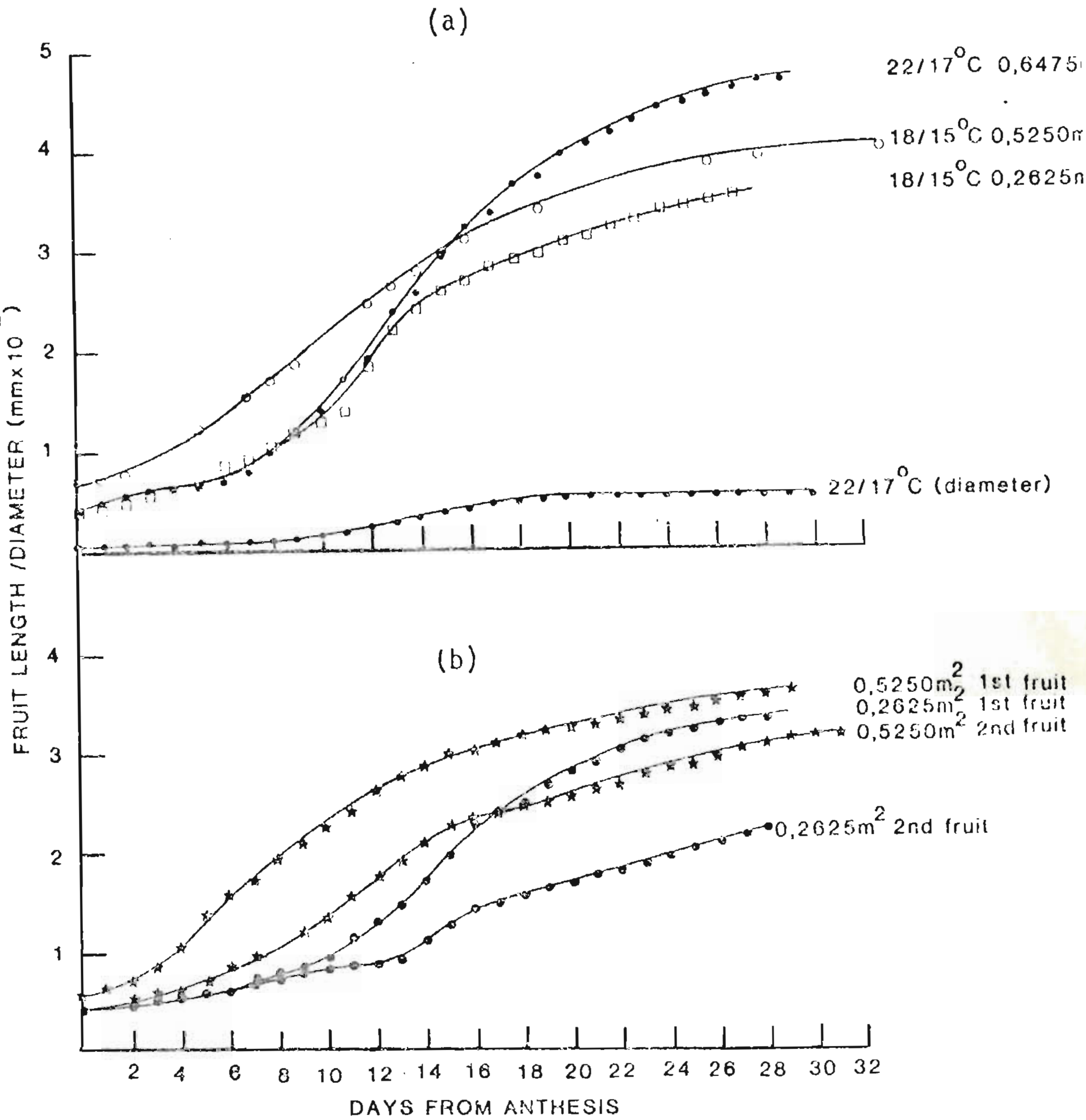


Fig. 2.14 Cucumber fruit growth curves (a) at different day night temperatures, and with different leaf area per plant, and (b) with different leaf areas and numbers of fruit per plant at 18/15 °C

The largest fruit were produced on plants with the maximum leaf area tested (0,6475 m^2) growing at 22/17 ^{0}C and with only one fruit per plant (Fig. 2.14a). In these fruit the slope of the exponential phase was greatest and occurred for the longest time ($\pm$ 14 days). Fruit on plants growing at 18/15 ^{0}C and with a smaller leaf area grew to a shorter final length, and had a flatter sloped curve in the exponential phase, which occurred over a shorter time ($\pm$ 10 days) (Fig. 2.14a). The smallest leaf area (0,2625 m^2) affected fruit development to a greater extent.

Where two fruit were allowed to develop at the same time on plants with different leaf areas (Fig. 2.14b), the first fruit which set always predominated and grew to a greater length, as reported by de Stigter (1969) in seeded cucumbers. The start of the exponential phase always occurred earlier in the first fruit which set and lasted for a longer period. The fruit length was always larger on plants with the greatest leaf area. The greatest difference in growth between two fruit on one plant occurred at the smallest leaf area.

In this experiment plants were also grown at a temperature regime of 30/20 ^{0}C. At this temperature no fruit set took place until the plants were nearly 3 m in length. Normal flowering took place but all flowers senesced without appreciable development. Flower abscission is mostly seen where growers apply insufficient fertiliser and plants have a smaller leaf area than desirable.

Further, summer temperatures inside tunnels in South Africa are often 30/20 ^{0}C (Maree,1979a;b; c; North, 1979) and reported flower abscission under these conditions appears to be a high temperature effect. Allen (1980) reported reduced yields using thermal screens due to resulting higher night leaf temperatures which prevented carbohydrates built up during the day from being translocated. In the author's opinion high temperatures probably also induced severe internal water stress, food reserve depletion due to high respiration rates, and disturbed hormonal relationships at a critical time leading to abscission layer formation in the peduncle. Physiological research is required to further examine these effects.

Fruit growth research is also important in determining if any flower pruning is necessary, for if a fruit will not develop to a marketable size (> 300 mm) it should be removed early on. Most present recommendations are that where two flowers form per node, one should be removed (Anon., 1981c).

Although a plant with reduced leaf area can still produce a relatively large fruit it produces fewer total fruits as there is a high percentage of flower abortion.

Leaf:fruit ratios require further investigation. More temperature regimes should be tested in conjunction with different fertiliser regimes. Fruit dry matter accumulation should be recorded.

2.5.4 Conclusions Leaf area and temperature have been shown to affect fruit growth rates and the eventual size to which a fruit grows. A reduced leaf area resulted in smaller fruit. Plants growing at 22/17 ^{o}C tended to produce larger fruit than those growing at 18/15 ^{o}C. At 30/20 ^{o}C a high proportion of flower abscission was recorded.

2.6 CUCUMBERS - EFFECT OF SPACING AND VOLUME OF MEDIUM ON ENVIRONMENT GROWTH AND YIELD IN SUMMER (Experiment 10)

2.6.1 Aim As in tomatoes this research was undertaken to quantify the growth of the cucumber under local conditions, and to measure its yield in response to factors like spacing and pot volume.

2.6.2 Procedure Cucumber (cv. Pepinex 69) seeds were sown in ® Speedling trays on 1979:10:15 and transplanted into pots containing a 1 local peat:3 sand medium in the small tunnel (2.2.2).

The experiment was laid out exactly as for tomatoes (Experiment 7:- 2.3.2) and consisted of a 2 x 2 factorial with split plots and three replications, each replication consisting of one double row of plants running the length of the tunnel. There were two between-row spacings (600 mm and 300 mm) and two in-row spacings (400 mm and 200 mm) as the whole plot factors, with four volumes of medium (17 ℓ, 13 ℓ, 10 ℓ and 7 ℓ) as the sub plot factor, and four plants per sub plot.

Records were taken of the number of fruit harvested per plant, the fruit mass, fruit length and total yield from first harvest (1979:11:20) until 1980:01:10. By this time treatment differences had clearly shown up and the plants in the close spacing had started to deteriorate. Radiation profiles (2.2.3) for each spacing treatment were obtained during December in the centre double row of plants. Potting medium temperatures(2.2.3) were also recorded during December in the 10 ℓ pots in the centre double row of plants, in each spacing treatment.

2.6.3 Results and Discussion

a) Irradiance profiles Fig. 2.15 shows three dimensional graphs of irradiance as a function of local time, and height above pot level for the different spacings on a typical sunny summer day (1979.12.07).

At midday the above-plastic irradiance level was over 1 000 W m^{-2}. This was reduced to $\pm$ 600 W m^{-2} inside the tunnel, above the crop. For close between-row spacings (Figs. 2.15b and d) the irradiance was reduced to low levels (< 200 W m^{-2}) within 500 mm of the top of the crop. With wide between-row spacings (Figs. 2.15a and c) slightly more irradiance penetrated to pot level.

A slight peak in the irradiance level was reached at 13h00 in wide spaced rows, whereas in the close spacings the level of irradiance in the canopy layer below 1 m remained uniformly low all day ($\pm$ 40 W m^{-2}).

Three dimensional irradiance profiles in the four spacing treatments are given in Fig. 2.16. Generally the widest spacing had the highest irradiance at all levels in the canopy. There was a reduction in the amount of irradiance as the between-row spacing and the in-row spacing was reduced. Ninety per cent. of the irradiance was intercepted by the top 1 m of canopy of the plants, which were 2 m high at the time of the measurements.

b) Radiant density profiles (2.2.3) Radiant density levels at different heights in the canopy on 1979:12:21 are shown in Fig. 2.17.

Typical outside levels were $\pm$ 25 000 kJ m^{-2}, reducing to 19 000 kJ m^{-2} within the plastic, and to 5 000 kJ m^{-2} at 1 m above pot level within the crop canopy. These levels can be compared with those at Lee Valley Experiment Station, U.K., where maximum outside summer radiant density levels reach 16 000 kJ m^{-2} (Anon., 1980a).

As with irradiance, there was a greater percentage radiant density (Fig. 2.18) at all levels in the canopy in the wider spaced rows. The lowest percentages were recorded in the closest spacings

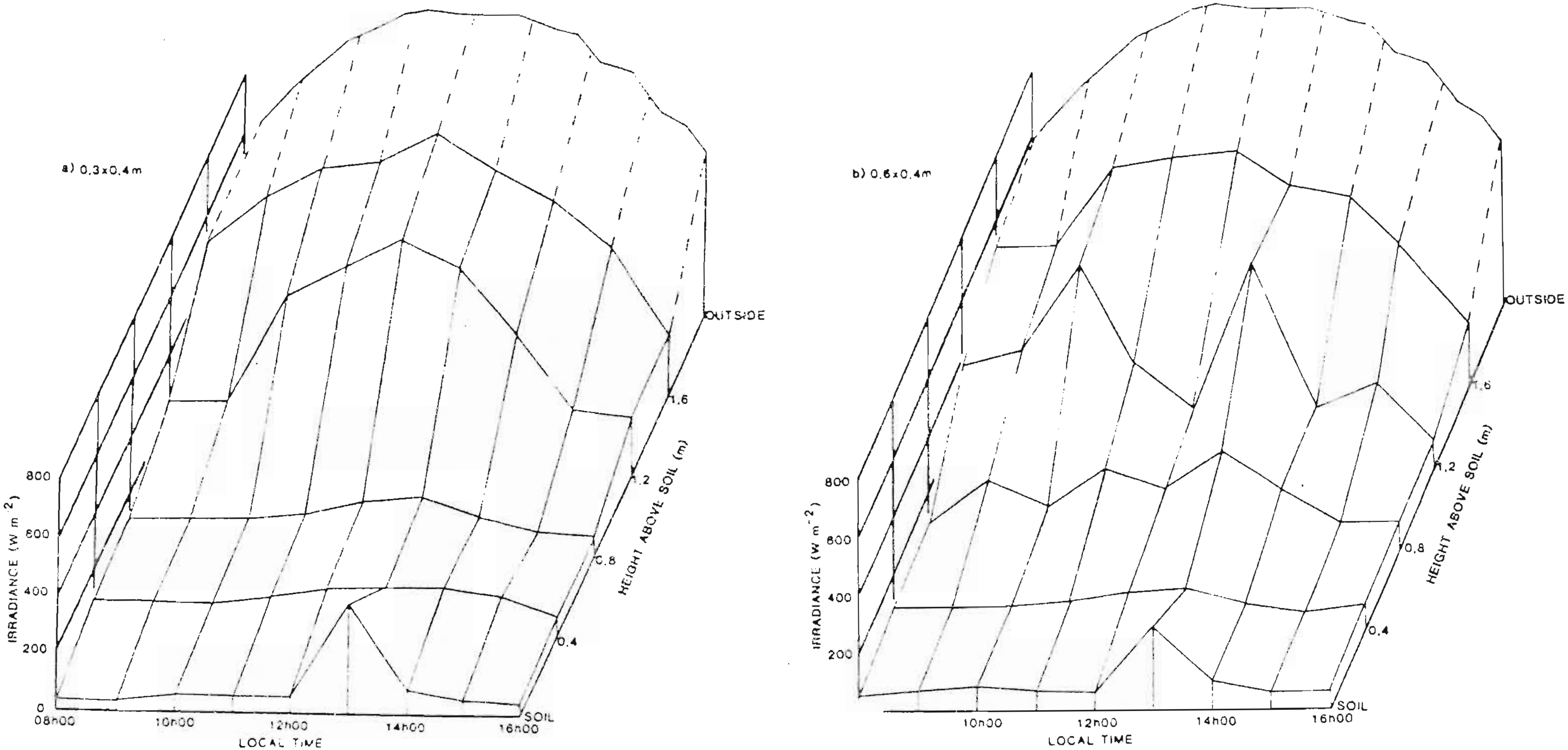


Fig. 2.15 Irradiance as a function of time and height above pot level for different spacings on a typical sunny summer day (1979:12:07)

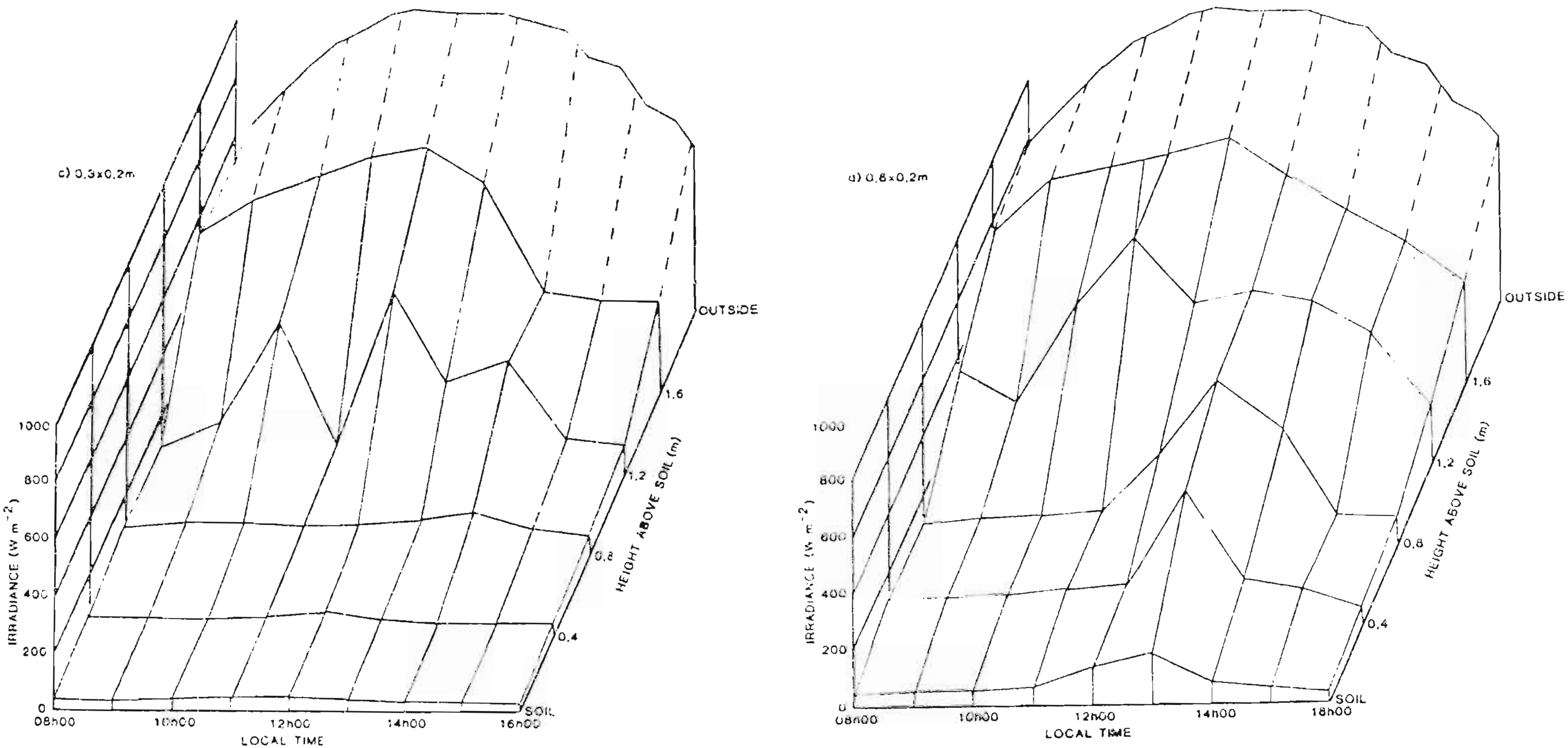


Fig. 2.15 Continued

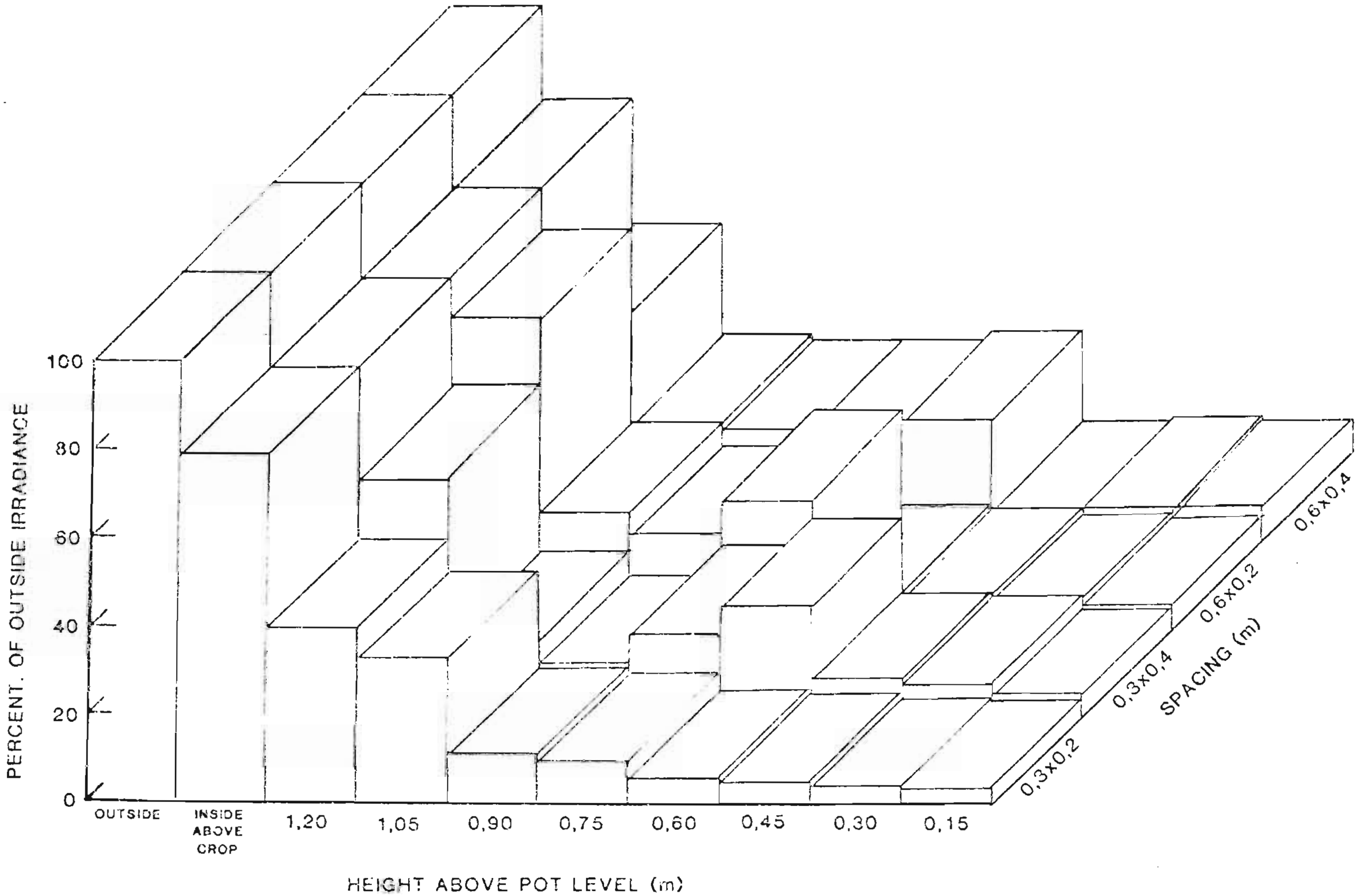


Fig. 2.16 Histogram showing percentage of outside irradiance inside a plastic tunnel and in different layers of a cucumber

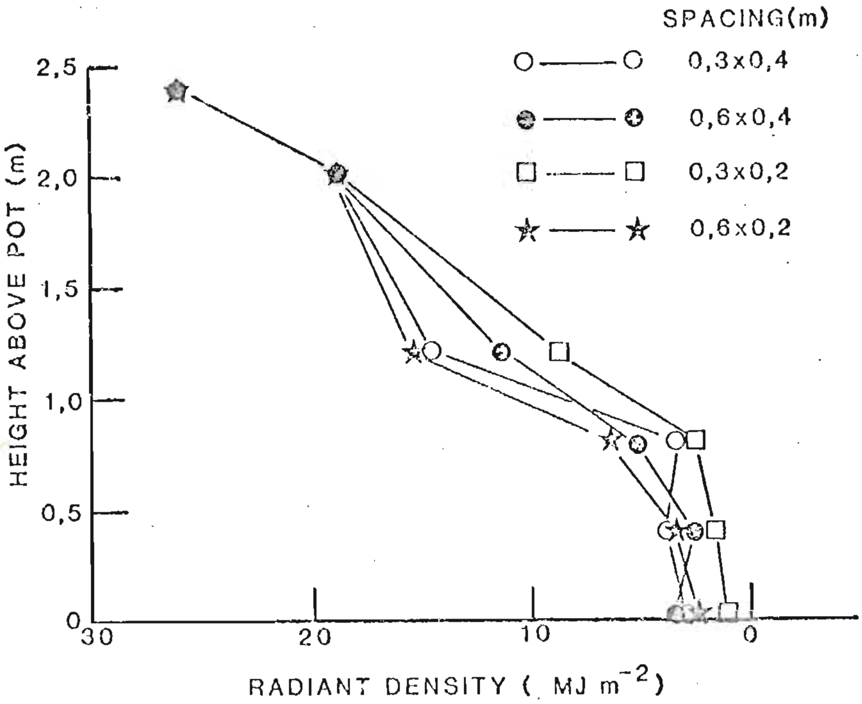


Fig. 2.17 Radiant density levels at different heights in the centre of a double row of cucumbers at different spacings on a sunny day (1979:12:21)

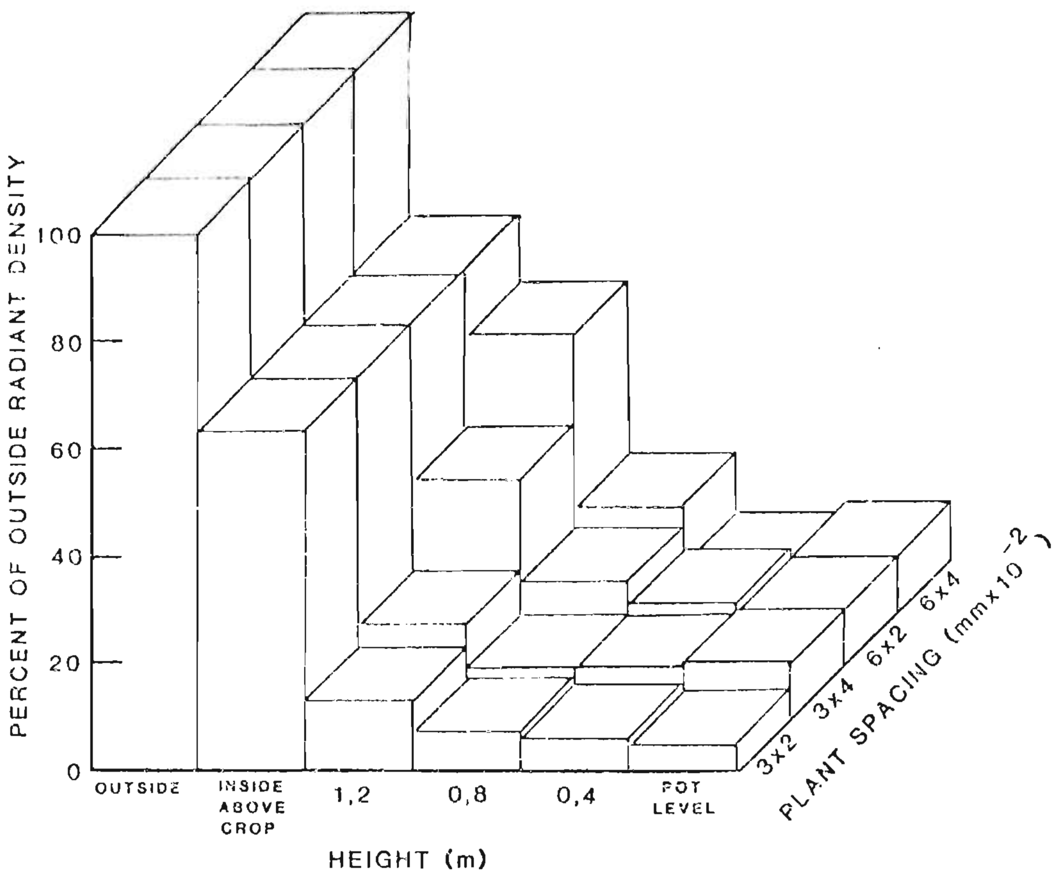


Fig. 2.18 Histogram showing percentage of outside radiant density inside a plastic tunnel and in different layers of a cucumber canopy at different spacings on 1979:12:21

(300 x 200 mm). The plastic covering reduced the incoming radiant density by 30 per cent.

c) Air and pot temperatures Fig. 2.19 shows the mean weekly air temperature outside and inside the tunnel for a one-week period, together with the temperature of the potting medium in 10 ℓ pots in the different spacing arrangements. Midday air temperatures inside the tunnel were ± 3 °C higher than outside air temperatures, this difference reducing to ± 1 °C at the coldest part of the day (03h00). Maximum temperatures inside the tunnel were typically ± 32 - 35 °C, reaching 40 °C on hot days, and minimum air temperatures were 17 - 19 °C. Normal daily temperatures thus fluctuated widely around the recommended 20 °C (Slack *et al.*, 1978; Anon.,1981c).

Pot temperatures did not fluctuate as widely as air temperatures, with maximum and minimum levels reaching 28 °C and 18 °C respectively. Pot and air temperature fluctuations were related, there being approximately a 3h00 lag of pot temperatures behind air temperatures (Fig. 2.19).

Pots in the different spacing arrangements had similar temperatures, the exception being the 300 x 400 mm spacing which had a lower minimum and higher maximum. This treatment was closest to the door in the replicate in which measurements were taken.

In the comparable trial with tomatoes in winter (2.3) the pot temperatures varied between 4 and 12 °C.

d) Yield and fruit quality Total yields per plant (Fig. 2.20) depended mainly on the volume of medium. Smaller volumes of medium (7 ℓ and 10 ℓ) resulted in highly significantly lower yields than the 13 ℓ volume, as did the largest volume tested. The yield in the 7 ℓ pots was significantly lower than with 10 ℓ and 17 ℓ.

Both between and in-row spacing differences were not significantly different (Fig. 2.20). There was a definite tendency, however, for yields to be lower at the closest in-row spacing, and this effect was consistent with all pot volumes. The in-row effect was greater than the between-row effect.

The significantly highest yield was recorded in 13 ℓ pots at a spacing of 400 mm in the row (Fig. 2.20c). The number of fruit per plant was also significantly best for the same treatment combination (Fig. 2.21). However the differences in the 10 ℓ pots with 200 mm

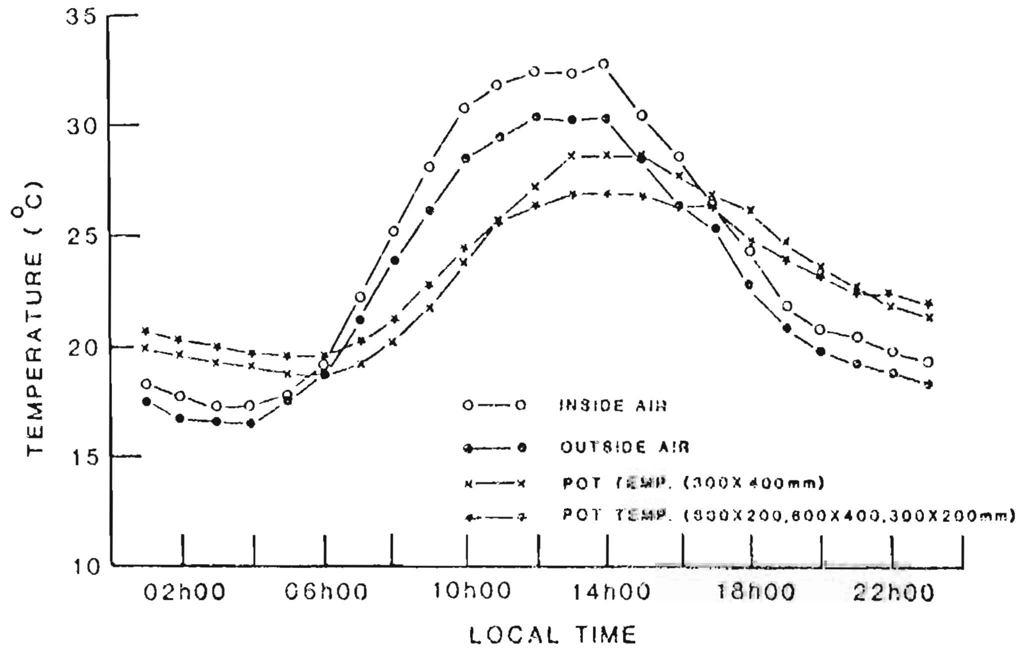


Fig. 2.19 Mean hourly maximum and minimum air and potting medium temperatures for the seven day period 1979:12:24 - 1980:01:01

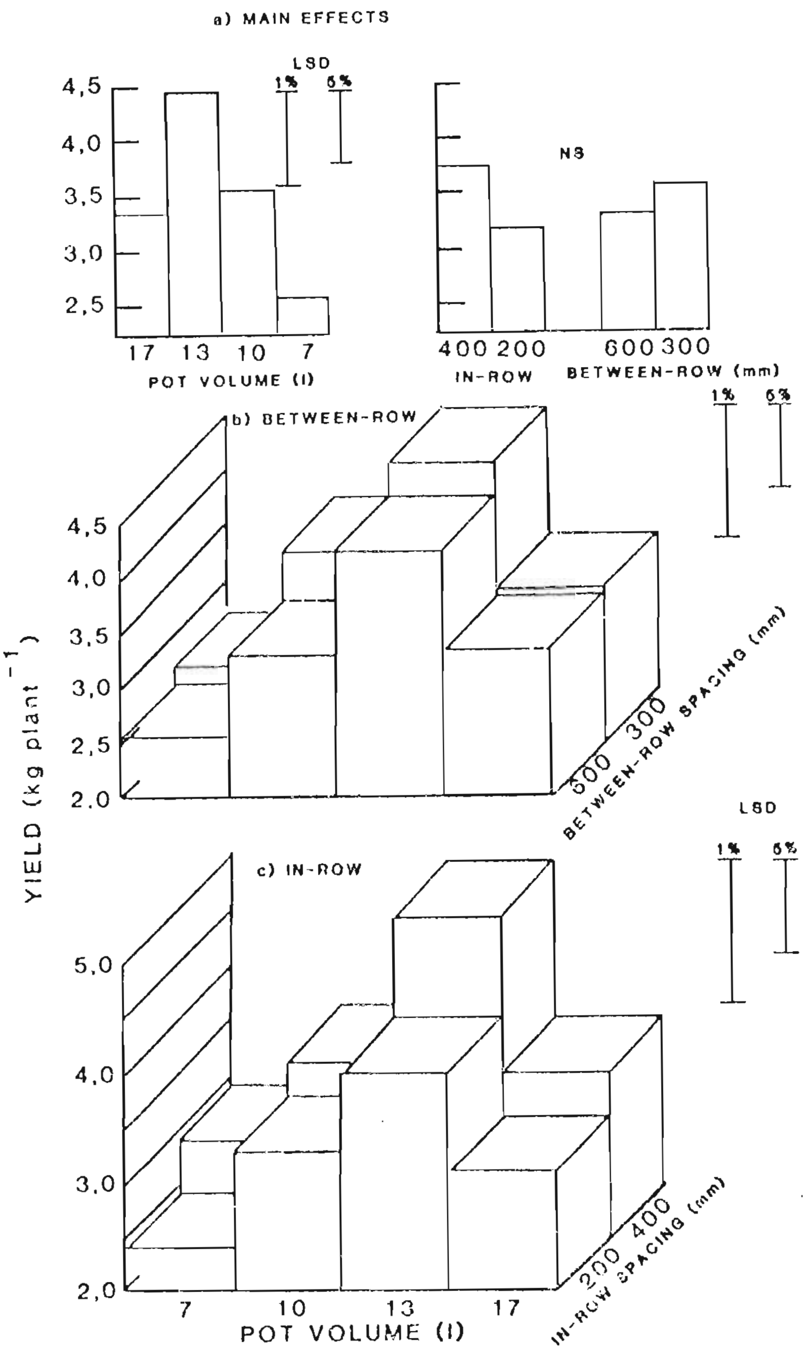


Fig. 2.20 Effect of volume of medium and between and in-row spacing on cucumber yield

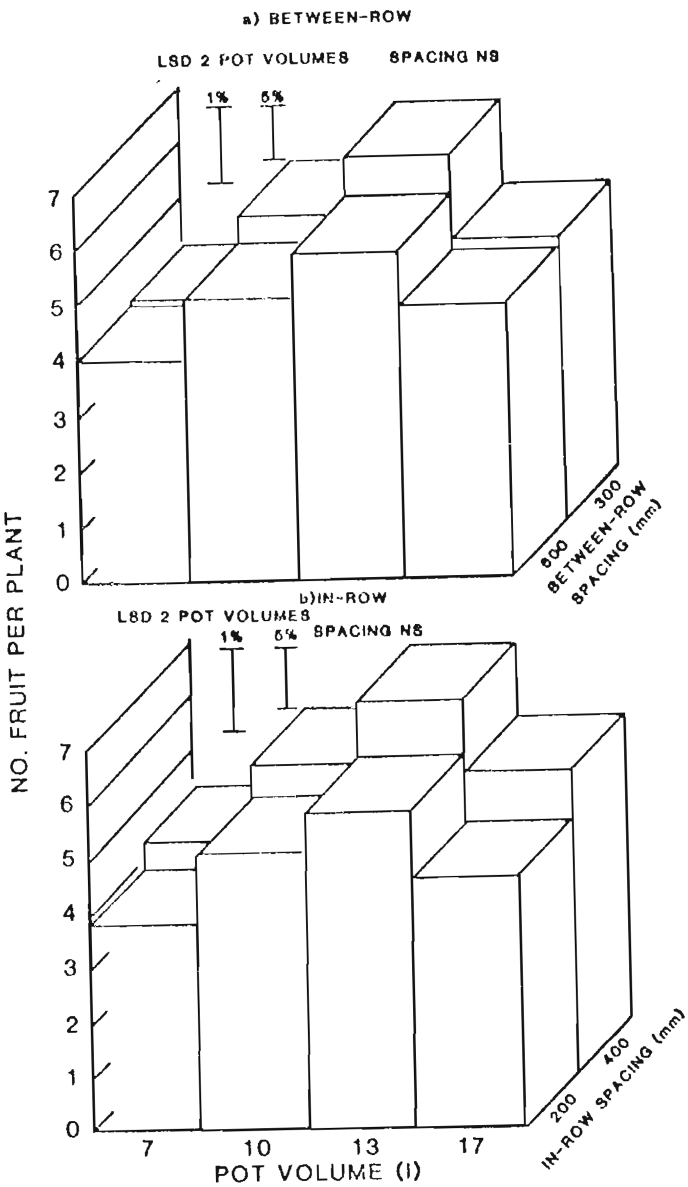


Fig. 2.21 Average number of fruit on cucumber plants grown in different volumes of medium and at different between and in-row spacings

in-row spacing, and the 17 ℓ pots with 400 mm in-row spacing, were not significantly different than the best treatment (13 ℓ and 400 mm in-row spacing).

The overall average fruit mass (Fig. 2.22) was also greatest on plants in the 13 ℓ pots and at the widest in-row spacing. This was significantly better than in the 7 ℓ and 10 ℓ volumes, but not the 17 ℓ volume. In each fruit size class (Fig. 2.22) there was a tendency (not significant) for fruit in the 13 ℓ pots to have the greatest mass.

2.6.4 Conclusions The experiment was limited by the size and type of the tunnel, so that a maximum of ± 10 fruit could be harvested from the best treatments. There were nevertheless definite treatment effects. The most significant effect was the greater yield in the 13 ℓ volume as compared with any other sizes tested. The cucumber plant's requirement for vigorous vegetative growth was obviously better suited to a larger volume pot. The slightly lower yield at the highest volume (17 ℓ) is hard to explain, especially since Maas & Adamson (1980) recommend 28 ℓ per plant, although this is for a much longer harvesting period. This experiment in effect, measured'early yield' due to the limited size of the tunnel used. It may, however, be due to the fact that only one microtube fed into each pot, and did not wet all the medium. Maas & Adamson (1980) and Maree (1981c) recommend that there should be two tubes per pot.

In Europe cucumbers are grown in peat bags containing 42 ℓ for 3 plants (i.e. 14 ℓ per plant). Allen (1980) believes that these modules are too small and that a minimum of 56 ℓ per module should be used. Recently Maree (1981c) has had good results with 20 ℓ $plant^{-1}$. The author has used similar volumes per plant in a trench system with good effect.

The 200 mm in-row spacing was too close from a management point of view. It also resulted in the lowest yields per plant. In such close spaced plants very little useful radiation reached the lower levels of the crop canopy, resulting in premature senescence of lower leaves. The wider in-row spacing produced the highest yields, confirming the recommendations of Maree (1979b) at Stellenbosch, and overseas recommendations (Table 2.2).

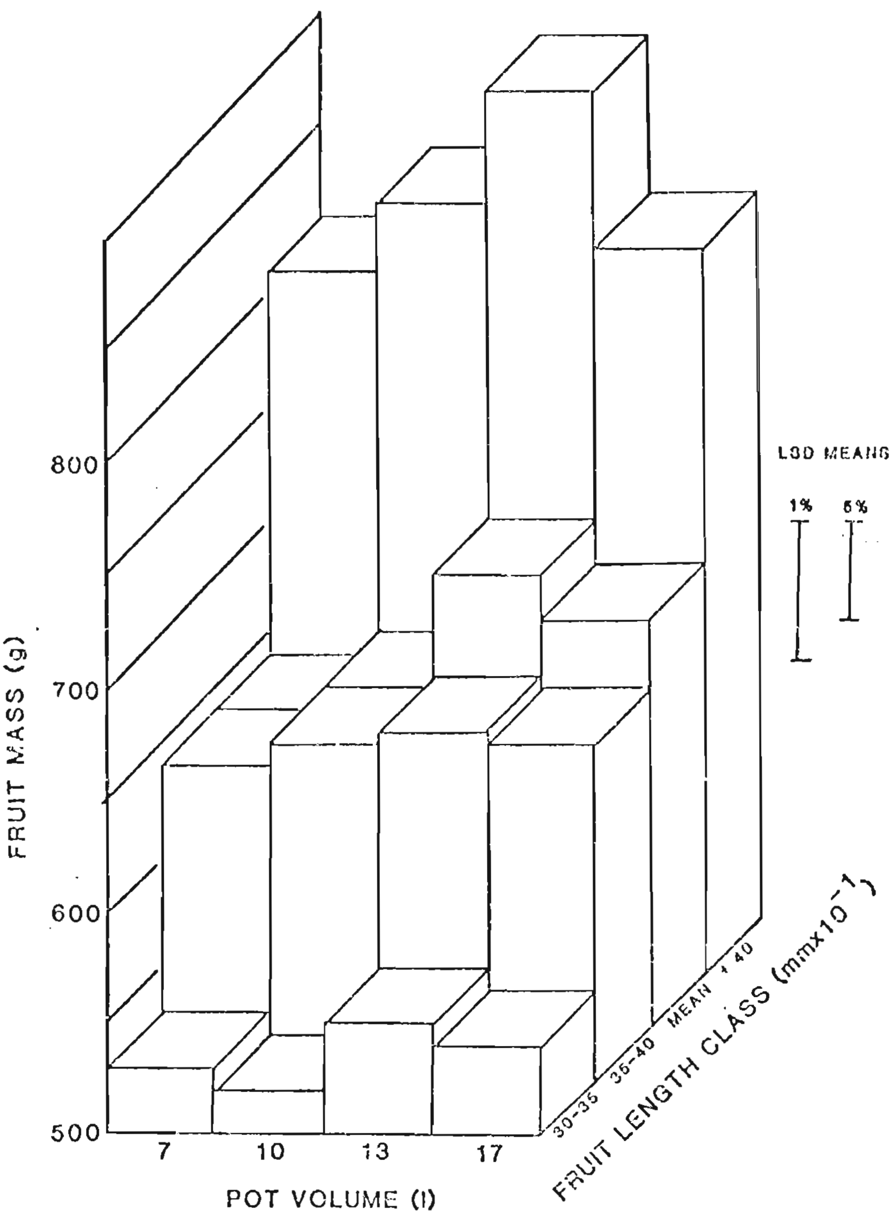


Fig. 2.22 Average mass of fruit in different size classes from cucumber plants grown in different volumes of medium

Between-row spacings in the double row system were not critical in terms of yield per plant with little difference between 600 and 300 mm. For general practical purposes a 500 mm spacing is recommended.

As in tomatoes the spacing chosen must balance the yield per hectare with quality, and the management of the crop. Training methods and pest and disease control are important in this case.

2.7 CUCUMBERS - EFFECT OF SHADE ON ENVIRONMENT, GROWTH AND YIELD IN AUTUMN (Experiment 11)

2.7.1 Aim To test whether shade cloth could effectively reduce temperatures inside a naturally ventilated tunnel and at the same time to measure the effect on the environment and plant growth.

2.7.2 Procedure ® Speedling grown cucumber (cv. Pepinex 69) seedlings, sown 1980:03:14, were transplanted into 13 ℓ pots containing a 1 sand:1 Irish peat moss medium in the ® Gundle 'roll-up sides' tunnel on 1980:03:28.

The pots were arranged in four double rows at a spacing of 500 x 500 mm in each double row so that half the plants were under, and surrounded by, a 30 per cent. ® Alnet shadecloth erected inside the central portion of the tunnel. The other half were not shaded. In addition, two fruiting regimes were imposed on the plants so that only one fruit was allowed to develop every 5th node, or every 10th node.

There were four replicates consisting of the four double rows of pots. Within each treatment in each replicate there were 11 plants, one of which was chosen at random at weekly intervals for growth analysis (2.2.4) starting two weeks after transplanting (1980:04:11).

The nutrient solution used contained ® Chemicult + $Ca(NO_3)_2$ + $MgSO_4$ as described in Table 1.3.

No treatment differences were found between the two pruning treatments, which will not be discussed further.

2.7.3 Results and Discussion

Environment

a) Relative humidity and air temperature Differences in air temperature between the shaded and unshaded treatments were small. On a typical cloudless day maximum and minimum air temperatures were 27,2 and 16,9 °C respectively, compared with 28,4 and 15,9 °C under plastic only. The small difference was because the shade cloth was inside the tunnel, and the two areas were adjacent with free air movement from the rolled up sides during the day.

This problem could be overcome by placing the shade cloth outside the tunnel, thus reducing the energy input into the system, and thereby reducing the temperature, as reported by Maree (1979b) and Hammes *et al.* (1980).

The atmospheric water vapour pressures were generally greater under shade, but the small differences could be attributed to the free flow of air through the neighbouring environments in the well ventilated 'roll-up sides' tunnel.

b) Radiation and PAR The radiant densities for both environments in relation to the height above ground are shown in Fig. 2.23 at two different growth stages. The shade treatment typically reduced the total radiant density by 1 to 2 MJ m^{-2} throughout the crop canopy. Maximum levels recorded were between 5 and 6 MJ m^{-2} under plastic, and 3 and 4 MJ m^{-2} under plastic and shade cloth, reducing to 2-3 and 1 MJ m^{-2} respectively at pot level.

The reduction in radiative load due to the plastic, and the plastic and shade cloth is shown in Fig. 2.24. At 11h00 the plastic reduced the irradiance from over 700 W m^{-2} to about 450 W m^{-2}, with the shade cloth causing a further reduction to 300 W m^{-2}. The typical M shaped profiles were also recorded in 2.3 (Savage & Smith, 1980).

Above crop level, the total daily photosynthetic photon density was 8,19 µmol m^{-2} and 11,7 µmol m^{-2} for the shaded and unshaded environments respectively during April/May.

These irradiance levels may have been low enough to adversely affect photosynthesis rates as Challa (1976) found that individual leaves of greenhouse cucumbers were unsaturated at 200 W m^{-2}. Sale (1977) recorded maximum net CO_2 uptake rates at about 600 to 800 W m^{-2} in field cucumbers.

c) Pot temperature For four cloudless days the 08h00 and 17h00 pot temperatures averaged 23 °C for the unshaded area and 21,8 °C for the shaded area, with pot temperatures in both environments typically fluctuating between a 13 °C minimum and a 30 °C maximum. As in tomatoes,

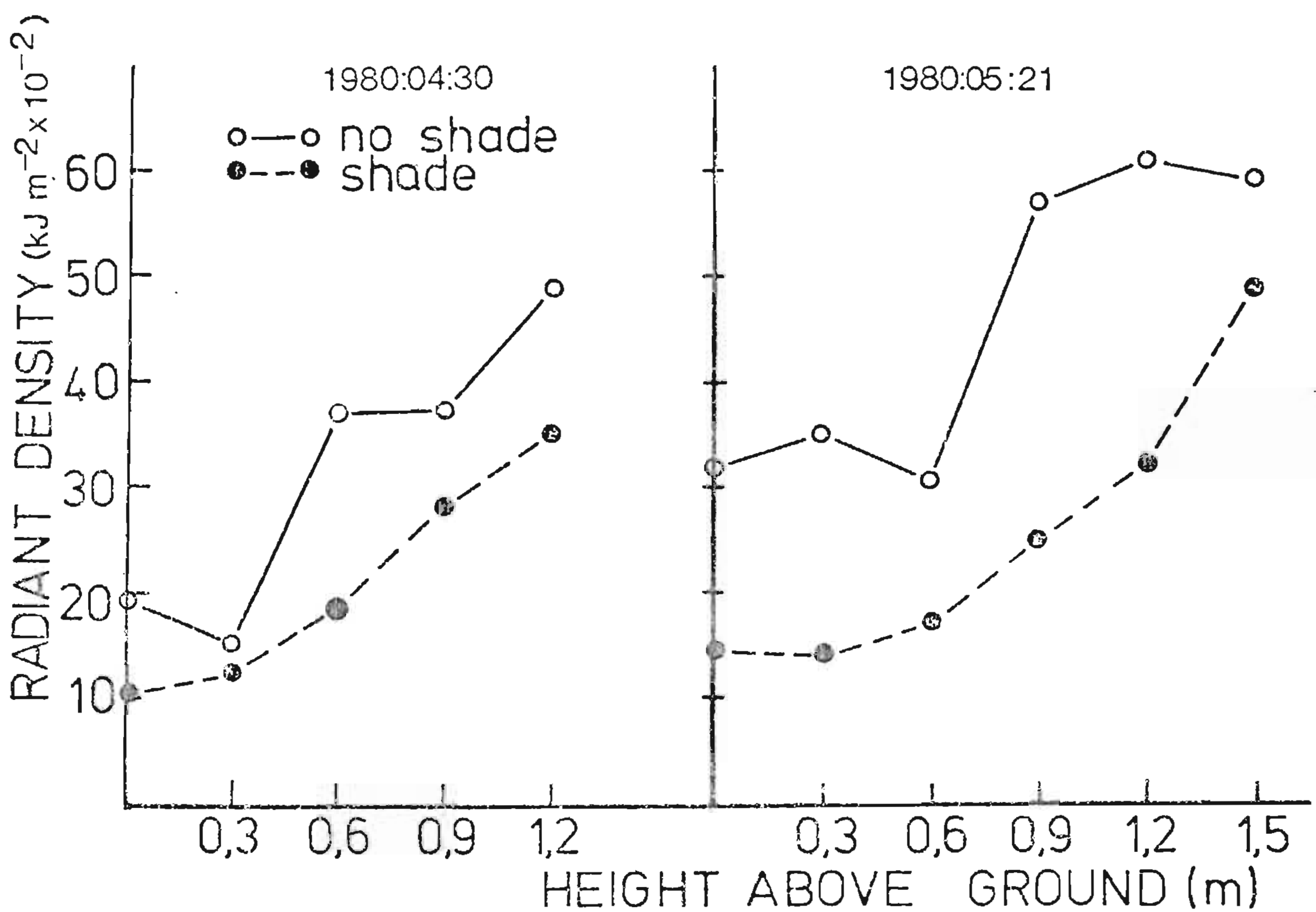


Fig. 2.23 Radiant density at different heights in the centre of a double row of greenhouse cucumbers grown in a plastic tunnel with or without shade, on two separate sunny days

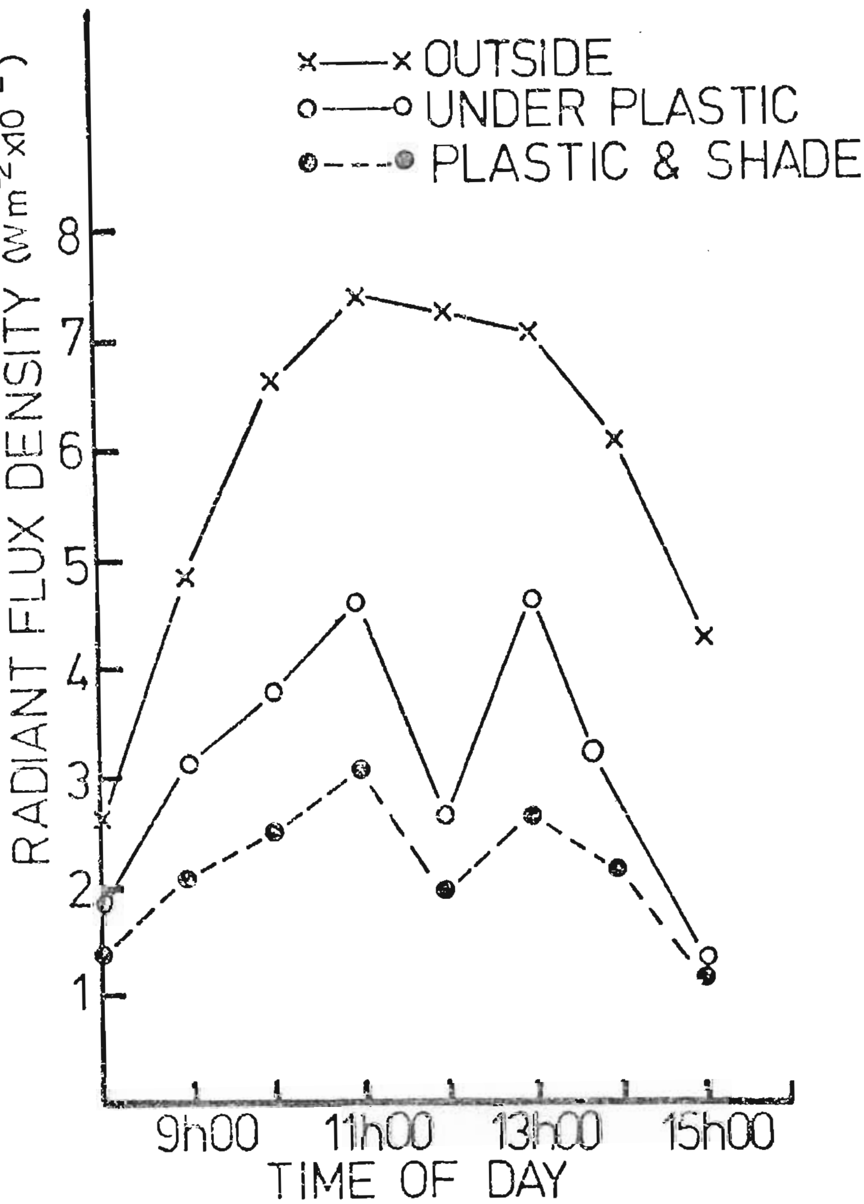


Fig. 2.24 Irradiance outside and inside a plastic tunnel with and without 30 % shadecloth on 1980:04:30, a sunny day

these figures are far more extreme than the minimum of 18 °C (Bauerle, 1975) and the maximum of 23 °C (Anon., 1981c) recommended in the literature.

d) Leaf temperature There were no noteworthy differences in average leaf temperatures with or without shade. The daily fluctuation in leaf temperature was greatest without shade, probably due to the shade cloth preventing some back radiation in the evening and at night. Allen (1980) reported a similar effect where a thermal screen was used.

Plant characteristics

a) Stomatal resistance (Fig. 2.25) In general, the stomatal resistance to water vapour movement was greater for the shaded than unshaded plants. This resulted from the reduced radiative load, as discussed by Slatyer (1967). Ludwig & Withers (1978) also reported that stomatal resistance was high at an irradiance of 50 W m^{-2}. In the present study, midday resistances averaged 9 s cm^{-1} and 5 s cm^{-1} for shaded and unshaded plants respectively (Fig. 2.25).

b) Height and number of leaves After transplanting the shaded plants grew more than the unshaded plants, and remained taller throughout the trial (Fig. 2.26). Shaded plants also had a greater number of leaves on any given date, and a greater internode length for the first six weeks (Fig. 2.26). Thus the shaded plants initially showed typical etiolation symptoms, although these were not striking.

c) Leaf area and specific leaf area (SLA) From week four shaded plants also had a larger total leaf area (Fig. 2.27), an apparent response to the lower radiation intensity under the shade cloth. SLA values (Fig. 2.27) were always higher in shaded plants indicating that there was a greater leaf area per unit mass of leaf. Chermnykh *et al.* (1975) noted that shaded plants had an increased total leaf area, and decreased leaf thickness, which would explain the higher SLA values. Further research on leaf morphology and physiology under shade is necessary to determine the effects on yield.

d) Dry matter Total dry matter accumulation and its components (roots, stems, leaves and fruit) are shown in Fig. 2.28. From early on (week 5) the total dry matter yield was greater in unshaded than in shaded plants, mainly due to a greater amount of dry matter formed in the roots and the fruit. From week 7 shaded plants had a greater

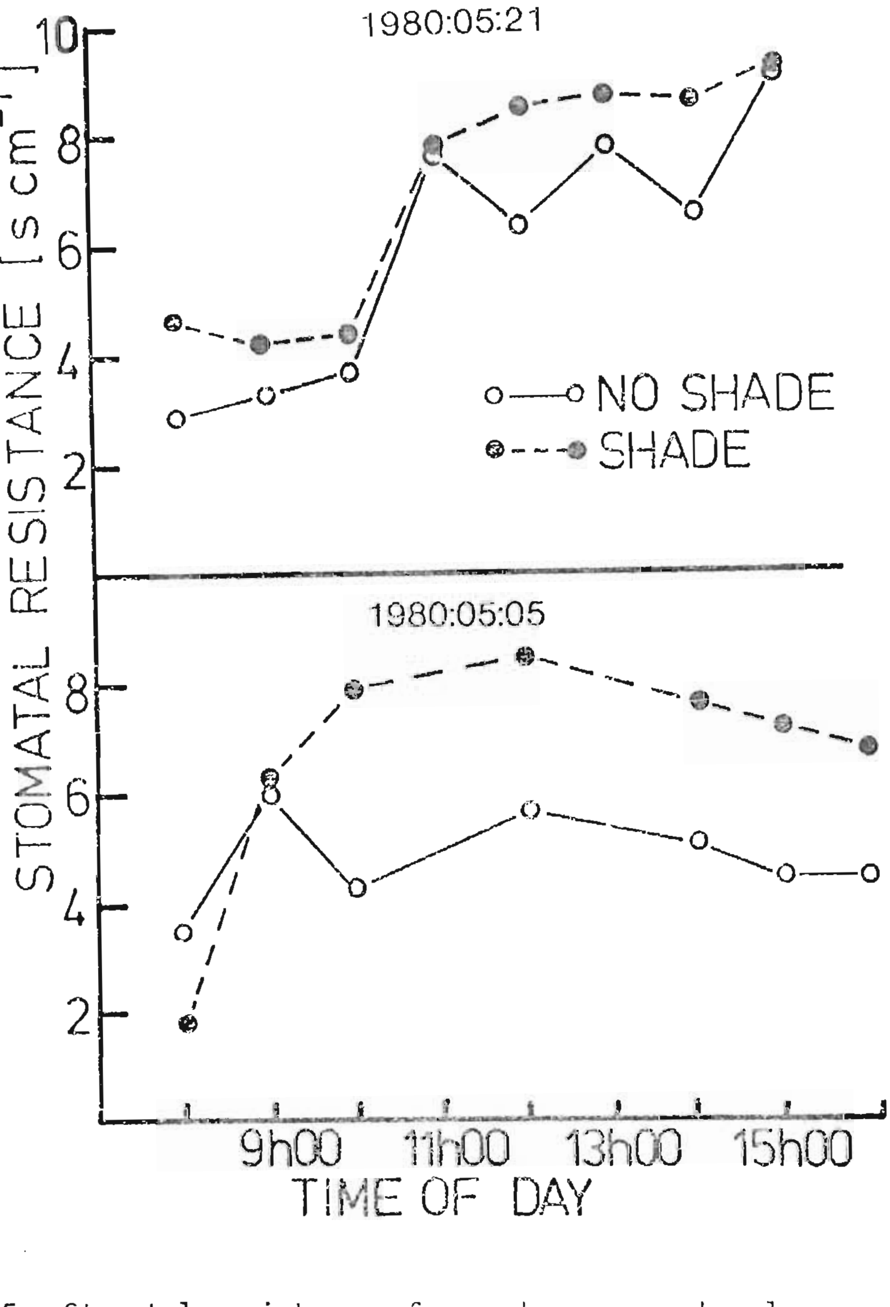


Fig. 2.25 Stomatal resistance of greenhouse cucumber leaves on plants grown in a plastic tunnel with or without 30 % shadecloth

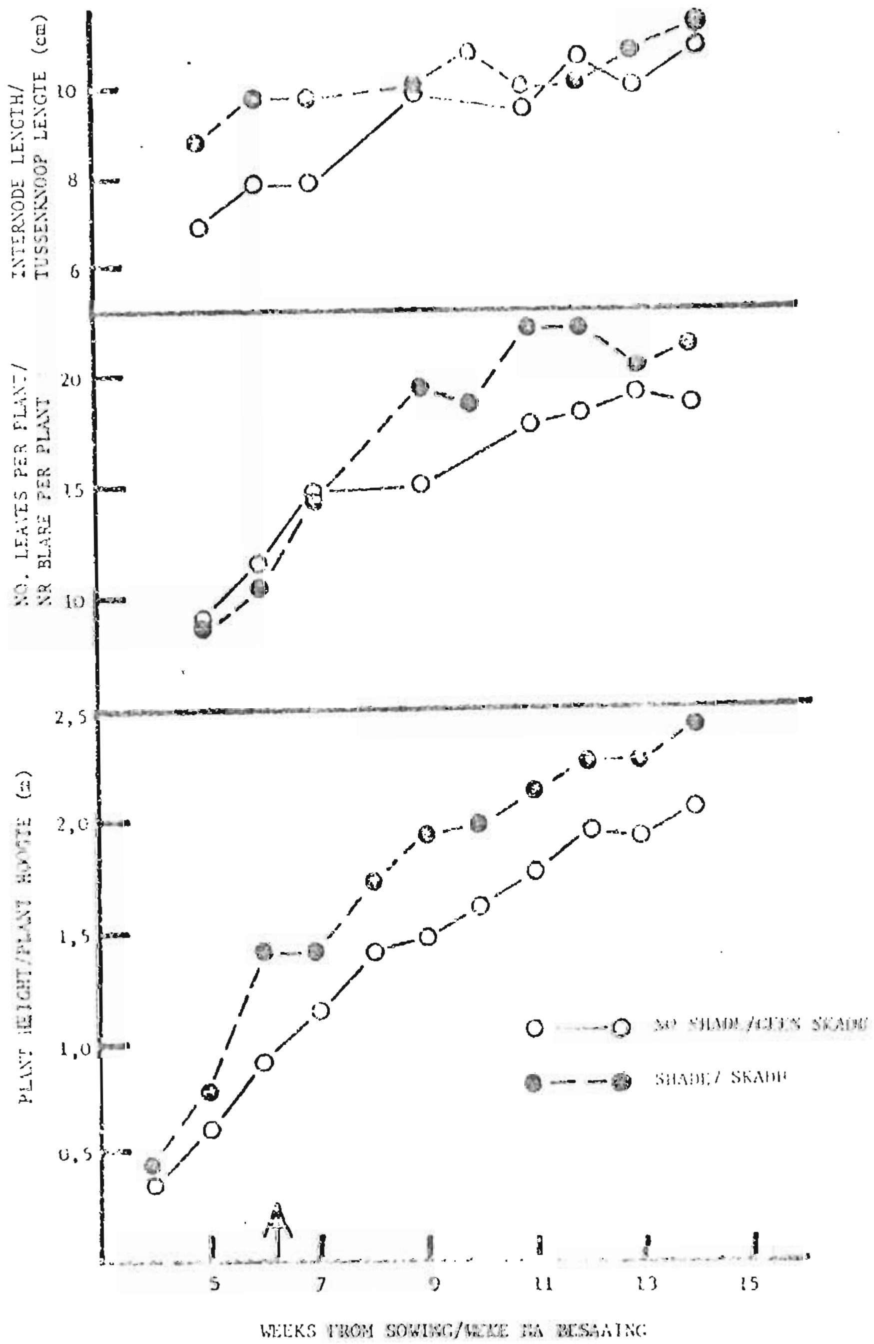


Fig. 2.26 Greenhouse cucumber plant growth in a plastic tunnel with and without 30 % shadecloth

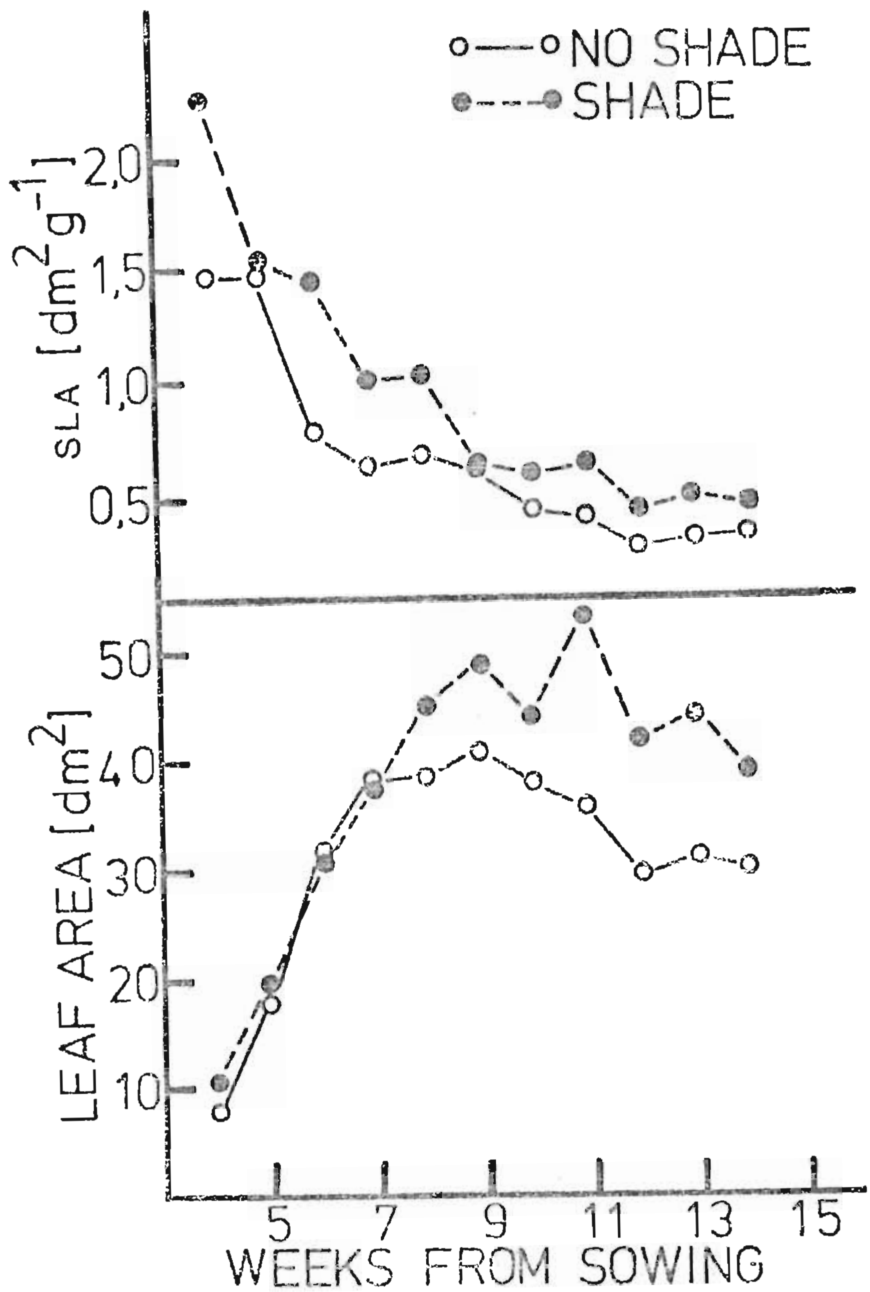


Fig. 2.27 Leaf area and specific leaf area (SLA) of greenhouse cucumber plants grown in a plastic tunnel with and without 30 % shadecloth

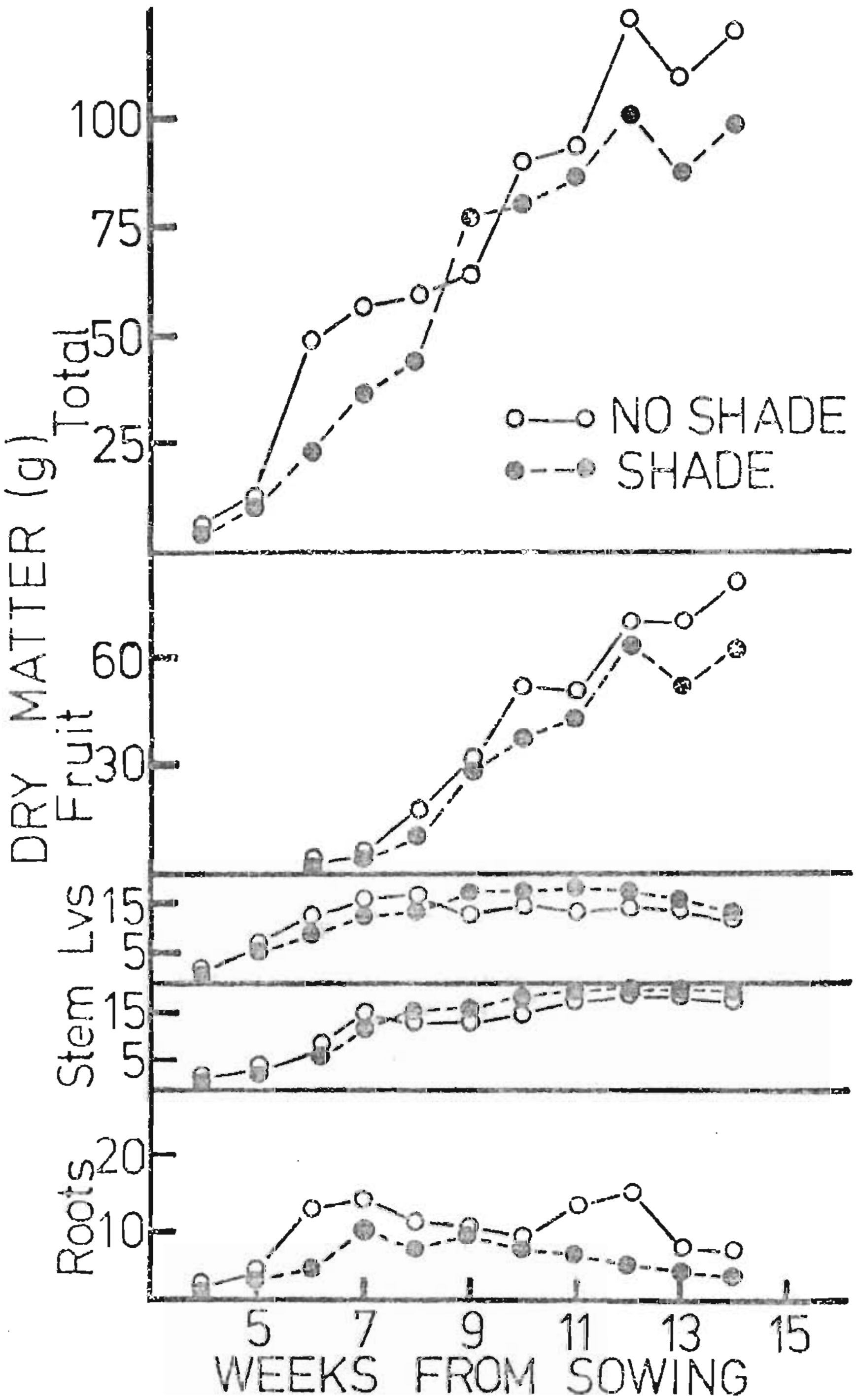


Fig. 2.28 Dry matter accumulation in different parts of greenhouse cucumbers grown in a plastic tunnel with and without 30 % shadecloth

mass of dry matter in their leaves and stems, but this did not compensate for the lower mass in the roots and fruits. The smaller root system on shaded plants was most noticeable.

These facts are further emphasized in Fig. 2.29. Shaded plants had a greater proportion of their dry matter distributed to the leaves, and this diminished as the fruit yield accumulated. The proportion of dry matter partitioned to stems remained relatively constant as the plant aged, but that to roots diminished.

Growth analysis

a) Crop growth rate (CGR) CGR values fluctuated widely from week to week, but were mostly in the range of 1 to 4 g plant^{-1} day^{-1}. On average, for the whole period of the trial the unshaded plants had a CGR of about 2 g day^{-1} compared with 1,5 g day^{-1} for the shaded plants.

b) Relative growth rate (RGR) RGR values were high in the first four weeks of growth before any fruit set took place (Fig. 2.30), but dropped to a uniformly low level once the first fruit were harvested (week 5) until the end of the trial. There were no important differences between shaded and unshaded plants, except for the early stages when unshaded plants had a slightly higher RGR.

c) Net assimilation rate (NAR) Fig. 2.30 shows that unshaded plants had a higher NAR on most sampling dates during the trial i.e. they produced more dry matter per unit of leaf area in a given time. As with RGR, the NAR values were greater in the initial period of the trial, until the first fruit were harvested. Thereafter, they fluctuated around 5 and 7,5 g m^{-2} day^{-1} for shaded and unshaded plants respectively.

2.7.4 Conclusions Plants experiencing differing radiation loads had definite characteristics. Shaded plants grew taller, had more leaves and a slightly greater internode length. They produced a greater leaf area, had a higher specific leaf area, and a smaller root system. Total dry matter yield was lower due to less dry matter in roots and fruit.

A higher leaf resistance to water vapour movement was measured in shaded leaves. It appears that this was in response to the larger transpiring surface produced with a smaller root system. The leaf stomatal distribution should be examined to further investigate this aspect.

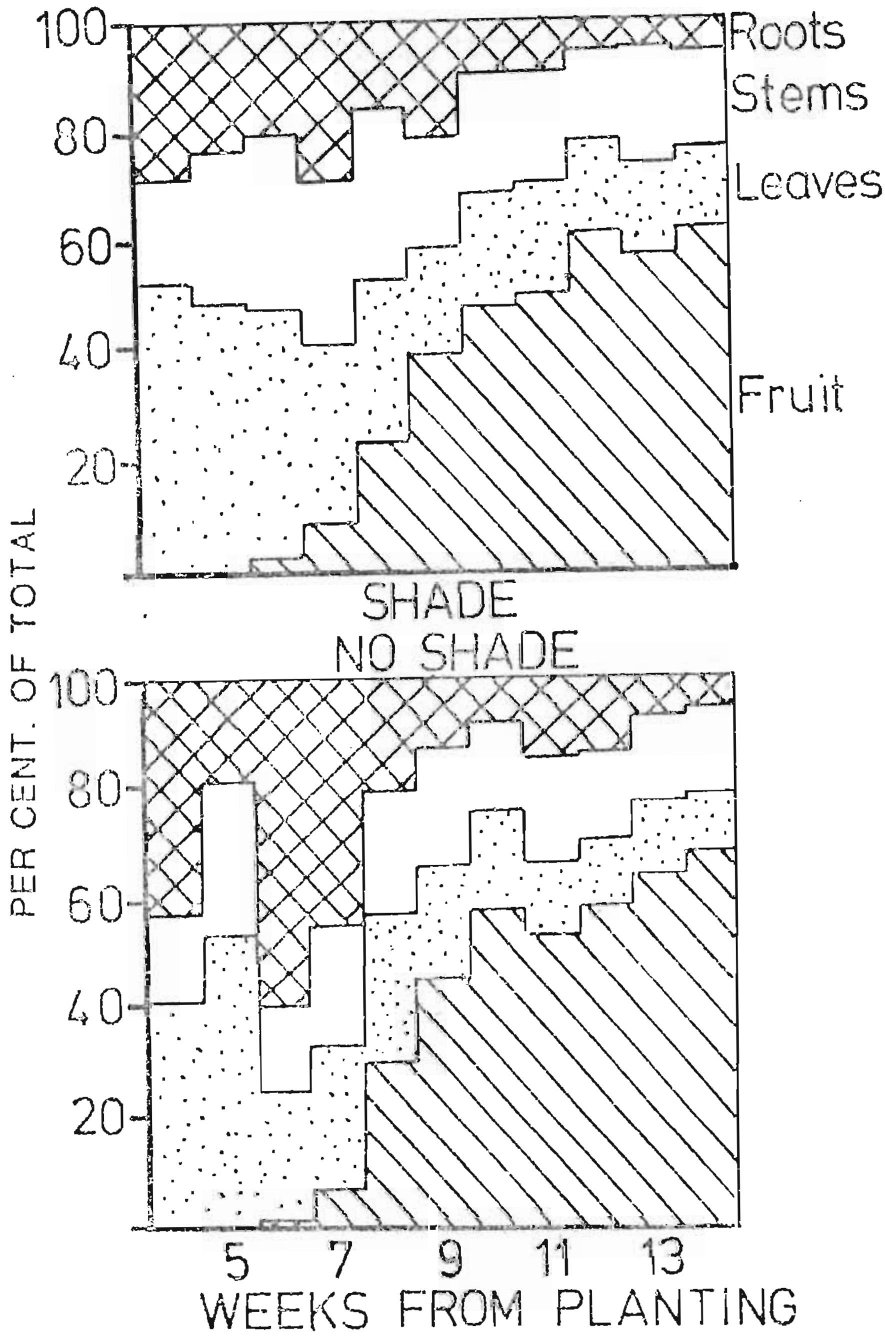


Fig. 2.29 Percentage distribution of total dry mass in greenhouse cucumber plants grown in a plastic tunnel with and without shade

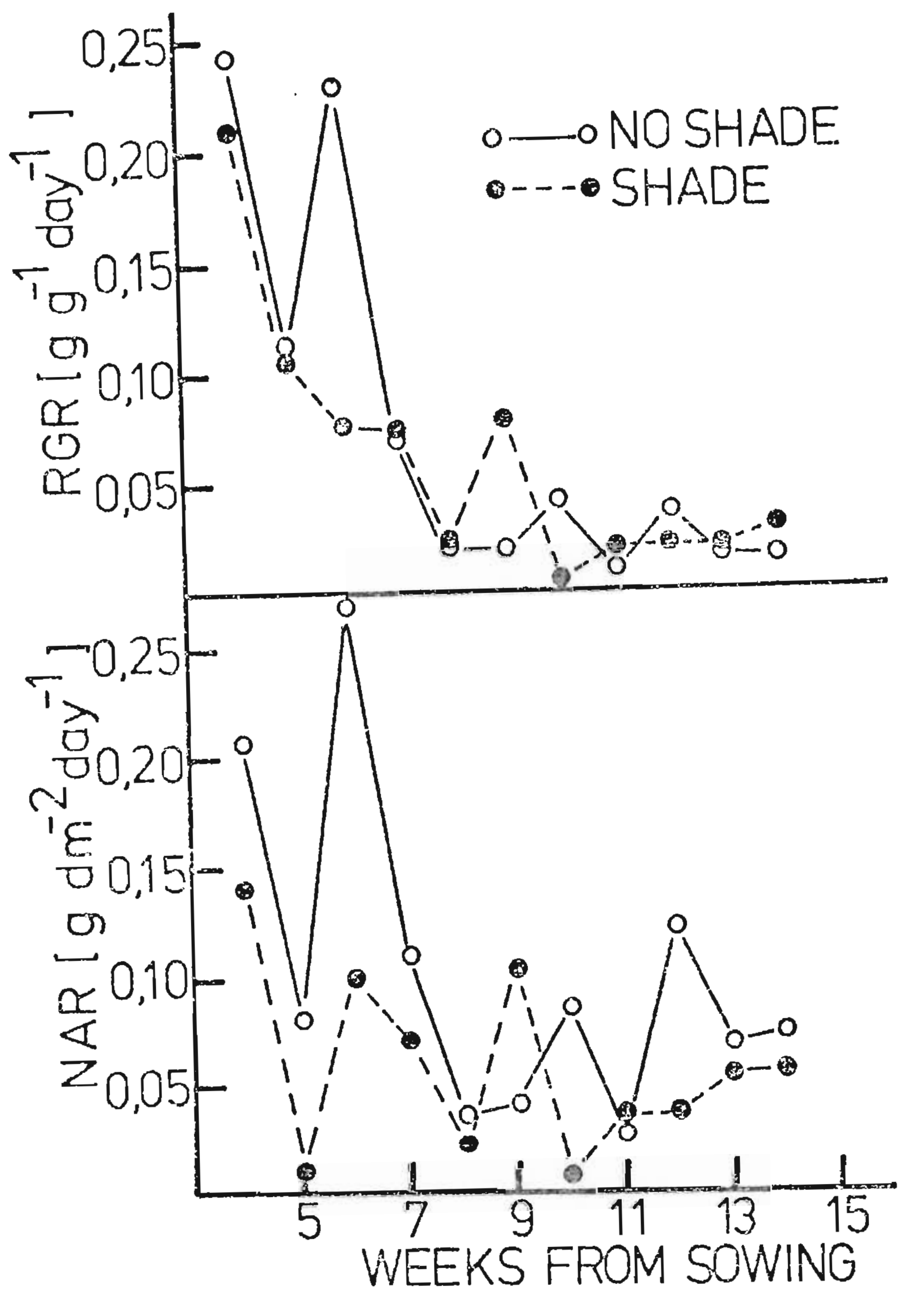


Fig. 2.30 Relative growth rates (RGR) and Net assimilation rates (NAR) of cucumber plants grown with or without shade in a plastic tunnel

In respect of photosynthetic efficiency RGR values were fairly similar, but NAR values were higher in unshaded plants. Thus the shaded plants were functioning less efficiently, presumably due to the lower radiation intensities, and these plants compensated by increasing their leaf area at the expense of root growth and of yield.

The decreasing trend in RGR and NAR with age has also been reported for other plants (Thorne, 1960), and the values recorded here are similar to those of Milthorpe (1959). A direct comparison with the work of Challa (1976) is difficult as his records were only up to the five leaf stage, and not for fruiting plants.

Large fluctuations in CGR, RGR and NAR made some of the data difficult to interpret, due mainly to sampling procedure, and the fact that fruit maturity differed between plants in successive samples. In future work it is suggested that the 'average' plant from three to four replicated plots should be sampled, rather than a random plant, using correlations between total dry mass and length, or number of nodes, as determined by Nelson (1981).

This experiment was conducted in autumn, at a time when shading, as shown by these results, may not be beneficial in the Natal midlands region. Further research is required in mid-summer when radiation intensities are higher.

Separate tunnels should be used with the shade cloth covering over the tunnel rather than inside. The objective should be to reduce both radiative load and tunnel temperature, on cloudless days without sacrificing yield potential during the prolonged periods of overcast summer weather typical of the region.

2.8 GENERAL DISCUSSION AND CONCLUSIONS (Chapter 2)

Climate measurement has shown that at no time of the year are the conditions inside a naturally ventilated tunnel in the Pietermaritzburg region of Natal optimum for tomato or cucumber plant growth and yield.

In comparison to overseas recommendations of 18-23/15-19 ^{o}C (day/night) temperatures for both tomatoes and cucumbers local tunnel temperatures fluctuate diurnally between 25 ^{o}C and 1 ^{o}C in winter and 40 ^{o}C and 15 ^{o}C in summer. Similarly the temperatures of the root systems fluctuate from 15-29 ^{o}C in summer and 5-15 ^{o}C in winter, as compared to the recommended 20 ^{0}C. Under such conditions plant growth is adversely affected in that in tomatoes poor pollination takes place in mid-summer, and in winter, resulting in small unmarketable fruit. In cucumbers plant growth almost ceases at below 10 ^{0}C resulting in poor yield and quality during the winter period.

Nevertheless relatively good yields can be obtained in tomatoes and cucumbers. Without heating, and with only natural ventilation methods available, few growers can produce year round, resulting in large fluctuations in the prices of these products. The slightly modified climate in the tunnel enables growers to take advantage of these prices going into autumn, and in spring.

Greater degrees of climatic control should be examined, keeping the overall cost structure in mind. Double layered tunnels, and thermal screens may be useful in this respect. In addition evaporative cooling in summer may be justified. Recent advances like selected wavelength shading with chemical solutions (von Bavel, Sadler & Damaguez, 1981) should also be tested where economical.

The simplest forms of climate modification like shade cloth or painting the plastic white (Maree, 1979c) can prevent excessive temperatures in mid summer, but use of these systems can reduce yields when used at the wrong time.

Radiation is sufficient for good growth at all times of the year, the maximum irradiance levels being $\pm$ 1 000 W m^{-2} in mid summer and $\pm$ 750 W m^{-2} in winter. The typical plastic sheeting used in South Africa has been shown to reduce this by $\pm$ 30 per cent. depending on the time of year and age of the plastic. With 30 per cent. shade cloth this was further reduced to $\pm$ 50 per cent. of outside irradiance, at which levels cucumber plants showed some etiolation symptoms and had a reduced NAR. European workers use lower levels than this in growth chamber experiments. Sale (1977), however, has shown that in field cucumbers in Australia CO_2 uptake was still increasing at 700 W m^{-2}.

It is apparent therefore that shade cloth should be used only where necessary. It does, however, serve a dual purpose in Natal, as a hail guard in summer.

Research into spacing practices has shown that similar plant populations to overseas are suitable locally, and that at $\pm$ 2,8 plants m^{-2} the interception of radiation was more even in all layers of the canopy, as found by Harper *et al.* (1979). In cucumbers closely spaced plants intercepted $\pm$ 90 per cent. of incoming radiation in the top 1 m of canopy. Plants produced better at wider in-row spacing. Overseas a double row system is most often used in cucumbers, but Maree (1981c) has recommended a single row system in South Africa. This depends on the trellising system and where layering is used a double row system works well (Moorat, 1981). Where an umbrella system is used (Jorgenson & Jonsson, 1978; Anon., 1981c) single rows may be more manageable. Further research on layout, spacing, pruning and training systems is required in South Africa with cucumbers for long season crops.

Volumes of organic based media, with some water holding capacity, have been shown to affect the yields of tomatoes and cucumbers grown as short term crops under local conditions. In tomatoes 10 ℓ pots were better than 7 ℓ and 13 ℓ, in comparison to the 14 ℓ used in Europe with peat and the 28 ℓ in Canada with sawdust. It was apparent that some restriction on root volume resulted in a better fruit:leaf ratio under high radiant density conditions. With a larger volume of medium tomato plants tended to become too vegetative at the nutrition level tested, with resultant lower yields.

In cucumbers,where the greatest amount of vegetative growth is desirable,it was found that larger volumes of medium were desirable (13 ℓ) as found by Maree (1981c) with sawdust, and suggested by Allen (1980). In Canada, Maas & Adamson (1980) have preferred 28 ℓ of sawdust for cucumbers. In a trench system with bark such large volumes have recently been used successfully by the author. Further research on this aspect is justified with the cost of the medium being balanced against yield to provide the most profitable combination.

Physiological research is required to determine photosynthesis rates in plants grown under different degrees of shading, and at different temperatures to explain certain responses. Research into pollination problems in cool and hot weather would also help to extend the production period. Fruit set hormones should also be evaluated in this respect.

CHAPTER 3

COMPARISON OF GROWING MEDIA AND NUTRITION PROGRAMMES FOR TRANSPLANTED CUCUMBERS AND TOMATOES

3.1 LITERATURE REVIEW

Although most tunnel growers in South Africa started growing in the soil, the majority have been forced to use soilless media because of diseases such as *Corynebacterium michiganense, Fusarium oxysporum f sp lycopersici, Pseudomonas solanacearum*, and nematodes. The most important factors controlling tunnel growers' yields in both cucumbers and tomatoes in Natal are media and nutritional programmes and their management.

3.1.1 Media Growing media are many and varied the world over. Their properties have been described and summarised by many authors, notably Baker (1957), Boodley & Sheldrake (1972), Hartmann & Kester (1975), Bunt (1976), Mastalerz (1977), Nelson (1978) and Poincelot (1980). A brief summary of the functions and properties of a desirable medium, according to these authors is appropriate here.

The medium must serve four basic functions: provide water, supply nutrients, permit gas exchange to and from the roots, and provide support for the plant. In modern greenhouse systems with cucumbers and tomatoes the nutrient supply function is not as critical as this is done via the nutrient solution, although it makes management easier. The support function is often not required also, as the plant can be artificially supported. Desirable properties of a medium include:

a) A stable organic matter content which will not diminish significantly in volume during the growth of a crop.

b) Organic matter with a reasonable carbon: nitrogen ratio, and rate of decomposition such that nitrogen depletion is not a problem.

c) A bulk density light enough to enhance handling and shipping but sufficiently heavy to prevent plant toppling (nursery).

d) A high moisture retention coupled with good aeration (35-40 per cent. water and 10-20 per cent. air by volume after watering).

e) A high cation exchange capacity (CEC) for nutrient reserve (10-30 me/100 g of dry medium).

f) A $pH_{(H_2O)}$ level between 6,2 and 6,8 for crops in general.

g) Freedom from weed seeds, nematodes, and toxic chemicals.

h) A low salinity level.

i) Capability of being sterilised.

Most of these points apply to cucumbers and tomatoes. Management may become more difficult and exacting where a medium does not meet certain of these criteria.

Any individual components selected by a grower for a mixed medium should meet the four functional requirements, must be readily and easily available, and economical.

A minimum number of components should be used in formulating a mix (Nelson, 1978) .

Materials are mainly inorganic or organic. The inorganic materials are usually added to mixtures to improve aeration and drainage, whereas the organic materials are utilised to increase water retention and cation exchange capacity (Mastalerz, 1977).

Inorganic types include perlite, pumice, sand, styrofoam, vermiculite, rockwool, leca clays (Bunt, 1976). Costs for perlite, vermiculite and leca clays have escalated recently because of the energy cost required for heating to prepare a suitable product for horticultural use (Bunt, 1976). Of the inorganic media vermiculite, perlite, sand and recently rockwool have all been used for cucumbers and tomato culture.

Vermiculite, although having a high CEC and K and Mg content (Table 3.1) has a tendency for the lattices to collapse with use resulting in reduced aeration and drainage (Bunt, 1976). For this reason it is often mixed with perlite or peat, as in the Cornell 'Peatlite' mixes (Boodley & Sheldrake, 1972). In South Africa, the local product also has a high pH ($\pm$ 8-9), and is expensive, but has been used successfully (Nelson, 1969; Smith *et al.*, 1979; Maree, 1981d).

Perlite has a low water holding capacity, but works well in a capillary watering system (Bunt, 1976). Mixes with perlite are well drained and well aerated. It has virtually no CEC and runs out of added nutrients quickly (Wilson, 1981). It is thus more suited to total liquid feeding systems (Morgan, 1972; Wilson, 1980a). Perlite is being recommended by Lee Valley Experiment Station, U.K. (Allen, 1980) for growing tomato seedlings for NFT, as less collar burn due to salt build up at the surface takes place. Morgan (1972) and Wilson (1980a) have given recommendations for growing tomatoes and cucumbers in perlite. A simple, inexpensive perlite culture system has also recently been described for studying the nutrition of greenhouse crops (Paterson & Hall, 1981).

Rockwool (mineral wool) has also received publicity recently (Jorgensen & Jonsson, 1978; Jorgensen & Ottosson, 1978; Sonneveld, 1980; Maree, 1981a). It has virtually no CEC and little water holding capacity, but has a pore volume of 97 per cent. (Bunt, 1976), and is most suited to a total liquid feeding system. It may also be suitable for raising seedlings for NFT (Allen, 1980).

Jensen (1975) tested 10 different media, all mixtures with sand, and including vermiculite, rice hulls, redwood bark, pine bark, perlite and peat moss. His results indicated that sand alone was as good as sand amended with other substrates. As a result sand was chosen by the Environmental Research Laboratory, Tucson, Arizona, for growing greenhouse vegetables.

Organic materials include composts, peat, wood by-products (bark and sawdust), and sugar cane by-products (milo, bagasse). Chemical analyses of these materials are shown in Table 3.1.

An estimated 70 per cent. of tomatoes in Europe are grown in peat modules (Winsor, 1980). Sphagnum peat moss is the most popular form of organic matter for preparing substrates for container grown crops (Mastalerz, 1977). Its properties have been reviewed in detail by Bunt (1976). It satisfies more of the criteria for a growing medium than any other available form of organic matter (Mastalerz, 1977). The good quality imported peats in South Africa are, however, too expensive to use for container growing of vegetables under protection.

Cropping in peat differs from that in soil in a number of ways (Adams, Davies & Winsor, 1978a). Nitrogen may be immobilised, and root growth may be restricted by the volume of substrate available. Further, a higher proportion of potassium is soluble in water (Adams, Graves & Winsor, 1978b), and appreciable losses may occur through leaching. As a consequence both the available and reserve nutrient contents of a peat substrate will

TABLE 3.1 Chemical analyses of some organic and inorganic materials used in potting media

Material	Author	% of dry mass (x 10 000 = ppm) N	P	K	Ca	Mg
BARK						
Douglas Fir	Bollen (1969)	0,04	0,006	0,09	0,12	0,01
Hardwood mix	Cappaert, Verdonck & De Boodt (1974)	0,60	0,025	0,22	0,41	0,05
Ireland	Barragray & Morgan (1978)		0,002	0,035	0,195	0,017
Sitka spruce	Wilson (1981)	0,0004	0,0017	0,017	0,023	0,008
Hardwood mix	Anon. (1974)	0,03	0,009	0,018		0,024
Softwood (South Africa)	Nixon (1981)		0,002	0,002	0,128	0,044
SAWDUST						
Douglas Fir	Bollen (1969)	0,04	0,006	0,09	0,12	0,01
Softwood (South Africa)	Nixon (1981)		0,03	0,17	0,54	0,079
PEAT						
Sphagnum (UK)	Bunt (1976)	2,50	2,50	0,04	0,20	0,15
Local (SA)	Nixon (1981)	3,44	0,014	0,084	0,54	0,085
VERMICULITE						
U.S.A.	Roode (1981)			0,038	0,539	0,134
South Africa	Roode (1981)			0,019	0,022	0,416
MILO	Wood (1981)	1,52	0,93	0,29	2,23	0,47
MUSHROOM COMPOST						
South Africa	Nixon (1981)		0,12	0,265	0,705	0,088
PERLITE	Anon. (undated c)			4,07		

fluctuate more widely, and the interpretation of substrate analysis is more difficult. Foliar analysis provides a more reliable indication of the nutrient status of such crops than does analysis of the medium (Adams *et al.,* 1978b).

In Scotland, Wilson (1981) has recently done much research on growing tomatoes and cucumbers in pine bark. Hard wood and pine bark has also been widely publicised as a general growing medium in America at the University of Illinois (Gartner, Hughes & Klett, 1972; Gartner *et al.,* 1973; Gartner & Williams, 1978), and at the University of Georgia (Pokorny, 1973; Brown & Pokorny, 1975; 1977; Airhart, Natarella & Pokorny, 1978a; Airhart *et al.,* 1978b).

Recommendations are that both barks should be milled through a 12,8 mm screen (Gartner & Williams, 1978; Wilson, 1981) so that the mix contains 20-40 per cent. of the particles < 0,8 mm, and 10-20 per cent. of the particles > 6,4 mm in size. Optimum particle size distributions suggested by different authors are shown in Table 3.2.

TABLE 3.2 Suggested optimum particle size distribution for hardwood bark according to different authors after milling through 12,7 mm screen

Size (mm)	Percentage		
	Gartner & Williams (1978)	Pokorny (1975)	Wilson (1981)
>6,4	0,7		)
3,2-6,4	12,9	26	) 15
1,6-3,2	17,6	37	22
0,8-1,6	17,6	26	17
0,5-0,8	9,7	5	)
<0,5	26,5	4	) 46

Media containing coarse bark have a significantly higher CEC than those containing fine bark (Brown & Pokorny, 1975). The CEC is also greatly reduced as sand is added to the medium. Percolation rates are higher for larger bark particles, and also for bark alone, in comparison to bark/sand mixtures. Airhart *et al.* (1978a) reported that media containing pine bark required less frequent irrigation when compared to plants grown in peat moss. Brown & Pokorny (1977) and Airhart *et al.* (1978a) have shown that capillary pores exist within the internal structure of the bark itself. The internal water and nutrients are not easily removed by irrigation water passing through the medium, this giving rise to a high CEC.

For overcoming nitrogen depletion problems Gartner *et al.* (1972) found that ammonium nitrate was consistently the best nitrogen source. When ammonium nitrate was used the pH remained fairly stable, while a straight ammonium source led to a lowered pH, and a straight nitrate source to an increased pH.

As the Ca content of hardwood bark may be high (Table 3.1), Gartner & Williams (1978)found that addition of Ca and Mg reduced growth of nursery plants, and thus did not recommend addition of these two elements to hardwood bark media.

Some inhibition of growth due to toxic substances has been recorded in fresh hardwood bark (Worrall, 1978; Gartner & Williams,1978; Wilson, 1981). This is overcome by composting, the minimum period recommended being 30 days (Gartner & Williams,1978), 60 days (Wilson, 1981) or six months (Pokorny, 1973). The degree of inhibition varies from species to species, and from season to season, with the greatest inhibition to growth occurring with bark harvested in winter, and the least with that in the summer months (Gartner & Williams,1978).

Composting also helps overcome the negative nitrogen period. Gartner & Williams recommend that the following amounts of fertilisers should be added to each m^3 of milled hardwood bark: 2,7 kg ammonium nitrate, 2,3 kg superphosphate, 0,45 kg sulphur and 0,45 kg iron sulphate. In comparison Maleike, Sample, Zaeske & Coorts (1975) applied the following per m^3 : 5,39 kg ammonium nitrate, 2,96 kg superphosphate, 0,60 kg sulphur, 0,60 kg iron sulphate and 0,30 kg potassium nitrate. Gartner & Williams have summarised the advantages (A) and precautions (B) in using hardwood bark as follows:

A1. Bark is economical and readily available (not all areas).

2. Excellent water holding capacity.

3. It provides a well-drained and well-aerated medium which is difficult to overwater.

4. The plants are able to obtain water readily, and the mix does not dry out rapidly.

5. Bark contains Ca and Mg, and all the minor elements necessary for growth.

6. It is light in mass and easy to handle.

7. It reduces nematode populations.

B1. Lime should not be added as bark contains 0,2-0,4 per cent. Ca by dry mass. However for tomatoes and cucumbers lime addition has been recommended (Wilson, 1981).

2. Nitrogen must be added - ammonium nitrate is best, at a rate of 4 kg m^{-3}.

3. A thorough mix is important.

4. It must be composted for $\pm$ 60 days before use, and be kept moist during this period.

Recent research by Gartner (1981) has pinpointed the following differences between hardwood and pine bark:-

1. It was essential to compost hardwood bark, but pine bark had the same amount of nitrogen available whether composted or not.

2. Pine bark dried out more rapidly and required at least a third more watering.

3. It was essential to add lime to pine bark, but when hardwood bark had lime added the pH increased above the optimum level. With hardwood bark it was essential to add sulphur (1 kg m^{-3}) to maintain the proper pH.

4. Hardwood bark helped inhibit root rots. These existed when pine bark was used.

5. Pine bark did not break down as readily as hardwood bark, so it was essential to add trace elements to pine. These elements were naturally available in hardwood bark during the composting.

Adamson & Maas (1971; 1976), Cotter (1974), Adamson (1977), Worrall (1978), Maas & Adamson (1980) and Marcc (1981c) have perfected the use of sawdust. In comparison to bark, sawdust generally requires more N in the composting period (Bunt, 1976). Both bark and sawdust are relatively resistant to decomposition compared with straw, as they contain larger amounts of lignocelluloses. Adamson & Maas state that sawdust is inexpensive, clean, light in mass and easily handled, but like bark it requires more initial care to ensure moisture availability for young plants, and to bring it to field capacity. They prefer it to sand, due to its lighter mass. Jensen (1975) points out that sand is more permanent and does not have to be replaced every few years.

Straw bales have also been successfully used in parts of the world (Anon., undated b; Wilson, 1978), and in South Africa (Maree, 1979a). The main problems are weeds which germinate from seeds in the straw, and the higher N requirement. During the initial composting process energy is released as heat which can be beneficial during winter.

Other organic media which have been used successfully include milo (a sugar cane waste product), spent mushroom compost, sunflower husks oil cake and rice husks.

3.1.2 Nutrition Hydroponics was earlier defined as 'the science of growing plants in a medium, other than soil, using mixtures of the essential plant elements dissolved in water' (Harris, 1970; Sholto-Douglas, 1975). All systems deal with the placement of nutrients in intimate contact with the plant's roots. Ellis *et al.* (1974) have used the term nutriculture to describe such systems.

The term aggregate culture was used where some form of solid medium was used in the nutriculture system (Ellis *et al.*, 1974; Cooper, 1979). In such systems the nutrient solution may be recirculated (Harris, 1970; Ellis *et al.*, 1974; Adamson, 1977; Cooper, 1979), or drained to waste in an open system.

In the latter, open system, a complete, balanced, nutrient solution may be used at every watering (Jensen, 1975; 1980; Adamson, 1977; Maas & Adamson, 1981). Alternatively, base fertilisation (Bunt, 1976) or pre-enrichment (Anon., undated a) of the medium before planting may be used followed by watering with a N:P:K solution only.

The basic nutrient requirements of plants were established over a century ago. Knop's solution of 1865 is quite similar to the widely used recommendation of Hoagland & Arnon (1938) and Arnon & Hoagland (1940). The tables of nutrient formulations in Hewitt's book on water culture methods (1966) demonstrate the range of combinations and concentrations of salts acceptable to plants. This has been shown more systematically by Steiner (1966; 1981), and explains why it has been possible to maintain nutrient solutions in NFT on the basis of overall conductivity, although this leads to some imbalance from the original concentrations with time (Hurd, 1978). Hewitt (1966) made the statement that, 'almost as many different nutrient solutions have been devised as there have been experiments'. Although many formulae for nutrient solutions have been published, they have much in common (Ellis *et al.*, 1974). The greatest difference between formulae lies in the ratio of nitrogen to potassium. Theoretically each plant type in each part of the world will have its own nutritional requirements. In practice there is much tolerance (Harris, 1970; Ellis, *et al.*, 1974), especially with tomatoes.

Examples of complete nutrient solutions recommended worldwide for tomatoes and cucumbers are shown in Table 3.3. For tomatoes the general recommendation is 150 ppm N, 60 ppm P and 300 ppm K. Notably, however, Jensen (1975) uses a lower K level. Cucumbers generally require more N and Ca and less K (see later). This is reflected in the recommendations of Ellis *et al.* (1974), Jensen (1975) and Sonneveld (1980)(Table 3.3).

Examples of recommendations for the pre-enrichment of different media by various authors are shown in Table 3.4. The amount of pre-plant fertiliser addition depends on the inherent content of the medium (Table 3.2), and its availability. Note also that different fertilisers have different elemental compositions depending on the country of origin. The percentage composition of fertilisers used in compiling Tables 3.3, 3.4 and 3.5 is shown in Table 3.9.

Table 3.4 shows that pre-enrichment recommendations differ markedly. Usually this can be explained by the type of medium. Sawdust, and bark (to a lesser extent) which are subject to continuous microbial decomposition require more N. This is reflected in the high N status of the Scottish bark recommendation (Wilson, 1981). Wilson has also found that iron deficiency commonly occurs in bark media, and thus adds extra iron to the medium.

The Guernsey, Scottish and U.K. peat recommendations (Anon., undated e; Wall, 1973; Moorat, 1981) have a high K status and total salt content in the medium. This holds back tomato plant growth and induces early flowering, when radiation levels are too low for good growth.

TABLE 3.3 Recommended concentrations of elements (ppm) in nutrient solutions according to different authors

Crop & System / Author	Harris (1970)			TOMATOES - OPEN SYSTEMS: Ellis *et al.* (1974) Jensen (1975)	TOMATOES - OPEN SYSTEMS: Sonneveld (1980)	TOMATOES - OPEN SYSTEMS: Wilson (1980a)	TOMATOES - OPEN SYSTEMS: Maas & Adamson (1980)	TOMATOES - NFT: Cooper (1979)	TOMATOES - NFT: Winsor *et al.* (1979)			CUCUMBERS - OPEN SYSTEMS: Ellis *et al.* (1974) Jensen (1975)	CUCUMBERS - OPEN SYSTEMS: Sonneveld (1980)	CUCUMBERS - OPEN SYSTEMS: Anon. (1981c)
Medium	General			Sand	Rockwool	Perlite	Sawdust					Sand	Rockwool	Sawdust
Element	Min.	Opt.	Max.						Min.	Opt.	Max.			
N	90	140	200	144	154	180	168	200	50	175	300	260	168	185
P	30	60	90	62	47	40	55	60	20	50	200	62	47	36
K	200	300	400	154	293	375	403	300	50	400	600	154	234	210
Ca	120	150	240	165	130	143	163	170	125	225	400	330	140	210
Mg	40	50	60	50	24	25	50	50	25	50	150	50	18	25
Fe	2,0	4,0	5,0	2,5	0,56	10	1,2	12	1,5	3	6	2,5	0,56	1,0
Mn	0,1	0,5	1,0	0,62	0,55	2	1,07	2	0,3	1	5	0,62	0,55	0,3
B	0,1	0,5	1,0	0,44	0,22	0,3	0,46	0,3	0,1	0,2	2	0,44	0,22	0,7
Cu	0,01	0,05	0,1	0,05	0,03	0,1	0,034	0,1	0,01	0,1	1	0,05	0,03	0,03
Zn	0,02	0,1	0,2	0,03	0,26	0,1	0,11	0,1	0,05	0,1	5	0,03	0,26	0,1
Mo	0,01	0,02	0,1	0,09	0,05	0,02	0,023	0,2	0,01	0,05	0,1	0,09	0,05	0,05

TABLE 3.4 Pre-enrichment recommendations for growing tomatoes in different media according to various authors. Percentage elemental composition of each fertiliser is shown in App. Table 2

Author Medium	Barragray & Morgan (1978) Bark	Wilson (1981) Bark	Maas & Adamson (1980) Sawdust	Anon. (undated e) Peat (Scotland)	Moorat (1981) Peat	Wall (1973) Peat	White & Brundell (1978) Peat	Anon. (1980a) Peat: Vermiculite
FERTILISER			($kg\ m^{-3}$)					
K_2SO_4	0,42				0,44	0,425		0,60
KNO_3		0,54		1,2	0,88	0,850		
NH_4NO_3		1,174						
Superphosphate	0,67	1,313	2,4	1,2	1,75	1,786	4,0	1,2
Urea formaldehyde	0,72				0,44	0,425		
Calcitic limestone	5,5	5,0		4,5				5,9
Dolomitic limestone		5,0	4,0	5,0	5,35	5,44	10,0	
Keiserite	1,13							
Gypsum								0,5
$MgSO_4$							0,44	0,3
FRIT 253A		0,5		0,5	0,44	0,44	0,5	0,11
$FeSO_4$		0,2						0,04
$Ca(NO_3)_2$							0,47	
ELEMENT		AMOUNT OF EACH ELEMENT SUPPLIED ($g\ m^{-3}$ of MEDIUM)						
N		484		162	273	273	56	122
P	148	148	456	135	198	198	452	240
K	260	200		703	515	515		390
Ca	2200	2200	720	2200	1570	1570	1879	2236
Mg	181	615	492	615	658	658	1242	29
S		143		318	763	263	57	129
Fe		76	liquid drench (Fe, B, Mn, Cu, Zn, Mo)	60	53	53	76	8
B		6		10	9	9	6	2
Mn		15		25	22	22	15	5
Cu		6		10	9	9	6	2
Zn		0,39		0,7	0,5	0,5	0,39	0,15
Mo		12		20	18	18	12	4

The Canadian mixture for peat/vermiculite (Anon., 1980b) has a high Ca and low Mg level because their vermiculite is naturally high in Mg (Table 3.1), but low in Ca. South African vermiculite has three times the amount of Mg, but is lower in Ca (Table 3.1).

Generally, Wilson (1981) has recommended that a medium for tomatoes should contain 2 200 g Ca and 600 g Mg m^{-3} medium. Barragray & Morgan (1978) suggest that the desired level of nutrient in a bark medium before planting should be 2 000 g Ca, 150 g P, 350 g K and 600 g Mg m^{-3}. Moorat (1981) recommends that the final chemical analysis of a pre-enriched sphagnum peat should be: $pH_{(H_2O)}$ 5,5-6,5, N 50-70 ppm,P 40-50 ppm, K 280-300 ppm, Ca 150-250 ppm, Mg 50-60 ppm.

Typical daily liquid feeding nutrient solutions in a pre-enrichment system are shown in Table 3.5. In these systems the nutrient solution only contains N, P and K, or in some cases N and K only, which simplifies matters considerably from a management point of view. This is only possible because the other nutrients are in the medium, and the trace elements are in a safe and slow release form (Bunt, 1976).

TABLE 3.5 Subsequent daily liquid feeding of pre-enriched media for tomatoes according to the different authors in Table 3.4

Medium	Author	Element concentration (ppm)		
		N	P	K
Bark	Wilson (1981)	296	50	120
Sawdust	Maas & Adamson (1980)	168	-	253
Peat	Bunt (1976)	200	30	350
Peat	Moorat (1981)	169	27	284
Peat	Wall (1973)	170	-	279
Peat	White & Brundell (1978)	200	-	300

Much has been published on the nutritional requirements of tomatoes, but notably little on cucumbers. On tomatoes, reviews have been published by Cooper in 1956 and 1979. Winsor & Long (1963) and Davies & Winsor (1967) have shown the importance of N, P, K, Mg and liming on fruit composition. Wilson & McGregor (1976) have shown how compost nutrient balance affects yield and fruit quality, especially the levels of lime, and the balance of Ca and Mg. Blotchy ripening was more prevalent in composts containing a high level of lime, and when limestones of high Ca to Mg balance were used, in conjunction with liquid feeds containing a N:K ratio of 1:2. A high incidence of blossom end rot was found at low lime levels, and with limestones containing a low Ca:Mg balance, in conjunction with a liquid feed of a low N:K ratio (1:1).

Most European workers recommend a N:K ratio of 1:2 for tomatoes (Winsor, Davies & Long, 1967; Winsor & Long, 1968; Wilson, 1980b), as does Harris (1970) in South Africa. Although Adams *et al.* (1978b) showed that relatively modest levels of N and K sufficed for maximum yields of tomatoes grown in peat, other results, Adams *et al.* (1978a), stressed that higher levels of these elements, and particularly K were necessary both for even ripening, and good flavour and keeping quality. Jensen (1975), however, concluded that 156 ppm K gave equally good yields as the more recommended level of 300 ppm.

Jensen also tested levels of N between 29 and 260 ppm and found 144 ppm to be optimum for tomato production. Plants receiving less than the optimum amounts produced less marketable fruit, and less foliage. This increased the amount of sunburn. Tomato crops fed excess amounts of nitrogen did not yield higher but had less marketable fruit due to increased incidence of misshapen and fasciated fruit. Winsor & Long (1968), Maher (1972), Wilson & McGregor (1976) and Adams *et al.* (1978a;b) reached the same conclusion. Slightly higher levels may be needed for bark and sawdust (Maas & Adamson, 1980).

Although less information is available for cucumbers, research has shown that the N:K ratio should be closer to 1 (Attenburrow, 1978) with the K level kept at 250 ppm. Allen (1980) recommends that the K level should be 30 per cent. lower for cucumbers in NFT as compared to tomatoes, and that cucumbers should be grown at a lower conductivity (200-250 mS m^{-1} for cucumbers compared to 250-300 mS m^{-1} for tomatoes). Anon. (1980d) recommend 175 ppm and 282 ppm K. Ellis *et al.* (1974) and Jensen (1980) kept the N:K ratio at 1,7:1 from first harvest.

In NFT, Winsor & Massey (1978) and Massey & Winsor (1980) have shown that the uptake of nutrients by plants growing in a flowing nutrient solution is such an efficient process that surprisingly low concentrations of some elements suffice for growth. Growth reduction and leaf necrosis has been recorded at high P levels, presumably due to the addition of phosphoric acid which is widely used to control pH in NFT (Cooper, 1979; Winsor *et al.*, 1979). Phosphorus concentrations of 200 ppm are apparently not uncommon in commercial installations, and it has been suggested that these are associated with root death. Massey & Winsor (1980), however, found that 10 ppm P was slightly better (although not significantly so) than 5, 50 and 200 ppm. The main adverse effect of high P levels was precipitation of calcium phosphate. Although 5-10 ppm was sufficient for normal yields they recommended that higher concentrations (20-40 mg P ℓ^{-1}) would ensure some reserve of phosphate in the system.

3.2 GENERAL PROCEDURES

3.2.1 Structures The same structures were used as described in 2.2. All trials, except for the tomato trial described in 3.3.1, were carried out in the ® Gundle 'roll-up sides' tunnel.

3.2.2 Growing methods As in 2.2. In most trials the plants were topped at the overhead wire, and the experiment terminated once all the fruit had been harvested to that level. The plants were therefore cropped for a relatively limited period of time, the trials being terminated once it was evident that treatment differences had resulted.

3.2.3 Nutrient solutions In open nutriculture systems nutrient solutions were made up from straight chemicals based, with modifications, on the recommendations of Ellis *et al.* (1974), Jensen (1975; 1980), and Fontes (1980).

Table 3.6 shows Jensen's (1980) recommendations for tomatoes and cucumbers. As some of the chemicals were not available some modifications were made, based on the work of Fontes (1980). The final composition of the solution used for cucumbers is shown in Table 3.7.

Any further reference in this chapter to Jensen's solution will refer specifically to a solution made up as in Table 3.7. Modifications to this solution will be mentioned where appropriate. Where Jensen's solutions were used the concentrated stock solutions (usually 200 x required concentration - columns 2 and 3 in Table 3.7) were kept in

TABLE 3.6 Nutrient solutions recommended for tomato and cucumber production (1 000 ℓ)(after Jensen, 1980)

Fertilizer compounds	Nutrient solutions							
	Tomato				Cucumber			
	A		B		C		D	
	Seedlings to first fruit set		Fruit set to termination of crop		Seedlings to first fruit set		Fruit set to termination or crop	
	ppm	g/ 1 000 ℓ	ppm	g/ 1 000 ℓ	ppm	g/ 1 000 ℓ	ppm	g/ 1 000 ℓ
Magnesium sulfate ($MgSO_4.7H_2O$)	Mg 50	500	Mg 50	500			Mg 50	500
Monopotassium phosphate (KH_2PO_4)	K 77 P 62	270	K 77 P 62	270	Same		K 77 P 62	270
Potassium nitrate (KNO_3)	K 77 N 29	200	K 77 N 28	200	as		K 77 N 28	200
Calcium nitrate [$Ca(NO_3)_2$]	N 85 Ca 122	500	N 116 Ca 165	680	solution		N 232 Ca 330	1357
Chelated iron (Fe 330)	Fe 2,5	25	Fe 2,5	25	B		Fe 2,5	25
Micronutrients[1]	--	150 ml	--	150 ml			--	150 ml

Micronutrient preparation for nutrient solutions A, B, C and D

Salt	Element supplied	ppm of element	Grams of each micronutrient in the packet[1]
Boric acid (H_3BO_3)	B	0,44	7,50
Manganous chloride ($MnCl_2.4H_2O$)	Mn	0,62	6,75
Cupric Chloride ($CuCl_2.2H_2O$)	Cu	0,05	0,37
Molybdenum trioxide (MoO_3)	Mo	0,03	0,15
Zinc sulphate ($ZnSO_4.7H_2O$)	Zn	0,09	1,18

[1]Use one packet (15,95 g) micronutrients plus water to make 450 ml micronutrient stock solution (heat to dissolve). Use 150 ml of micronutrient stock solution for each 1 000 ℓ of nutrient solution.

TABLE 3.7 Amount of chemical required to make up 20 ℓ stock solutions, the amount of stock added to 1 000 ℓ water to make the final solution, and the final concentration of the nutrient mixture delivered to plants, modified from Jensen's (1980) recommendations for cucumbers

Chemical	g 20 ℓ^{-1} stock	g ℓ^{-1} in stock	litres stock added to 1 000 ℓ water	Conc. of final solution (g 1 000 ℓ^{-1}	ppm
KNO_3	1682,6	84,1	5,0	420,7	K 156
					N 56
$Ca(NO_3)_2$	3800	190,0	9,0	1710	Ca 289
					N 203
H_3PO_4	commercial product		0,270	64	P 64
$MgSO_4$	2008,8	100,4	5,0	502,3	Mg 49
					S 64
$FeCl_3 7H_2O$	470,0	23,5	0,50	11,8	Fe 2,5
TRACE ELEMENTS STOCK Amount added to 20 ℓ water					
$MnSO_4$	147,5	7,38	0,15	1,110	Mn 0,28
H_3BO_4	215,0	10,75		1,613	B 0,29
$ZnSO_4$	45,5	2,28		0,342	Zn 0,08
$CuSO_4$	23,8	1,19		0,179	Cu 0,05
$(NH_4)_6Mo_7O_4$	6,2	0,31		0,045	Mo 0,03

NB. Each chemical in the upper section was kept in a separate container as the stock solution. The trace element stock contained all the trace elements together in one solution, 0,15 ℓ of which was added to 1 000 ℓ.

20 ℓ plastic containers. The required amounts being added to a tank filled with water to give the final solution.

Nutrient solutions were also prepared by adding given amounts of commercial hydroponic mixtures to the recommended volume of water in the asbestos tank. Table 3.8 shows the element concentration in a solution containing different amounts of ® Chemicult.

TABLE 3.8 Amount of nutrient in a solution containing different amounts of ® Chemicult per litre of water (Percentage composition shown in App. Table 1)

Element	ppm in a solution containing			
	1 g ℓ^{-1}	1,15 g ℓ^{-1}	2 g ℓ^{-1}	3 g ℓ^{-1}
N	65	75	130	195
P	27	31	54	81
K	130	150	260	390
Ca	75	86	150	225
Mg	25	29	50	75
S	70	81	140	210
Fe	1,5	1,73	3,0	4,5
Mn	0,24	0,28	0,48	0,72
B	0,24	0,28	0,48	0,72
Cu	0,02	0,03	0,04	0,06
Zn	0,05	0,06	0,10	0,15
Mo	0,01	0,01	0,02	0,03

In some of the experiments (as stated in procedures) the solid fertiliser was added to an in-line diluter, through which some of the water flow was directed. The main water flow was from a municipal mains source, with a $pH_{(H_2O)}$ of 7-8 (Fig. 3.5).

The time of watering, and the amount of water applied on each occasion was controlled by a time clock via a solenoid valve. ® National time clocks with a minimum 15 minutes 'on time' interval were used, in conjunction with ® Electromatic timers. These allowed an 'on time' of from 10 s to 10 min. according to setting, within the 15 min. interval on the time clock. Usually three applications of nutrient solution were applied per day, the total volume varying with the crop, plant size and time of year.

Other nutrient solutions were made up according to recommendations from Guernsey (Anon., 1979; Moorat, 1981) and Scotland (Anon., undated d; Wilson, 1981). These are described where relevant.

TABLE 3.9 Fertilisers used in different nutrient solutions and in pre-enriching media, their percentage make up, and cost, as at December, 1981

Cost Cents kg^{-1} or Cents ℓ^{-1}	Fertiliser (source)	Approximate % content of nutrient element(s)											
		N	P	K	Ca	Mg	S	Fe	Mn	B	Cu	Zn	Mo
2,86	Calcitic lime												
	(Umzimkulu)				32,4	2,2							
	(Roedtan)				28,0	0,3							
2,86	Dolomitic lime												
	(Umzimkulu)				26,0	7,1							
	(Roedtan)				18,0	12,0							
11,3	Single Supers		11,3		19,7		10,9						
84,2	Phosphoric acid		23,8										
10,4	Calmafos		9,5		21	9		7					
	Gypsum				22		17,7						
21,4	LAN	28			13,3								
	(Limestone ammonia nitrate)												
27,3	UREA	46											
35	KNO_3	13,5		36,9									
24,6	K_2SO_4			40,0			16,4						
46	$Ca(NO_3)_2$	11,9			16,9								
110	MAP	11,0	21,0										
27	$MgSO_4.7H_2O$					9,5	12,9						
28	$FeSO_4.7H_2O$							20					
192	FRIT 504							14,3	7,0	3,8	7,0	7,0	0,05
	Urea formaldehyde	38											
62	$FeCl_3.6H_2O$							21,2					
59	$MnSO_4.4H_2O$								25				
75	H_3BO_4									18			
100	$ZnSO_4$											22,5	
71	$CuSO_4$										25,5		
2000	$(NH_4)_6MO_7O_4$												65

3.2.4 Pre-enrichment The required amounts of solid fertiliser were added to the medium and thoroughly mixed in an electrically operated concrete mixer. The different fertilisers used, their percentage make up, and cost at time of writing, are shown in Table 3.9.

3.2.5 Media A wide range of organic and inorganic media were tested. Most of the organic, and some of the inorganic media, contained nutrients, some of which would have been available for growth. The approximate nutrient contents of untreated media are shown in Table 3.1.

In addition the media had very different physical characteristics, both in respect of bulk density, air porosity and water holding capacity. These properties have been listed for ease of comparison in Table 3.10 from information in the texts of Bunt (1976), Mastalerz (1977), Nelson (1978), Beardsell, Nichols & Jones (1979) and Poincelot (1980).

TABLE 3.10 Physical properties of organic and inorganic media used in the different trials (After Bunt, 1976; Mastalerz, 1977; Nelson, 1978; Beardsell *et al.* (1979); Poincelot, 1980)

	Bulk density ($kg\ m^{-3}$)		Water retention	Air capacity	Total
	(dry)	(wet)	(% of volume)	(% of volume)	porosity
Pine bark (0-5 mm)	228	608	38	32	69
Pine bark (5-20 mm)	184	333	15	54	69
Peat moss (sphagnum)	104	693	59	25	85
Perlite	100	100	19	55	75
Sand	1600	1840	35	3	40
Sawdust	192	640	45	30	78
Vermiculite	100	640	53	28	80
Peat moss + perlite (1:1)	110	600	51	23	75
Peat moss + sand (1:1)	739	1419	47	10	65
Peat moss + sand (1:2)	1000	1600	47	8	48
Sawdust + sand	920	1299	41	12	52
Peat + polystyrene (1:1)	63		50	33	68
Manure	344	1008	67	8	74
= milo = Mushroom compost = Bagasse					

3.2.6 Statistical analysis See 1.2

3.3 TOMATOES - COMPARISON OF EIGHT GROWING MEDIA (Experiment 12)

3.3.1 Aim Good quality imported peats are too expensive to use for container growing of vegetables under protection in South Africa. A research programme was started in 1979 to test cheaper, easy to use, locally available media for their suitability in growing tomatoes.

3.3.2 Procedure Tomato seedlings (cv. Hotset) were grown in ® Speedling trays and transplanted into 10 ℓ pots containing eight different media in the small plastic tunnel. The eight media were:-

1. Vermiculite (South African)
2. Perlite
3. Umgeni river sand (a coarse grit)
4. Local peat : vermiculite 1:1 (volume basis)
5. Local peat : sand 1:2 (" ")
6. Local peat : sand 1:3 (" ")
7. Local peat : perlite 1:1 (" ")
8. Local peat : polystyrene 1:1 (" ")

There were two sowing dates, viz. 1978:02:16 and 1978:03:09, chosen so that harvesting would take place during the highest price period on local markets. The trial was a randomised split plots design, with the sowing date as the whole plot factor. There were three replications, each replication consisting of one double row of plants in the tunnel, and five plants per subplot.

Management was according to normal procedures using 1,5 g ℓ^{-1} ® Chemicult (Table 3.8) as the nutrient solution.

The number of marketable fruit (> 60 g) and fruit mass were recorded for each truss.

For one month during mid-winter the temperatures of the different media in pots in the centre row of the tunnel were recorded. These were discussed in 2.3.2 (Experiment 8).

Salinity levels were monitored at regular intervals, using a saturation extract, and were expressed as total salt content (Ca + Mg + Na). $pH_{(KCl)}$ was also monitored regularly.

3.3.3 Results and Discussion

Plant growth At the first time of planting the fastest growth occurred in the peat:vermiculite treatment (Fig. 3.1). All other treatments had the same growth rate as the vermiculite treatment shown. At the second time of planting there was no difference between treatments, but Fig. 3.1 shows that the growth was slower than in the first planting, as these plants experienced cold winter temperatures earlier in their development.

Total yield There were no significant differences between the average yield (mean of two planting dates) in the different media. However yields tended to be lowest for vermiculite, and highest for peat:vermiculite and peat:sand (1:3) (Fig. 3.2). All mixtures with peat tended to result in higher yields than any single medium (NS).

In all cases, except vermiculite, the first planting yielded higher than the second planting, and in peat:perlite this was significant. This trend was the result of smaller fruit in the second planting (Fig. 3.4) due to poorer pollination caused by cooler temperatures.

There was no significant difference between media at the second time of planting, although vermiculite, peat:vermiculite and peat:sand (1:3) gave the higher yields (Fig. 3.2).

The better yields in vermiculite and peat:vermiculite appear to be related to the warmer pot temperatures in these media as discussed in 2.4.3.

Non significance in this trial was due to the high CV (19,4 %) which resulted from the northern double row of plants growing and yielding better than the southern double row due to the orientation of the tunnel (see 2.4.3 for pot temperatures in this trial).

It must be noted that only five trusses were included in the yield figures due to the size of the tunnel. The highest yield of ± 3,5 kg plant^{-1} (= 9,5 kg m^{-2}) over a 12 week harvest period compares with 9,6 kg plant^{-1} for 23 weeks or 4,2 kg plant^{-1} over 9 weeks at Stellenbosch during a more favourable period with the cultivar Angela (Maree, 1981a), and ± 12 kg m^{-2} over 12 weeks in the U.K. (Allen, 1980).

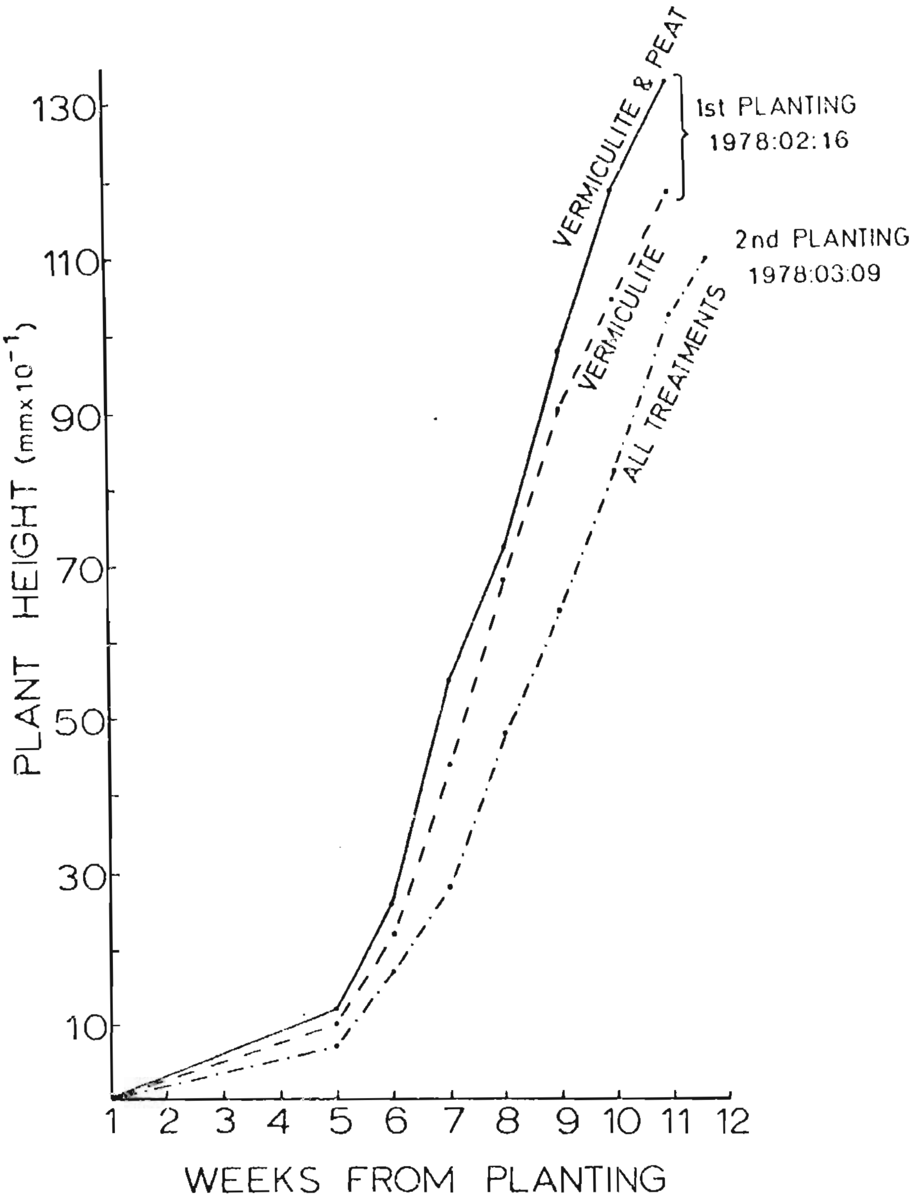


Fig. 3.1 Tomato plant growth at two different times of planting and in different media

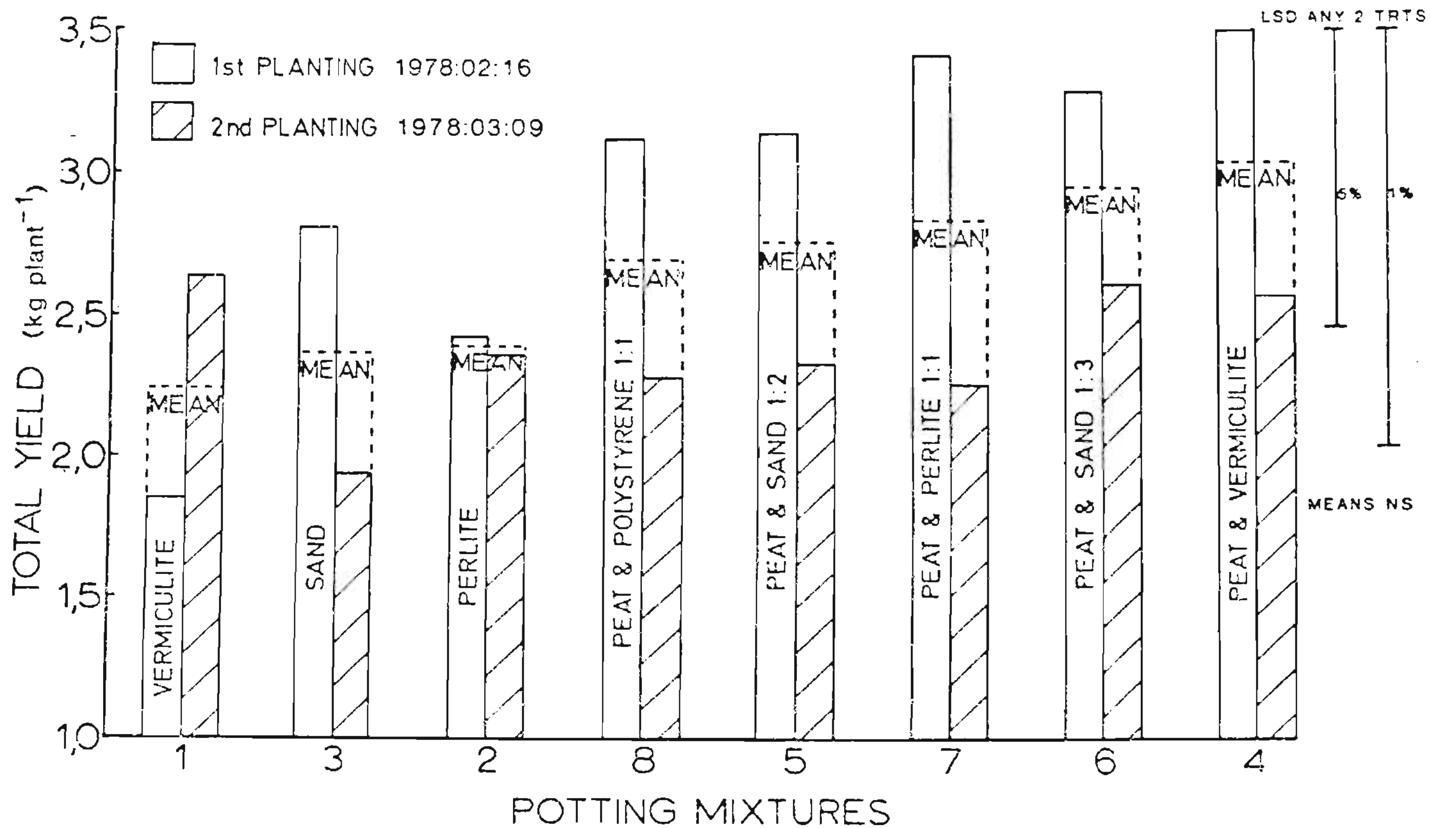


Fig. 3.2 Total yield of marketable fruit on two different planting dates for eight different potting mixtures

Components of yield The mean fruit mass decreased with increasing truss number (Fig. 3.3), and the fruit harvested near the end of the trial were about half the size of those from truss 1 for both times of planting.

In the first planting, vermiculite tended to give rise to the largest fruit (Fig. 3.3), due to fewer fruit per truss, even though it gave the lowest yield. All other treatments tended to produce fruit of a similar size, although at higher trusses plants in sand had smaller fruit, especially in the first planting.

In order to determine whether the decline in mean fruit mass at higher trusses was related to the number of fruit per truss these two variables were plotted together in Fig. 3.4. The number of fruit per truss remained relatively constant up to truss 5, but the mass declined with increasing truss number. This was related to the temperatures at the time of fruit set (see Figs. 2.11 and 2.12) and has also been reported for this time of planting by Oosthuizen & Millar-Watt (1978).

pH Average monthly pH measurements of the water and different mixtures are shown in Fig. 3.5. The water tended to alkalinity (± pH 8) except on the last sampling date when a pH of 6 was recorded. The nutrient mixture had an acidifying effect on the water, and the pH of the water + ® Chemicult mixture was approximately 6 throughout the trial.

The pH of the vermiculite was initially 8, but with constant watering it assumed the pH of the nutrient solution. Similarly perlite started at pH 7 but within eight weeks reached pH 6. The sand maintained a pH close to 6 throughout the trial.

The aciditity of the peat was dominant in all the peat mixtures, and most had a pH value of 4 to 5. The two highest yielding mixtures had pH 5. A similar relationship was found by Walliham, Sharpless & Pointy (1977). Usually, however, most recommendations are that the nutrient solution should be kept at pH 5,5 - 6,5 (Cooper, 1979; Maas & Adamson, 1980).

Total salt content (Fig. 3.6) During the trial the total salt levels fluctuated as excess water was applied once a week to maintain acceptable salt levels.

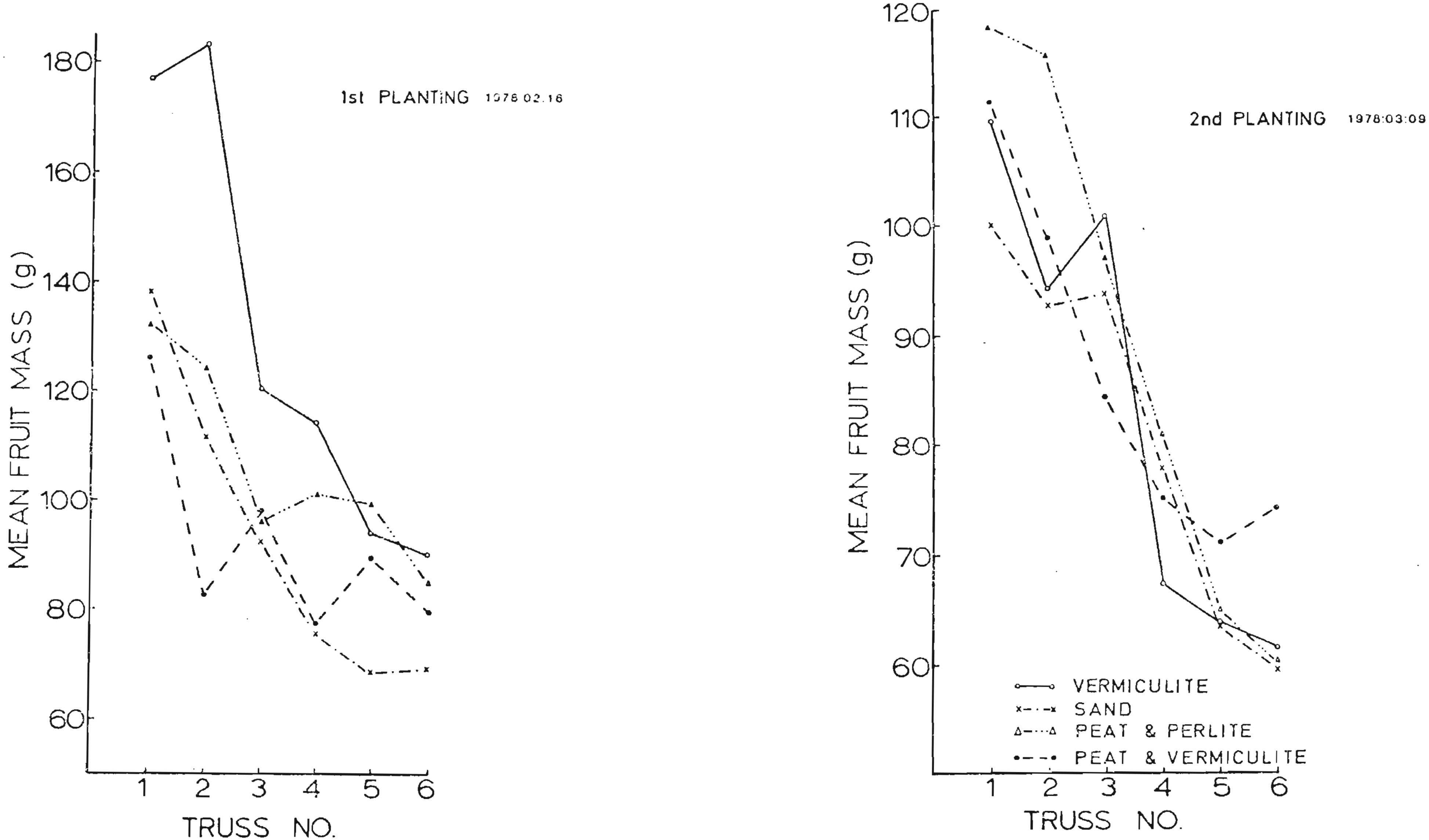


Fig. 3.3 The effect of truss no. on mean fruit mass per truss at

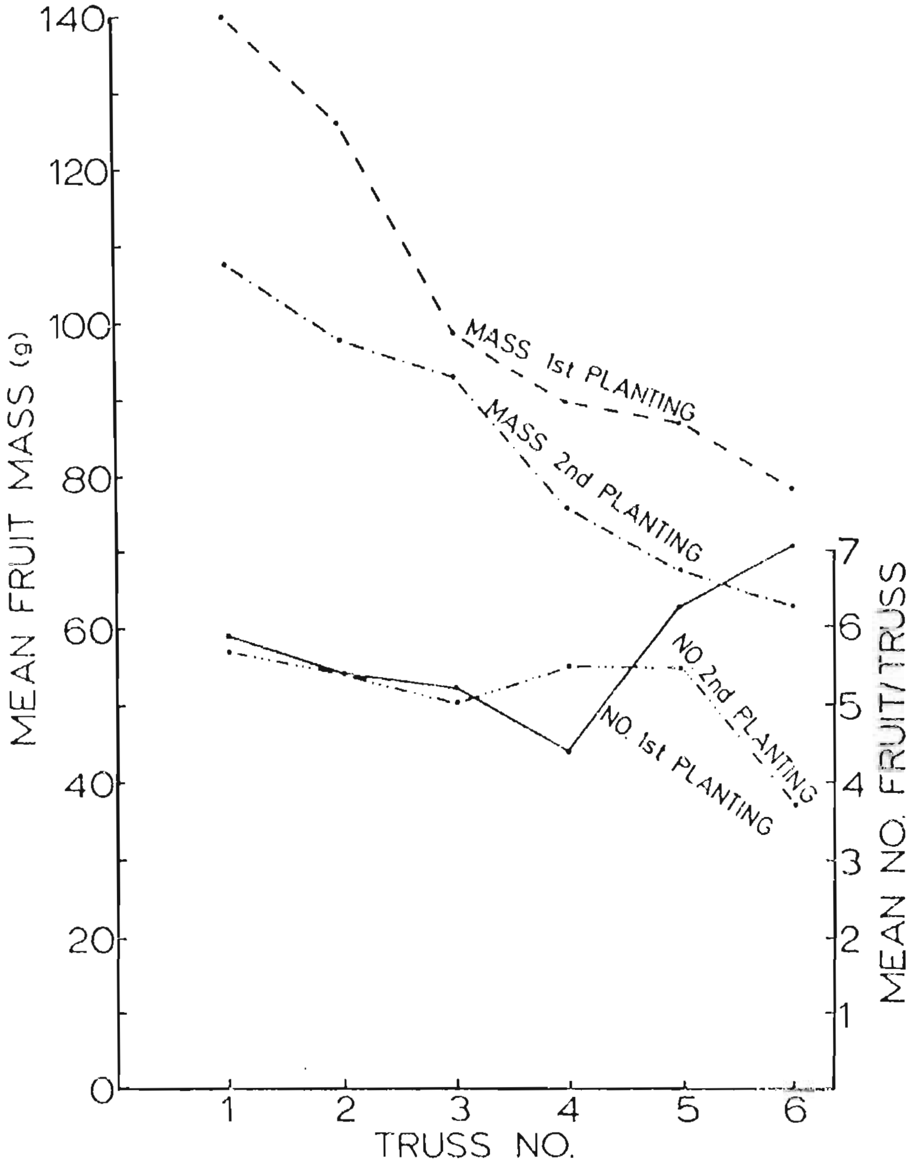


Fig. 3.4 Relationship between number of fruit and the mean fruit mass per truss

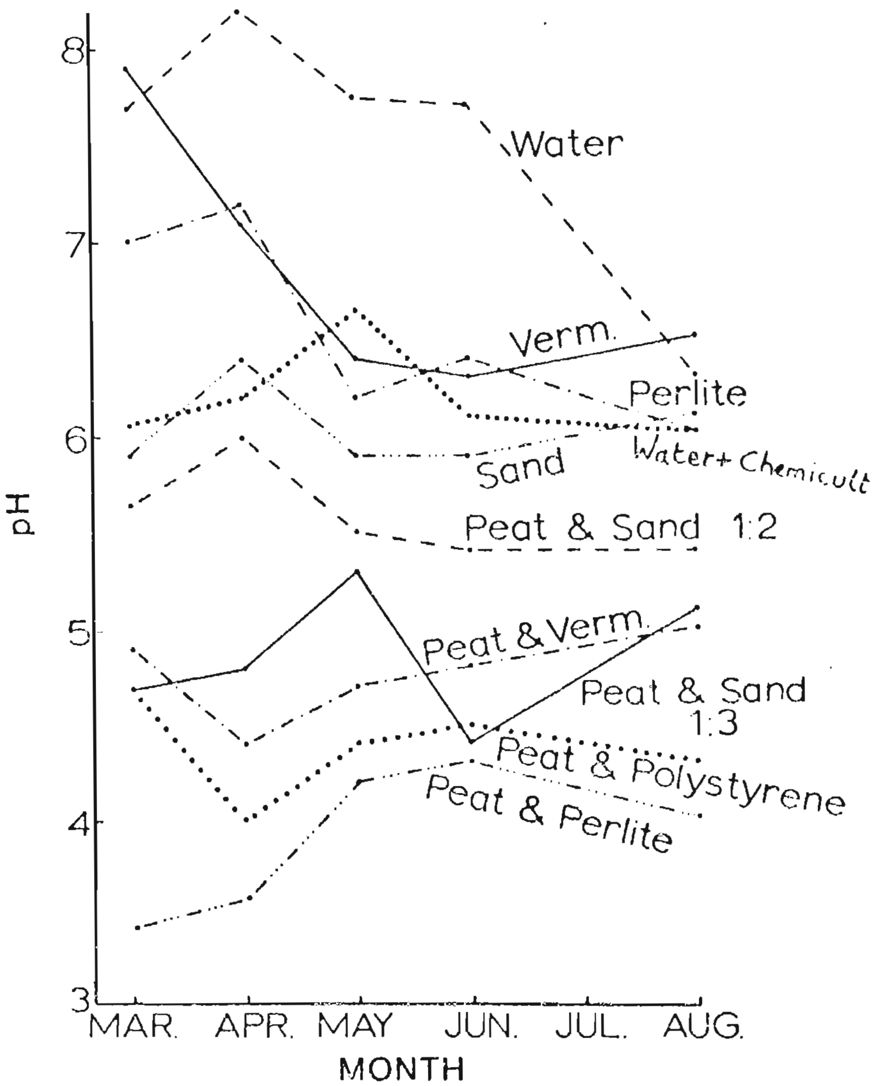


Fig. 3.5 The change in pH of the different potting mixtures with time

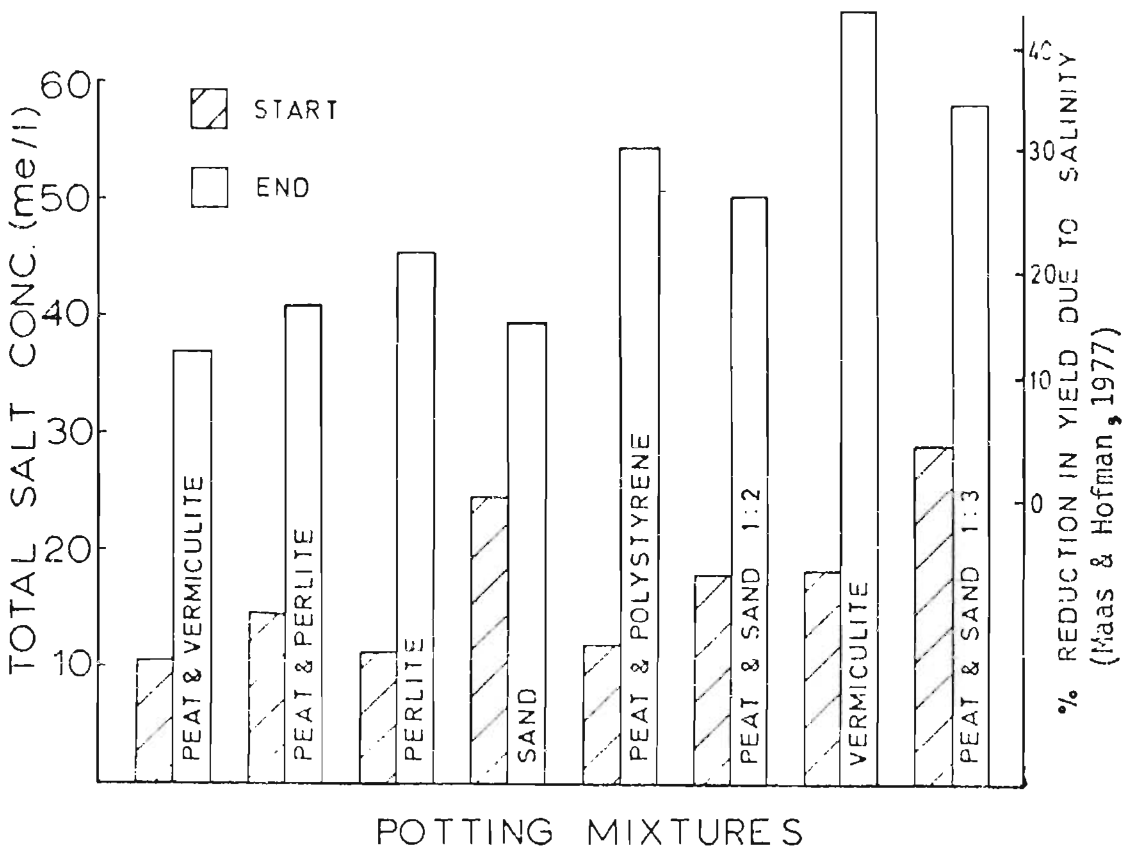


Fig. 3.6 Salinity levels in the different potting mixtures at the start and end of the trial

The lowest total salt levels were found in peat:vermiculite which gave the highest yield. The highest levels were found in the peat:sand (1:3) which also yielded well, and the vermiculite which yielded poorly at the first planting. No definite relationship was found between the salt content and yield in different media. Fig. 3.6 shows, however, that there was an increase in salinity from the start to the end of the trial. At the final levels yield would be reduced by the percentages shown if the criteria of Maas & Hoffman (1977) are applied. In nutriculture systems, however, it is recommended that the salinity level should be kept at 250-300 mS m^{-1} ($\pm$ 25-30 me ℓ^{-1}) for tomatoes (Anon., undated d; Anon, 1979; Allen, 1980).

Suitable salinity levels can be maintained by

a) Slightly over-watering at each irrigation (Jensen, 1980).

b) Providing for free drainage by making holes in the bases of pots, or by providing drainage pipes in beds (Jensen, 1980).

c) Monitoring salinity levels continuously, and when levels become too high reducing the strength of the nutrient solution, or flushing with water until the level returns to normal.

Observations on the root systems In general, the size of the root system appeared to be related to the water holding capacity of the medium (Table 3.10). Thus peat and vermiculite tended to result in smaller root systems confined to the central part of the pot. The largest and most branched root system was in sand alone. The root systems in the sand:peat mixtures depended on the amount of sand in the mixture, but were smaller than those in sand.

In most potting mixtures the roots were distributed evenly throughout the pot. In perlite, however, a large percentage were situated at the top of the pot, and few in the centre. This was also found in Experiment 14.

It appeared, therefore, that the size and extent of branching of the root system depended on the ease of obtaining water. Root proliferation would also depend on the watering frequency of the potting mixture in question. In this experiment all pots were watered at pre-determined intervals. This may have been insufficient for maximum yields in sand.

3.3.4 Conclusions All mixtures tested resulted in relatively good yields, but there was a tendency for peat:vermiculite and peat:sand mixtures to result in the highest yields under the management conditions used. The peat:sand mixes have an added advantage of re-usability, and at the time of this trial were the least expensive media (see 3.7).

TABLE 3.11 Details of the stock and final solutions of modified Jensen's nutriculture solution used in the tomato module trial (Experiment 13) (modified from Ellis *et al.*, 1974; Fontes, 1980; Jensen, 1980)

Chemical	g 20 ℓ^{-1} stock	g ℓ^{-1} in stock	ℓ stock added to 1000 ℓ water	Conc. of final soln g 1000 ℓ^{-1}	ppm
$Ca(NO_3)_2$	3800	190	5	950	N 113 Ca 161
KNO_3	1416	70,8	2,5	177	N 24 K 65
K_2SO_4	2330	116,5	2,5	291	K 116
$MgSO_4$	4120	206,4	2,5	515	Mg 49
H_3PO_4	Commercial	product	0,264		P 63
Trace element soln	TABLE 3.7		0,106		

TABLE 3.12 Details of composition of stock and final solution (1:200 dilution) in the Guernsey treatment of the tomato module trial (Experiment 13)

Chemical	g 20 ℓ^{-1} stock	g ℓ^{-1} in stock	ℓ stock added to 1000 ℓ water	Conc. of final soln g 1000 ℓ^{-1}	ppm
$Ca(NO_3)_2$	1200	60	5	300	N 47 Ca 57
KNO_3	2840	142	5	710	N 96 K 262
Urea	800	40	2	80	N 37
MAP	1360	68	5	340	N 37 P 71

3.4 TOMATOES - COMPARISON OF SIX MEDIA WITH AND WITHOUT PRE-ENRICHMENT (Experiment 13)

3.4.1 Aim This experiment aimed to compare the two most important nutriculture systems used worldwide viz. pre-enrichment and total nutrient solution feeding, under Natal conditions, in combination with different media. The previously found best medium, which was used by growers at the time, viz. local peat and sand (3:1) was included as the standard.

3.4.2 Procedure The trial was laid out as a randomised blocks design with split plots and four replications. The whole plot factor was a comparison of two fertilisation methods:-

1. Guernsey recommendations (Moorat, 1981) with the pre-enrichment fertilisers being the same as those in Table 3.4 (Column 6). The daily nutrient solution application was modified from that recommended by Moorat (1981) in Table 3.5, as shown in Table 3.12.

2. Modified Jensen's (1980) nutriculture solution as shown in Table 3.11. No pre-enrichment of the media took place.

The split plot factor was six different media with each sub-plot consisting of two adjacent modules or six plants. The six media were:-

1. Umgeni river sand : local peat (3:1)
2. Umgeni river sand : local peat (1:1)
3. Local peat
4. Bagasse (Wood, 1981) (a by-product of the sugar industry, but different to "milo")
5. River sand : bagasse (1:1)
6. Mushroom compost : vermiculite (3:1),

the mixtures being made on a volume basis.

The respective media were filled into 42 ℓ white plastic modules, similar to those used in Europe (Allen, 1980; Moorat, 1981). These were laid in the furrows of the 30 m ® Gundle 'roll-up sides' tunnel in a double row system to give a plant spacing of 500 x 400 mm.

Tomato seeds (cv. Estrella) were sown into 50 mm diameter black plastic pots filled with local peat on 1979:03:10. On 1979:04:15 the pots with the seedlings were placed in position in the modules, three to a module.

First harvest was on 1979:08:01, and the trial was continued to 1979:11:01 after the plants had earlier been topped at the overhead wire. Most plants had set 10 trusses.

Records were taken of the time to first flowering; the number of nodes to, and height of, the first truss; plant height; and stem diameter at the middle of the internode between the first and second truss. The number and mass of marketable fruit (> 50 g) harvested from each truss was recorded.

3.4.3 Results and Discussion

Plant growth and fruiting Measurements of plant height at time intervals throughout the growth period showed that on the average pre-enriched modules gave rise to faster plant growth. At 111 days after transplanting plants in pre-enriched media were on average 80 mm taller than those in non-enriched media. This difference was, however, non-significant (Fig. 3.7). There were, however, significant differences in the heights of plants growing in the different media (Fig. 3.7). Mushroom compost:vermiculite was significantly better than sand:bagasse and highly significantly better than bagasse. There were no significant differences between peat, peat:sand mixtures and mushroom compost: vermiculite. Thicker stems are usually associated with more vigorous vegetative growth. Fig. 3.7 shows that there were significant differences between plants in the different media, and between those receiving different fertilisation treatments. Plants in the pre-enriched media had significantly thicker stems, except in the mushroom compost treatment where the two fertilisation methods were equally good. This was probably due to the inherently high N, K and Ca levels in this medium (Table 3.1). On average this medium resulted in the most vigorous plants, although they were only significantly more vigorous than plants in bagasse and bagasse:sand.

The most vigorous plants were in pre-enriched sand:peat (3:1), which was significantly different from pre-enriched mushroom compost: vermiculite, sand:bagasse and bagasse, and all non-enriched media (Fig. 3.7).

Although some plants had vigorous vegetative growth no symptoms of excess nitrogen (balling of leaves at apex) were evident. According to Moorat (1981) it is important to maintain a balance between vegetative

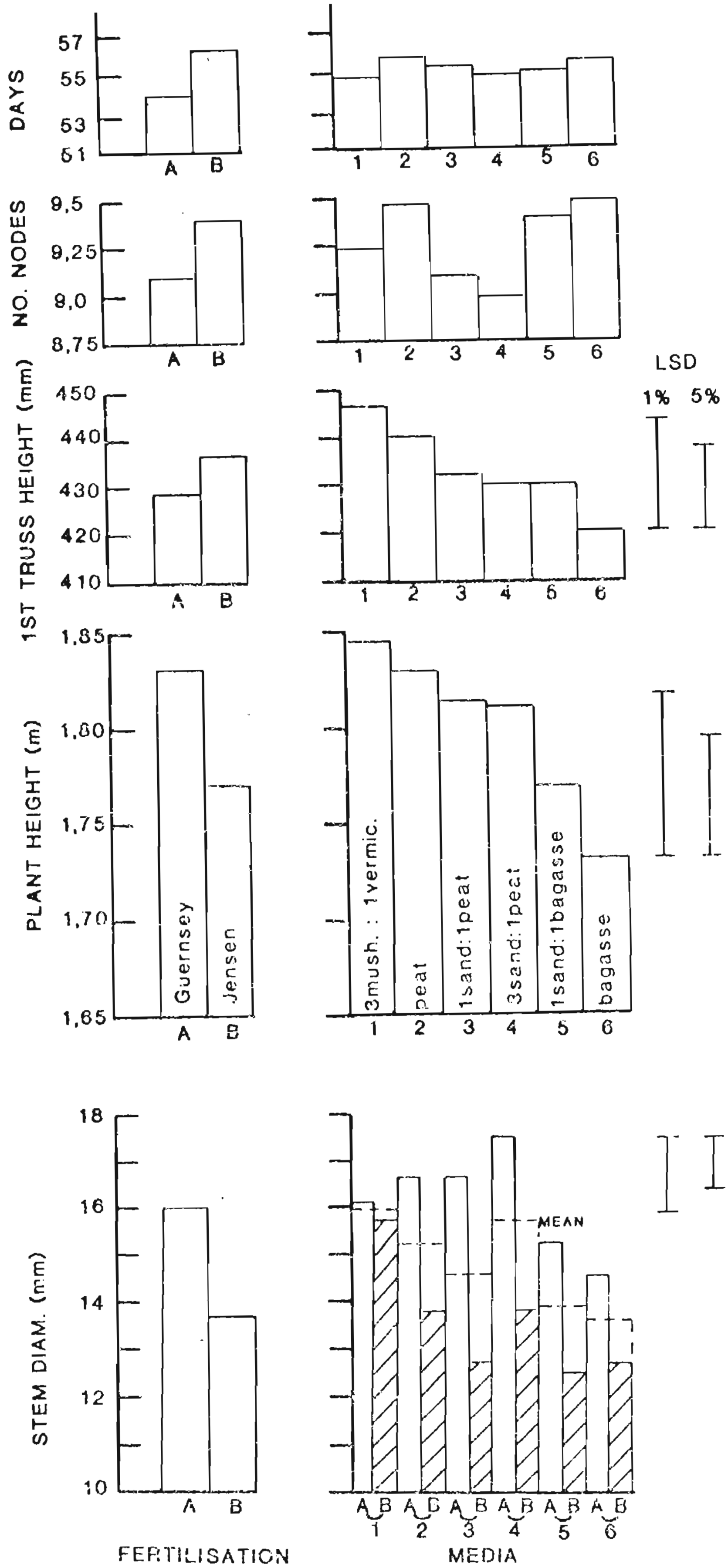


Fig. 3.7 Plant height and stem diameter between the first and second truss, first truss height, number of leaves subtending the first truss and number of days to flowering in tomatoes

growth and fruiting such that the plant stems never become excessively thickened and angular.

There were also significant differences in the height to the first truss amongst plants growing in the different media (Fig. 3.7). First flowering occurred at the shortest plant height in the pre-enriched 3:1 sand:peat medium. This was significantly lower than plants in bagasse, highly significantly lower than in sand:bagasse, and not significantly lower than in peat, sand:peat (1:1) and mushroom compost: vermiculite (Fig. 3.7). Generally, therefore, the most vigorous plants had a lower first truss.

The height of first flowering was related to the number of nodes subtending the first truss (Fig. 3.7). Plants which produced a lower first truss had fewer nodes to that truss. Differences, however, were small and non-significant.

Although there were no significant differences in the time to first flowering (Fig. 3.7), there was a tendency for plants growing in pre-enriched media to flower slightly earlier. The average time to first flowering was 55 days.

The amount of fruit harvested per truss, and the period of time over which this fruit was harvested in relation to the time of sowing is shown in Fig. 3.8. First harvest took place almost 16 weeks from transplanting. The average yield on the first truss was 1 kg. Harvesting from this truss continued over a five week period. The yield was lower on each successive truss, until after the sixth truss when almost no marketable fruit was harvested. The trial was terminated in early November (Truss 11).

This low yield on later trusses is believed to be related to poor pollination some 60 days before (Oosthuizen & Millar-Watt, 1978), when flowering occurred during the coldest part of the year. Temperatures during this period were typically as shown in Fig. 2.11 and were too low for viable pollen formation, and effective pollen germination and pollen tube growth (Calvert, 1964; Stevens & Rudich, 1978; Wittwer & Honma, 1979). Similar results were reported in Experiments 7 and 12.

In this trial, and in the others mentioned, the additional fruit harvested from trusses 7 to 11 only marginally increased yields, and did not change the treatment differences which were evident up to

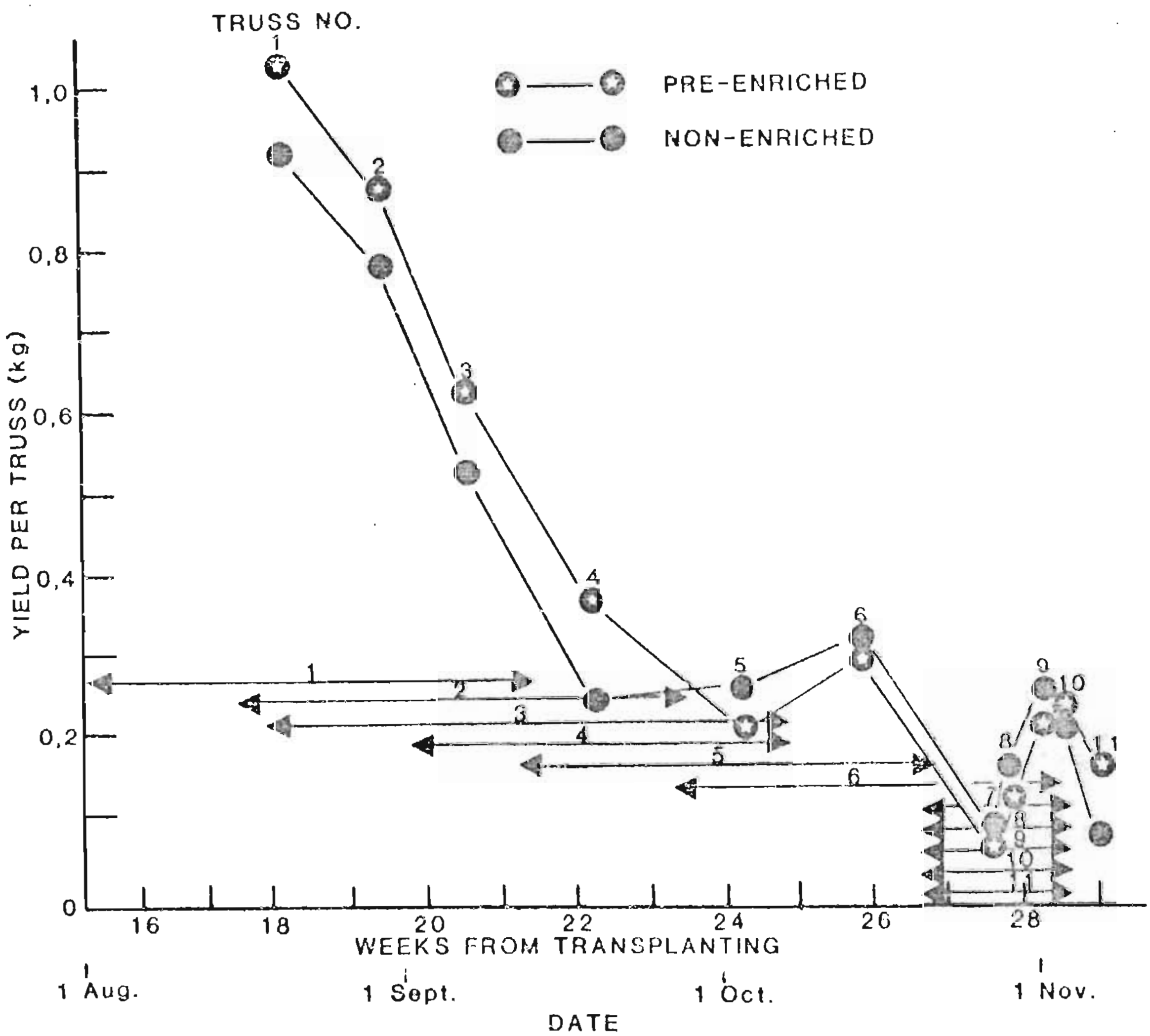


Fig. 3.8 Yield and harvest period of each truss on tomatoes in pre-enriched and non-enriched media

truss six. For this reason the yield results for this trial only include fruit harvested from the first six trusses.

Yield There were no significant differences between the plants in different media or those receiving different fertilisation treatments.

On average, however, pre-enrichment resulted in higher yields than non-enrichment, except in the mushroom compost:vermiculite (Fig. 3.9a), which gave the highest mean yield. The highest yield was obtained in the pre-enriched peat or peat:sand mixtures (Fig. 3.9a).

Examination of the truss by truss yield (Fig. 3.8) shows that the pre-enrichment resulted in higher average yields on truss one and two, but that there was little difference between fertilisation treatments on higher trusses. The early yield thus determined eventual treatment differences, although these were non-significant.

The mean fruit mass (Fig. 3.9b) was significantly higher in mushroom compost:vermiculite than all other media, and highly significantly higher than in bagasse and sand:bagasse. Pre-enriched media resulted in a heavier mean fruit mass in all treatments, and significantly so in sand:peat (3:1) and peat.

A comparison of Tables 3.10 and 3.11 shows that the Guernsey nutrient solution had higher levels of N (217 ppm compared to 137 ppm) and K (262 ppm compared to 181 ppm) than the Jensen solution used. This, as well as the pre-enrichment undoubtedly gave rise to the more vigorous vegetative growth reported, and also to the initially higher yields. At the time, however, it was thought that these plants were too vegetative.

Leaf analysis, and medium analysis, are necessary to interpret the effect of the different fertilisation treatments more exactly. Adjustments to the levels of nutrients of Jensen's solution could result in equally good results, especially if media were considered individually.

As in the previous trial yields were $\pm$9,5 kg m^{-2} for the 12 week harvest period (6 trusses), as compared to $\pm$ 12 kg m^{-2} in the U.K., due to the time of planting and limited climate control provided by the plastic tunnel.

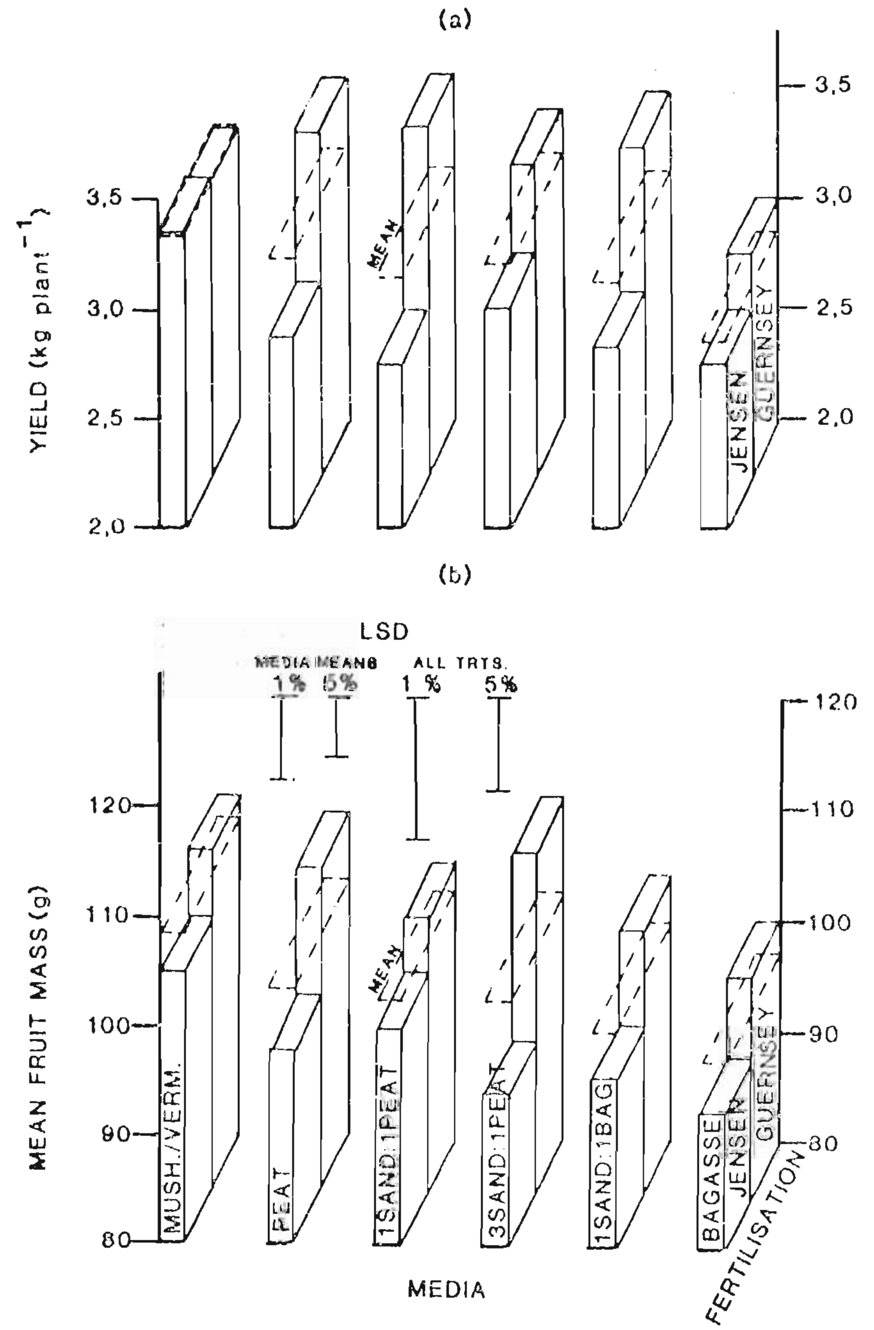


Fig. 3.9 Yield and mean fruit mass of tomatoes grown in different media and receiving different fertilisation treatments

3.4.4 Conclusions The sand:peat (3:1) media produced good results, as in the previous trial, and up to this time was still the most used media by growers mainly because of its lower cost (see 3.7) and re-usability Plentiful, cheap labour meant that the greater bulk density was not a problem.

In conjunction with this medium most growers used a commercial, complete, nutrient solution. The results of this trial showed that equally good or better results could be obtained using the pre-enrichment system. Management is easier using unskilled labour as fewer chemicals are handled in the feeding stage with no precipitation problems.

3.5 TOMATOES - EFFECT OF THREE NUTRITION PROGRAMMES AND FIVE MEDIA (Experiment 14)

3.5.1 Aim Previous experiments (12 and 13) up to late 1979 resulted in Natal growers adopting a nutriculture growing system based on a local peat:sand medium. Watering was with a solution modified from Ellis *et al.* (1974), made up from straight chemicals, or obtained as a commercial mixture.

Since 1980, however, local peat became unobtainable and an alternative became necessary. With an abundance of bark and sawdust in Natal, and noting the success of Maas & Adamson (1980) and Maree (1981c) with sawdust, and Wilson (1981) with bark, it was logical to test these media in response to the demonstrated grower need.

Further, commercial nutrient mixtures all differ in their percentage make up (App. Table 1), and recommended rate of application. Experiment 4, with seedlings, showed that by adjusting the elemental concentrations good results could be obtained. Thus a further objective was to compare pre-enrichment according to Wilson (1981) with Jensen's (1980) nutrient solution, and a commercial product, ® Chemicult balanced to the levels recommended by Jensen.

3.5.2 Procedure Black plastic bags (10 ℓ) were filled with five different media and laid out in double rows at a spacing of 500 x 400 mm in the 30 m ® Gundle 'roll-up sides' tunnel.

Tomato seeds (cv. Angela) were sown into bark in ® Speedling trays on 1981:02:25 and transplanted into the pots in the tunnel on 1981:03:20.

TABLE 3.13 Concentrations (ppm) of elements delivered to tomato plants from the three fertilisation methods in Experiment 14

Element	Concentration (ppm)			
	Scottish	Jensen	® Chemicult	Recommended Jensen (1980)
N	198	113	220	144
P	42	36	27	62
K	79	156	130	154
Ca		53	271	165
Mg		49	73	50
S		65	135	6,5
Fe		2,60	1,50	2,5
Mn		0,28	0,24	0,62
B		0,29	0,24	0,44
Cu		0,08	0,02	0,05
Zn		0,05	0,05	0,03
Mo		0,04	0,01	0,09

The trial was laid out as a randomised blocks design with split plots and four replications. The whole plot factor was a comparison of three fertilisation methods:-

1. Scottish recommendations (Wilson, 1981) for pre-enrichment of bark. To each m^3 of medium a 3,3:1:1,3 (N:P:K) fertiliser mixture was added in the form of 0,54 kg KNO_3, 1,47 kg LAN (Table 3.9) and 1,31 kg single superphosphate. In addition 5,0 kg ground limestone, 5,0 kg dolomitic limestone, 0,6 kg FRIT 504 (Table 3.9) and 0,2 kg $FeSO_4.7H_2O$ were added, and thoroughly mixed in a concrete mixer. Twenty-five days after transplanting (recommended as 3-4 weeks) daily liquid feeding commenced using a solution with the elemental concentration shown in Table 3.13. This was made up using KNO_3, MAP and urea.

TABLE 3.14 Details of the stock and final solutions of modified Jensen's nutriculture solution used in Experiment 14

Chemical	g 20 ℓ^{-1} stock	Stock conc. (g ℓ^{-1})	mℓ stock added to 1000 ℓ water	conc. final solution (g 1000 ℓ^{-1})	% element in compound	conc. of final soln (ppm)
KNO_3	1 682	84,1	4 500	421,5	K 36,9 % N 13,5 %	K 156 N 56
$Ca(NO_3)_2.3H_2O$	1 472	73,6	4 500	368,1	Ca 19,0 % N 15,5 %	Ca 70 N 57
H_3PO_4	-	-	271	135,5	P 26,6 %	P 36
$MgSO_4.7H_2O$	2 008	100,4	4 500	502,2	Mg 9,5 % S 13,0 %	Mg 49 S 65
$FeCl_3.6H_2O$	470	23,5	450	11,8	Fe 20,8 %	Fe 2,6
Trace element soln	TABLE 3.7		106			

After 10 weeks the plants showed Fe deficiency symptoms. This was corrected by adding an extra 2,6 ppm Fe as $FeCl_3.6H_2O$ to the solution.

2. Modified Jensen's (1980) nutriculture solution, made up as in Table 3.14 to give a final elemental concentration as shown in Table 3.13. No pre-enrichment of the medium took place.

3. ® Chemicult (App. Table 1) at a rate of 1,0 g ℓ^{-1} plus 1,5 g ℓ^{-1} $Ca(NO_3)_2$ + 0,5 g ℓ^{-1} $MgSO_4$ to give a solution with the elemental concentration shown in Table 3.13.

The split plot factor included the following five media, with four plants per split plot.

1. Pine bark milled through a 12 mm screen designated small bark (SB).

2. Well composted, unmilled pine bark with a large particle size - designated large bark (LB).

3. Fresh pine sawdust (SD).

4. Umgeni river sand:local peat (3:1) mixture (PS).

5. Perlite (P). Two grades of perlite were used, a fine grade in the Scottish treatment, and a coarse grade in the Jensen and ® Chemicult treatments (Grade C95, supplied by Perlite Industries, Johannesburg).

Management and watering was according to normal procedures (3.2).

Records included the time to first flower opening on the first truss, truss heights, and observations of the root systems at the end of the trial. The mass and number of fruit from each truss were recorded at weekly intervals, together with fruit grade, according to local market regulations, viz. grade 1 : > 50 mm diam., grade 2 : 40-50 mm diam., and grade 3 : 30-40 mm diam.

At the end of the trial samples of the different media were analysed for total salt content, using a saturated extract, according to methods at the Soil Analysis Laboratory, Cedara Agricultural College, Natal.

3.5.3 Results and Discussion

Flowering Fertilisation treatments gave rise to no significant differences in the number of days to first anthesis (Fig. 3.10a), which averaged 55 days.

There were, however, highly significant differences between media (Fig. 3.10a) and among the fertilisation/media interactions (Fig. 3.10b).

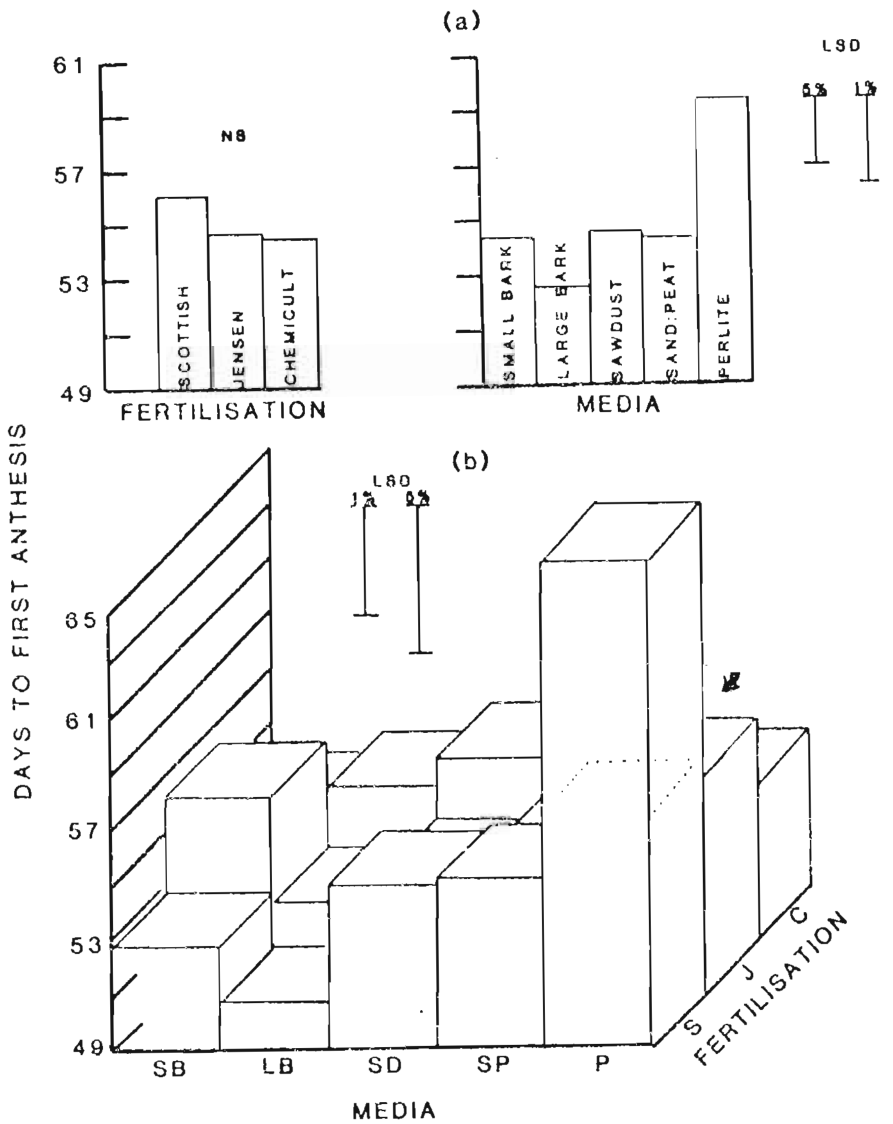


Fig. 3.10 a) Effect of fertilisation and media on time to first anthesis

b) Effect of treatment combinations on time to first anthesis

Plants in large bark flowered earliest (53 days), but only significantly earlier than those in perlite (59 days) (Fig. 3.10a). This was mainly caused by the late flowering in the Scottish/perlite combination, which was highly significantly later than in any other treatment (Fig. 3.10b). Plants in the Scottish/large bark combination flowered significantly earlier than those in the Jensen/small bark and perlite combinations.

The late flowering in the Scottish/perlite treatment was probably because perlite has no CEC (Wilson, 1981) and any pre-enrichment nutrients were quickly leached. These plants suffered a general nutrient deficiency early on, until the liquid feeding programme was started.

All trusses formed at approximately the same heights, and there were no significant differences in the total number of trusses per plant.

Yield Main effects for the three fertilisation methods and the five media are presented in Fig. 3.11a, and interactions between them in Fig. 3.11b. There were no significant yield differences (over all media) between ® Chemicult (ave. 5,6 kg) and Jensen (ave. 5,2 kg) nutrition programmes, but ® Chemicult was highly significantly better than the Scottish treatment (ave. 4,8 kg), and Jensen significantly better. With respect to media, the only significant differences (P = 0,05) found were that LB (ave. 5,4 kg) and SB (ave. 5,2 kg) gave higher yields than SP (ave. 4,5 kg).

The interaction histogram (Fig. 3.11b) indicates several trends. The high mean yields (6 kg plant^{-1}) in all ® Chemicult treatments except SP (4,8 kg) are noteworthy. In this nutrition programme the yield in LB was significantly higher than in SP. Jensen's treatment performed well except for a significantly lower yield in SP as compared to SD and perlite. In the Scottish nutrition programme LB was a significantly better medium than SD and perlite.

Overall the worst combinations were with Scottish nutrition and SD and perlite, averaging less than 4 kg plant^{-1}. In these combinations, the media gave rise to poor root development (Fig. 3.16), and deficiencies of Fe, Mg and Mn developed due to leaching of the pre-enrichment fertilisers. This did not occur with ® Chemicult and Jensen as these were complete nutrient solutions.

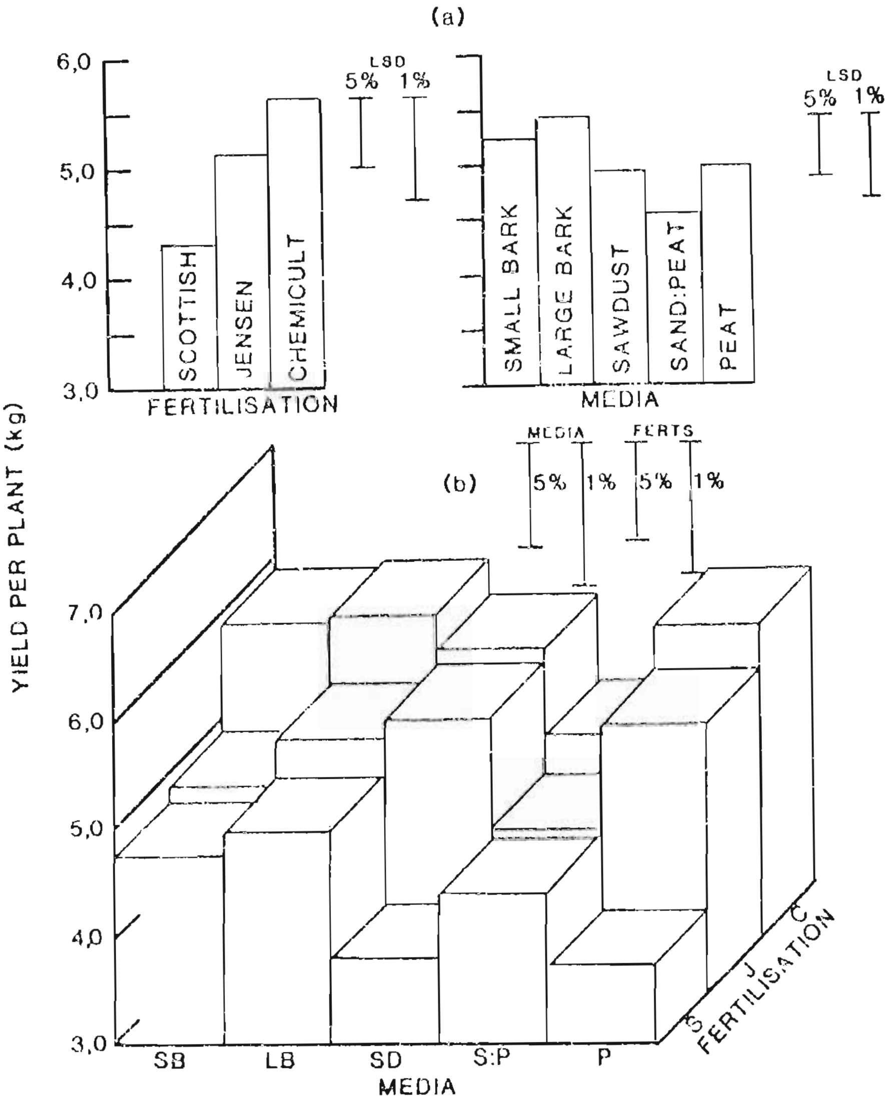


Fig. 3.11 Yield from tomato plants grown in different media and receiving different fertilisation treatments

a) main effects

b) individual treatment effects

Components of yield The average number of fruit per plant was 65, with no significant differences between media (Fig. 3.12a). Differences between the two best and the worst fertilisation treatments were, however, highly significant (Fig. 3.12a) with the Scottish treatments averaging only 54 fruit per plant compared to 72 fruit per plant with ® Chemicult and 70 with Jensen's programme. Indidividual treatment combinations were significantly different (Fig. 3.12b). In each media there were significantly fewer fruit per plant with the Scottish nutrition programme as compared to the other two programmes.

The mean fruit mass on plants in the Scottish and ® Chemicult fertilised plots was significantly greater (P 0,05) than with Jensen's programme (Fig. 3.14a). Sand:peat resulted in significantly smaller fruit than all the other media (Fig. 3.13a). In combination with Jensen's treatment this medium produced fruit with significantly the lowest average mass (57 g) (Fig. 3.13b). This appeared to be due to the plants being over-vegetative with branched, long flowering trusses with many flowers and small 'ribbed' fruit. Alternatively, plants in the pre-enriched SP had fruit with the greatest average mass (Fig. 3.13b). These plants had fewer fruit per plant (Fig. 3.12b).

As in previous trials the mean fruit mass decreased from truss 1 up the plant. A comparison of selected treatment combinations (Fig. 3.14) shows that the Jensen's/SP treatment resulted in a lower fruit mass at each truss. In comparison Scottish/SP and ® Chemicult/SD had better sized fruit on each truss (but fewer of them - Fig. 3.12).

The percentage fruit in each of three grades in the fertilisation and media treatments is shown in Fig. 3.15. The per cent. grade 1 fruit was significantly lower in Jensen's fertilisation method as compared to the pre-enriched Scottish method (60 per cent. vs 55 per cent.).

Amongst the media, SP resulted in a highly significantly lower percentage grade 1 fruit. This was highest in SD and LB. Treatments with a lower percentage grade 1 fruit had a correspondingly higher percentage grade 3 fruit. The percentage grade 2 fruit remained relatively constant in each treatment, and no significant differences were recorded.

There was a very low incidence of fruit quality defects and none were associated with any particular treatment.

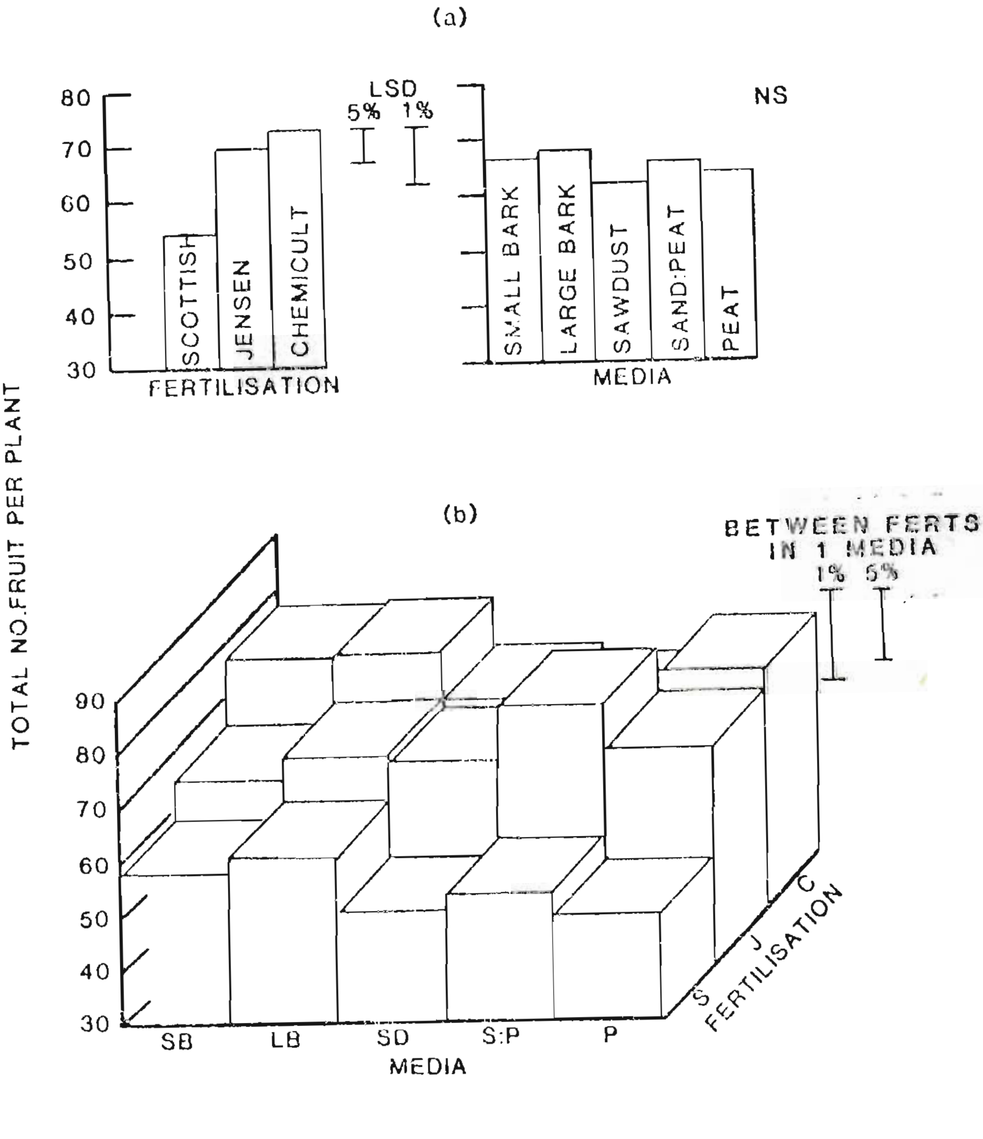


Fig. 3.12 Number of fruit on tomato plants grown in different media and receiving different fertilisation treatments

a) main effects

b) individual treatment effects

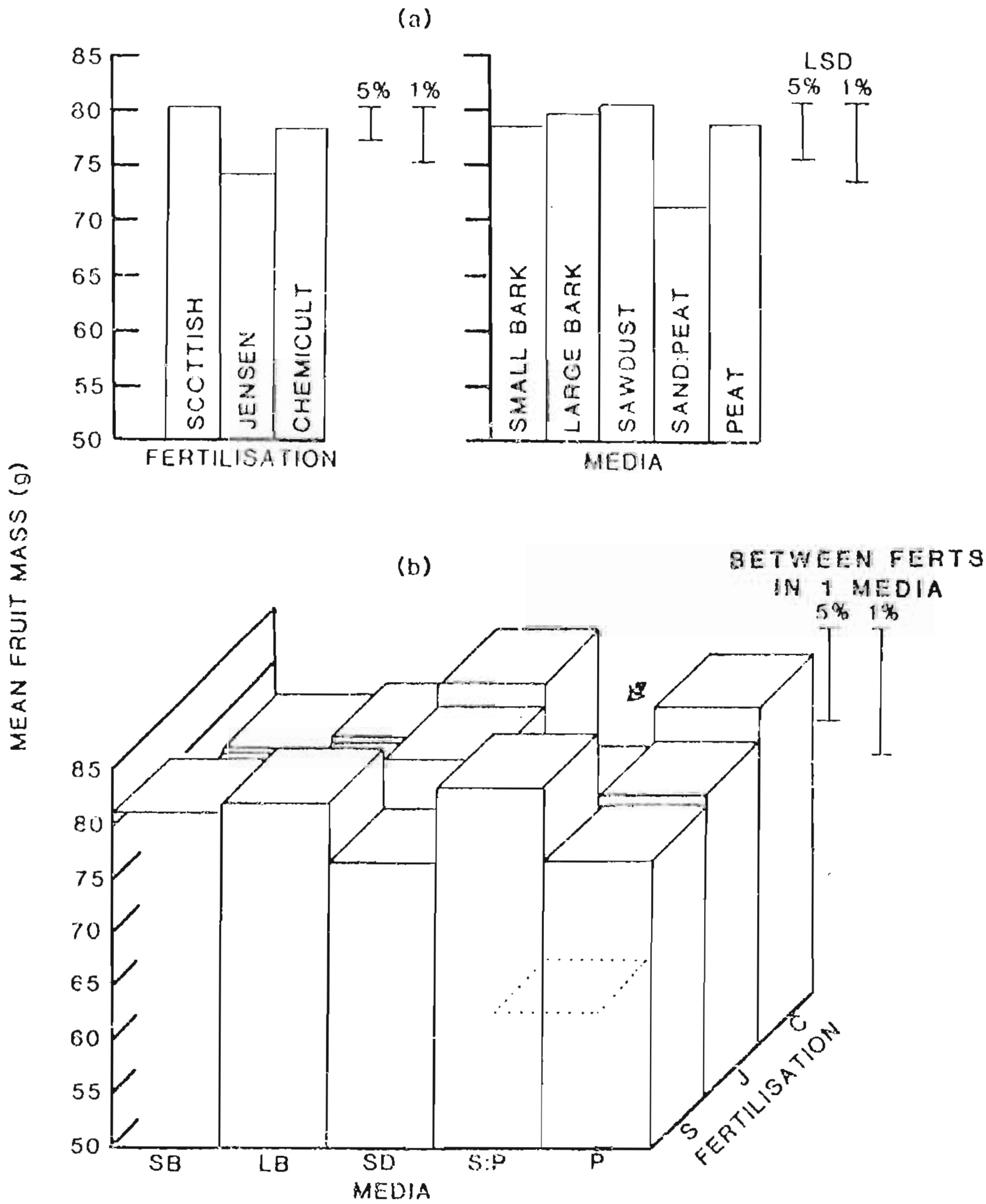


Fig. 3.13 Mean fruit mass on tomato plants grown in different media and receiving different fertilisation treatments

a) main effects

b) individual treatment effects

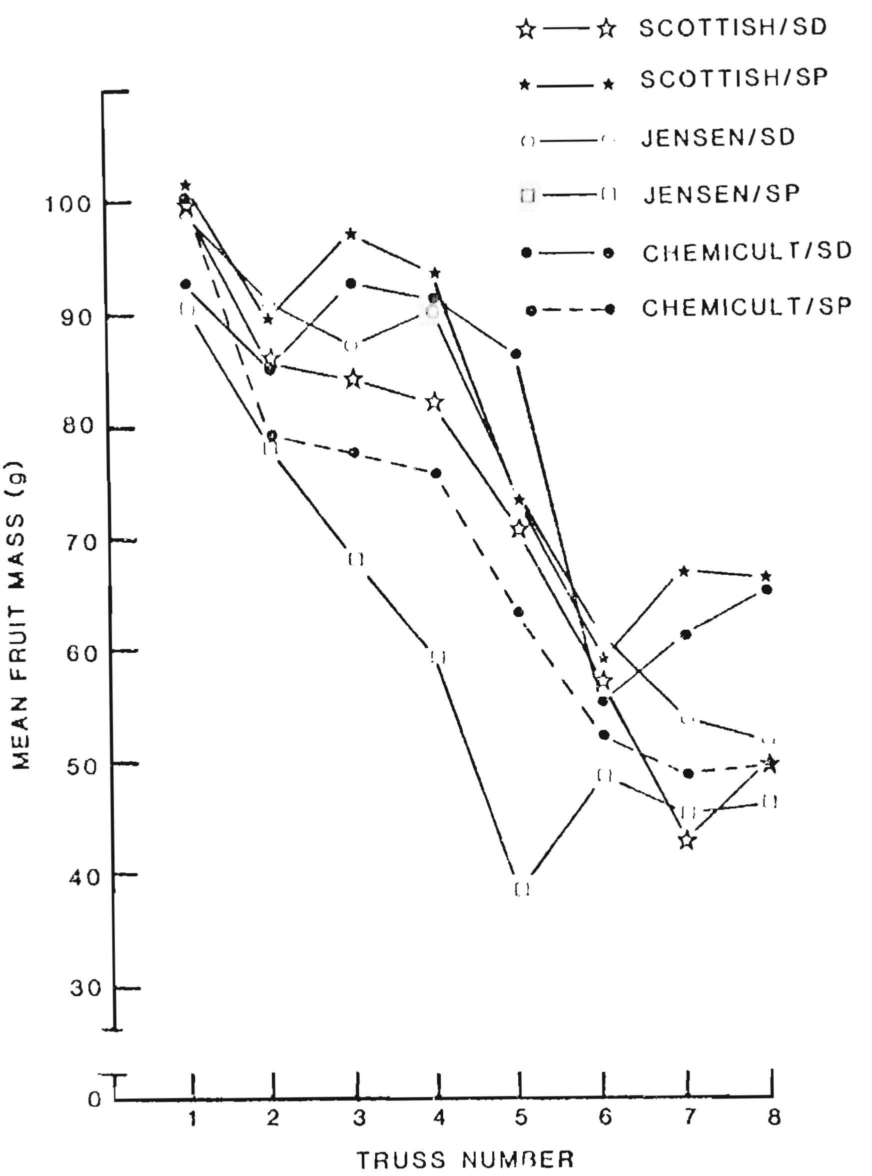


Fig. 3.14 Changes in fruit mass with truss number for selected best and worst treatment combinations

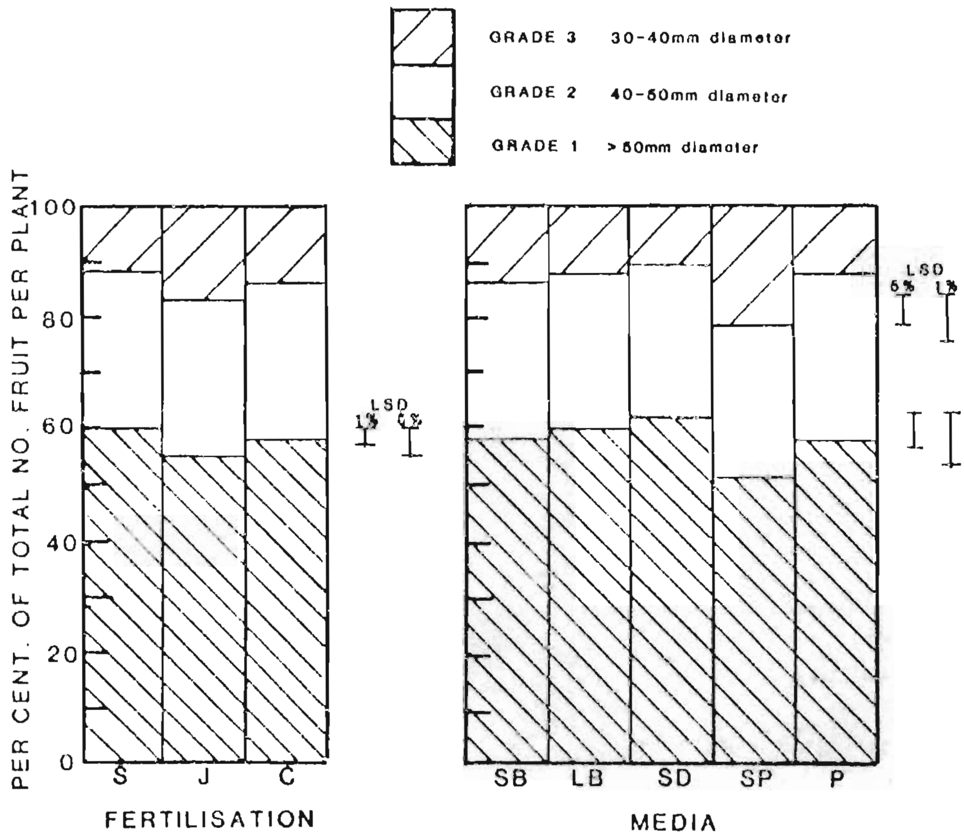


Fig. 3.15 Effects of fertilisation and media on percentages of grade 1, 2 and 3 fruit

Root observations (Fig. 3.16) The most prolific root system appeared to be in the SD medium. These roots permeated the whole medium and were well branched. In SP the root system was finely branched and very fibrous. Large bark resulted in roots which were thick and cordlike. Root systems in P and SB were intermediate, although the two grades of perlite resulted in very different root systems. In the fine grade perlite the roots were predominantly at the top, and virtually no root penetration occurred into the centre of the medium in the pot (Fig. 3.16). This was not the case in the coarser grade.

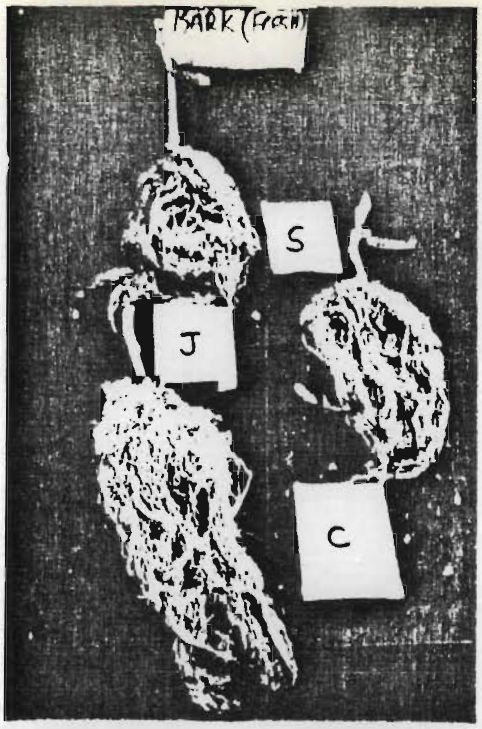
Differences between the root systems of plants receiving the different fertilisation treatments were also evident, with the smallest root systems being in the Scottish treatment, the most prolific systems in the ® Chemicult, and those with Jensen's programme intermediate (Fig. 3.16).

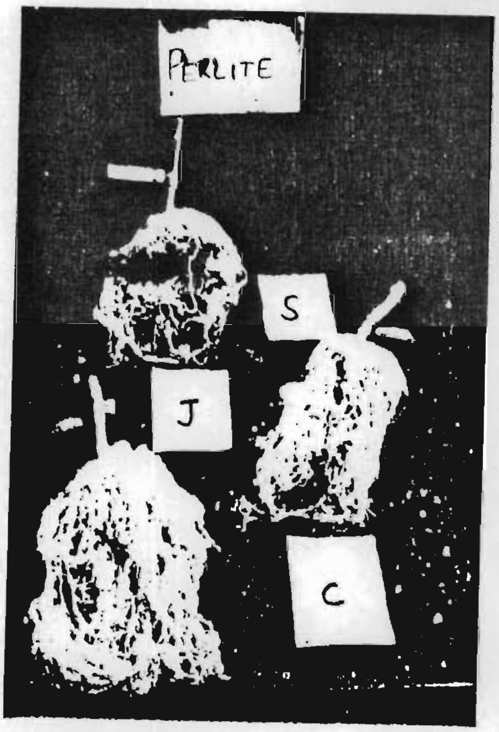
Media analyses (Table 3.14) The different media were analysed one week after final harvest. On average perlite had a pH above 7, especially the finer grade in the Scottish treatment which had a pH of 8,3. The lowest pH's were in the bark ($\pm$ 5), even in the Scottish nutrition treatment where lime had been added to the medium before planting.

Conductivities were highest in the large bark and sawdust, but the highest levels measured were still below those recommended for growing tomatoes (250-300 mS m^{-1} according to Allen, 1980; Moorat, 1981; Wilson, 1981). All pots received only water, for the final two weeks of the trial, and were thus leached fairly heavily. Media with the highest conductivities therefore retained more of the applied nutrients, i.e. LB and SD, Small bark had a lower conductivity than LB i.e. it retained less nutrients. Brown & Pokorny (1975) also reported that coarse bark had a higher CEC than fine bark.

The very low conductivity in perlite, is due to its extremely low CEC (Bunt, 1976), so that with only one or two applications of water most nutrients leach out. The SP also had a relatively low conductivity.

Total extractable Ca levels were highest in SD and LB, lower in SB and very low in SP and perlite. There was a similar trend in Mg levels. This corresponds with the findings of Gartner & Williams (1978). The


BARK
S
J
C


PERLITE
S
J
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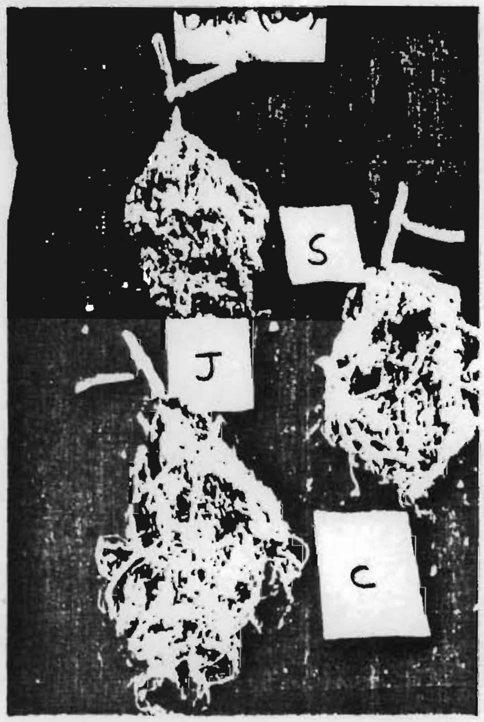
S
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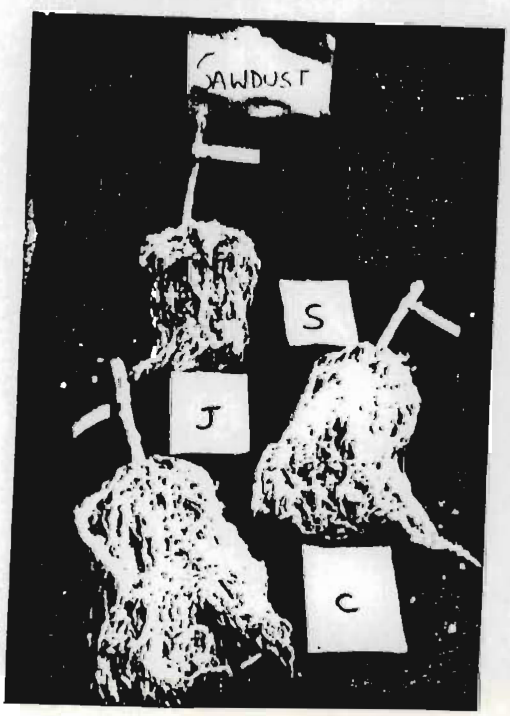
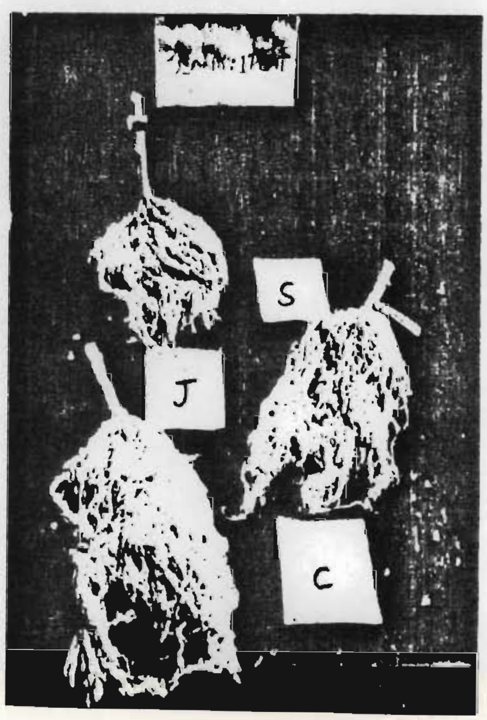

SAWDUST
S
J
C


S
J
C

fact that levels were lower in milled bark appears to be related to the lower CEC of this medium.

Potassium levels were also highest in SD and bark, and lowest in SP. Perlite, however, had a relatively high level.

Sodium levels were much higher in SD than in any other medium, but should not not have been limiting to growth.

In Guernsey (Moorat, 1981) a pre-enriched sphagnum peat should have levels of 200 ppm Ca, 300 ppm K and 55 ppm Mg. In comparison, the levels in Table 3.17 are far higher for Ca and Mg, and except in Sawdust too low for K. It must be noted, however, that the analysis shown was for 'total extractable' amounts, whereas the Guernsey extraction technique is for 'available' amounts (Hallas, undated).

Differences in the media due to the fertilisation method were also evident (Table 3.17). All media receiving Jensen's solution had a low pH, due to use of the phosphoric acid, despite the fact that the water used had a pH value above 7, as recommended by Maas & Adamson (1980). Media which received ® Chemicult had a slightly lower pH than those in the Scottish treatment. The acidifying effect of ® Chemicult was recorded earlier (Experiment 12).

The average conductivity was not markedly different in the different fertilisation methods, but this was more related to the CEC of the media since the pots were leached before analysis.

Total extractable Ca was highest in those media receiving the Scottish treatment, due to the lime applied as pre-enrichment, although the same was not true for Mg. The average Mg levels were higher in Jensen's treatment, due to the high level of Mg in the sawdust. Potassium levels were highest in the Scottish treatment, and lowest in Jensen's.

The media analyses, although giving information on media and fertilisation, did not correlate well with plant yields in the different treatments. One exception was sawdust, which had a good pH value and high levels of most cations, and yielded well with ® Chemicult and Jensen's solution. It would appear that too much pre-enrichment occurred with this medium causing the Ca and Mg levels to be too high in the Scottish treatment.

TABLE 3.15 Analysis of the different media receiving different fertilisation treatments at the end of Experiment 14

Fertilisation Media	pH (KCl)	Sat. Moisture Content	Conductivity mS m^{-1}	Total Extractable (ppm) Ca	Mg	K	Na
SCOTTISH							
SB	5,0	332	94	226	92	168	176
LB	5,4	280	227	532	225	371	166
SD	6,2	506	165	790	207	494	535
SP	5,4	39	106	116	8	41	36
P	8,3	432	51	35	21	337	318
Mean	6,1	318	129	340	111	282	246
JENSEN							
SB	4,5	370	68	193	133	72	166
LB	4,8	181	175	532	133	170	215
SD	4,2	530	257	790	788	248	729
SP	5,0	34	109	116	16	27	21
P	5,8	201	29	35	7	47	77
Mean	4,9	263	128	289	215	113	242
CHEMICULT®							
SB	5,4	318	110	369	172	37	265
LB	5,4	273	156	344	207	224	271
SD	6,3	653	89	392	110	688	627
SP	6,6	26	88	17	8	11	12
P	7,0	422	82	211	76	115	567
Mean	5,7	338	105	267	115	215	348
MEDIA MEANS							
SB	5,0	340	91	263	132	92	202
LB	5,2	245	186	355	188	255	217
SD	5,6	563	170	736	368	477	630
SP	5,7	33	101	52	11	26	23
P	7,0	351	54	86	35	166	321

It was apparent that perlite was unsuitable for pre-enrichment because of its low CEC, which resulted in pre-enrichment fertilisers being leached out in the first three weeks. A similar situation existed in the sand:peat medium. These media, however, performed well when used with a complete nutriculture solution like Jensen's or ® Chemicult.

Table 3.15 also shows the saturation moisture content of the different media. It can be seen that this was highest in sawdust, slightly lower in perlite and small bark, then large bark and very low in sand:peat. These figures show the same trend as that for moisture retention (Table 3.10).

3.5.4 Conclusions The LB medium resulted in good yields and the greatest number of fruit. ® Chemicult fertilisation produced the highest yields and number of fruit. It must be noted that in the Jensen's modified solution the levels of N and Ca used were lower than recommended. Further, as previously stated, media and leaf analysis should be regularly carried out during experiments. Further research into pre-enrichment is necessary to determine the optimum amounts of Ca and Mg to add in conjunction with the inherent content of the media. Further research is also required on the optimum levels of N, P, K, Ca and Mg to use under local conditions and in different seasons.

The conclusion can also be reached that virtually any reasonable medium can perform as well as any other provided the physical properties (e.g. aeration, CEC) are suitable, and that the nutrition is balanced to suit the chemical properties and rate of decomposition of the medium. In the final analysis convenience and cost play a large role.

Total nutrient feeding resulted in better results than pre-enrichment in all media. Pre-enrichment was not as poor in media with a higher CEC (bark) indicating that less leaching had taken place in the long run. It has therefore become obvious that pre-enrichment should only be considered where the medium has a good CEC.

3.6 CUCUMBERS - COMPARISON OF THREE NUTRITION PROGRAMMES AND FIVE MEDIA (Experiment 15)

3.6.1 Aim A suitable alternative medium to local peat was also required for cucumbers. This experiment aimed to compare several locally available media, including one which had been used several times for cucumbers, in conjunction with pre-enrichment or total liquid feeding using Jensen's (1980) recommendations and a commercial product balanced to these levels.

3.6.2 Procedure Black plastic bags (15 ℓ) were filled with five different media and laid out in double rows at a spacing of 500 x 500 mm in the 30 m ® Gundle 'roll-up sides' tunnel.

Cucumber seeds (cv. Pepinex) were sown in milled bark in ® Speedling trays on 1980:10:01 and transplanted into the pots in the tunnel on 1980:10:15. First harvest was on 1980:11:05 and the trial was terminated on 1980:12:15, by which time treatment differences were evident.

The trial was laid out as a randomised blocks design with split plots and four replications. The whole plot factor was a comparison of three fertilisation methods:-

1. Pre-enrichment of the media according to Guernsey recommendations (Moorat, 1981), with the pre-enrichment fertilisers being as shown in Table 3.4 (Column 6). The daily nutrient solution application was as in Table 3.5, made up using urea, MAP and KNO_3 as recommended by Anon. (1979). The N:P:K concentrations were 170:40:280 ppm respectively.

2. Modified Jensen's nutriculture solution as in Table 3.14, except that the amount of $CaNO_3$ was increased so that there was 259 ppm N, and 330 ppm Ca as recommended in Table 3.3 by Ellis *et al.* (1974) and Jensen (1980). No pre-enrichment of the media took place.

3. ® Chemicult at 1,15 g ℓ^{-1} (Table 3.8), balanced with added $Ca(NO_3)_2$ (1,5 g ℓ^{-1}) and $MgSO_4$(0,5 g ℓ^{-1}) to give a final solution containing 194 ppm N (Table 1.2). No pre-enrichment of the media took place.

The split-plot factor included five different media with four plants per split plot. The five media were:-

1. Mushroom compost - a compost made from horse manure and wheat straw and used for two mushroom crops before being steam sterilised and discarded. The product also contains ± 10 per cent. local peat, which was used as a topping to improve mushroom sporulation. A nutrient analysis of the product is shown in Table 3.3.

2. Pine bark - from old *Pinus patula* trees, and milled through an 18 mm screen in a hammer-mill before composting, without added nutrients, for six weeks before use.

3. 'Milo' or 'filter press cake' (Wood, 1981) a by-product of the sugarcane industry, and with a nutrient analysis as shown in Table 3.3.

4. Umgeni River sand:local peat mixture (3:1).

5. A mixture, the same as in (4) but used by a local grower for five cucumber crops prior to inclusion in this trial, and hereafter referred to as 'old peat'.

Management and watering was according to normal procedures (3.2) but only main stem fruit were harvested, and the trial was terminated when the plants reached the overhead wire.

At each weekly harvest the fruit from each treatment was measured, both in length and diameter, and its mass determined. The fruit was then categorised into 4 classes based on length:-

CLASS 1	>400 mm length
CLASS 2	350-400 mm length
CLASS 3	300-350 mm length
CLASS 4	< 300 mm length.

3.6.3 Results and Discussion

Yield Overall yield was highly significantly best in Jensen's treatment, with the plants producing an average yield of 4,3 kg of fruit over the six week harvest period (Fig. 3.17a). The next best fertilisation treatment was ® Chemicult, which was significantly better (P 0,05) than the Guernsey treatment, which averaged only 2,1 kg of fruit.

These differences appear to be best explained by examining the N content of the different nutrient solutions which were 259, 194 and 170 ppm respectively in the Jensen, ® Chemicult and Guernsey treatments. The K content was also higher in the Guernsey treatment, a fact which has been reported by Allen (1980) as being detrimental to cucumbers. Latest recommendations are that K levels should be 30 to 50 per cent. lower than those recommended for tomatoes in the U.K. i.e. 150-200 ppm vs 300-350 ppm (Anon., 1980d).

Media differences were also evident (Fig. 3.17a) with pine bark giving a significantly higher yield than sand:peat, and a highly significantly higher yield than old peat. Both milo and mushroom compost resulted in significantly higher yields than old peat, but

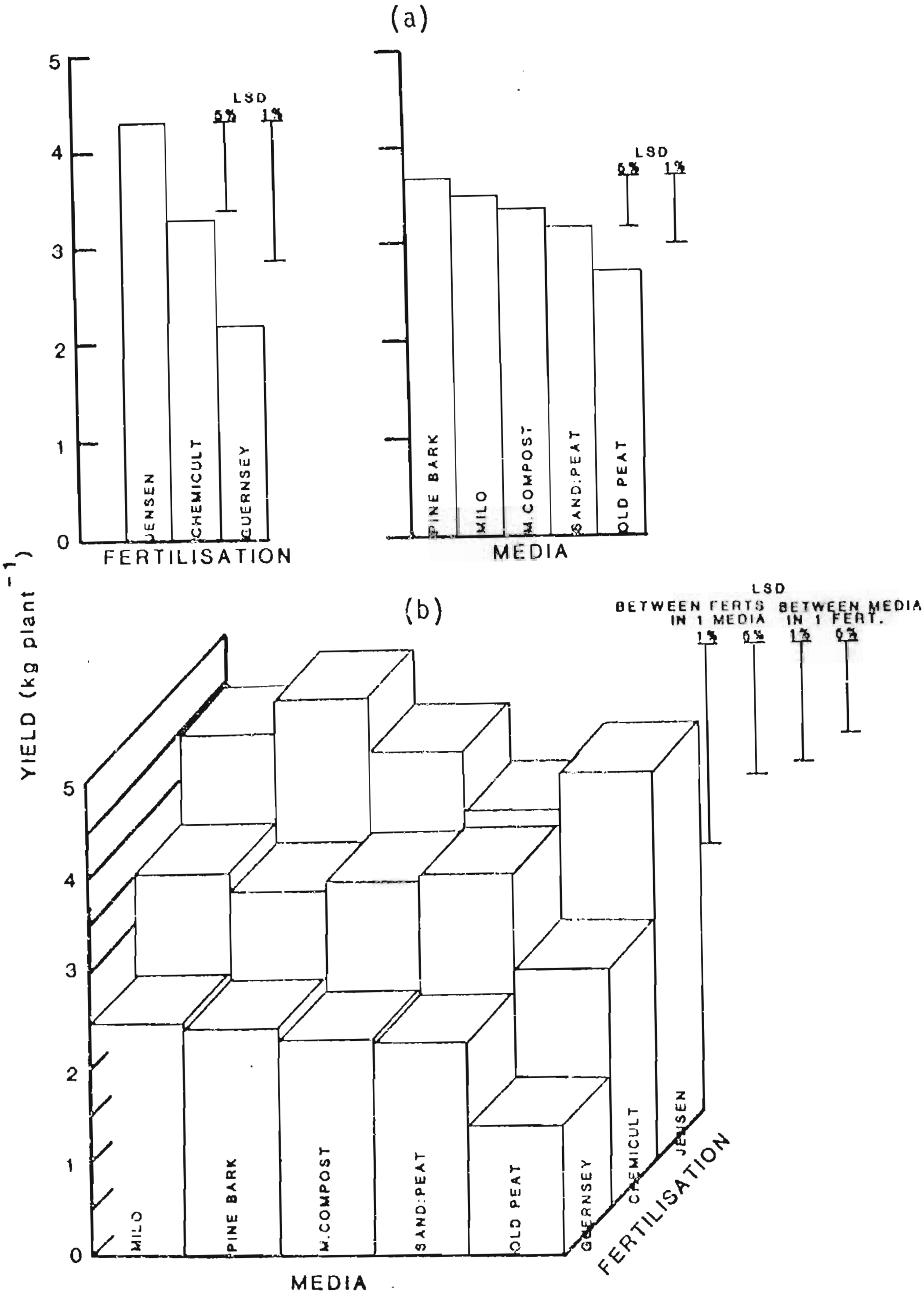


Fig. 3.17 Yield from cucumber plants grown in different media and receiving different fertilisation treatments

a) main effects

b) individual treatment effects

were not significantly different from pine bark. It was notable that the three media which had relatively high initial nutrient contents resulted in the highest yields with a complete nutrient solution, but with pre-enrichment performed badly. This indicated that medium nutrient levels were too high for cucumbers. This would need to be confirmed by medium and leaf analysis. As with tomatoes further research into pre-enrichment levels of K, Ca and Mg is necessary in order for the pre-enrichment system to be used successfully in cucumbers.

There was some interaction between media and fertilisation, the most notable being that the Jensen treatment highly significantly improved yields in the old peat (Fig. 3.17b). In all media Jensen's solution produced highly significantly better yields than the Guernsey treatment, and significantly better results than ® Chemicult, except in the sand-peat where ® Chemicult gave equally good yields, On average the single best treatment was the Jensen/pine bark combination, although this was not significantly different from the Jensen/milo and Jensen/mushroom compost combination

Within the Guernsey and ® Chemicult treatments the different media gave very similar results, except the old peat which was significantly the worst medium (Fig. 3.17b). As in previous experiments these yields were a relatively short harvest period, in comparison to long season crops overseas.

Number of fruit per plant The mean number of fruit per plant was greatest in the highest yielding fertilisation treatment (Fig. 3.18a). Amongst the media the use of pine bark and milo resulted in significantly more fruit per plant than peat:sand and old peat.

Examination of the individual treatment combinations (Fig. 3.18b) shows that the Jensen treatment improved the number of fruit per plant in old peat so that it was not significantly different from the best treatment.

Mean fruit mass There were no significant differences in mean fruit mass between any of the treatments. There was a trend for ® Chemicult to result in slightly heavier fruit, presumably because there were fewer fruit per plant.

Fruit size The proportion of class 4 fruit (smallest) varied between 3 and 6 per cent. without any consistent treatment differences (Fig. 3.19).

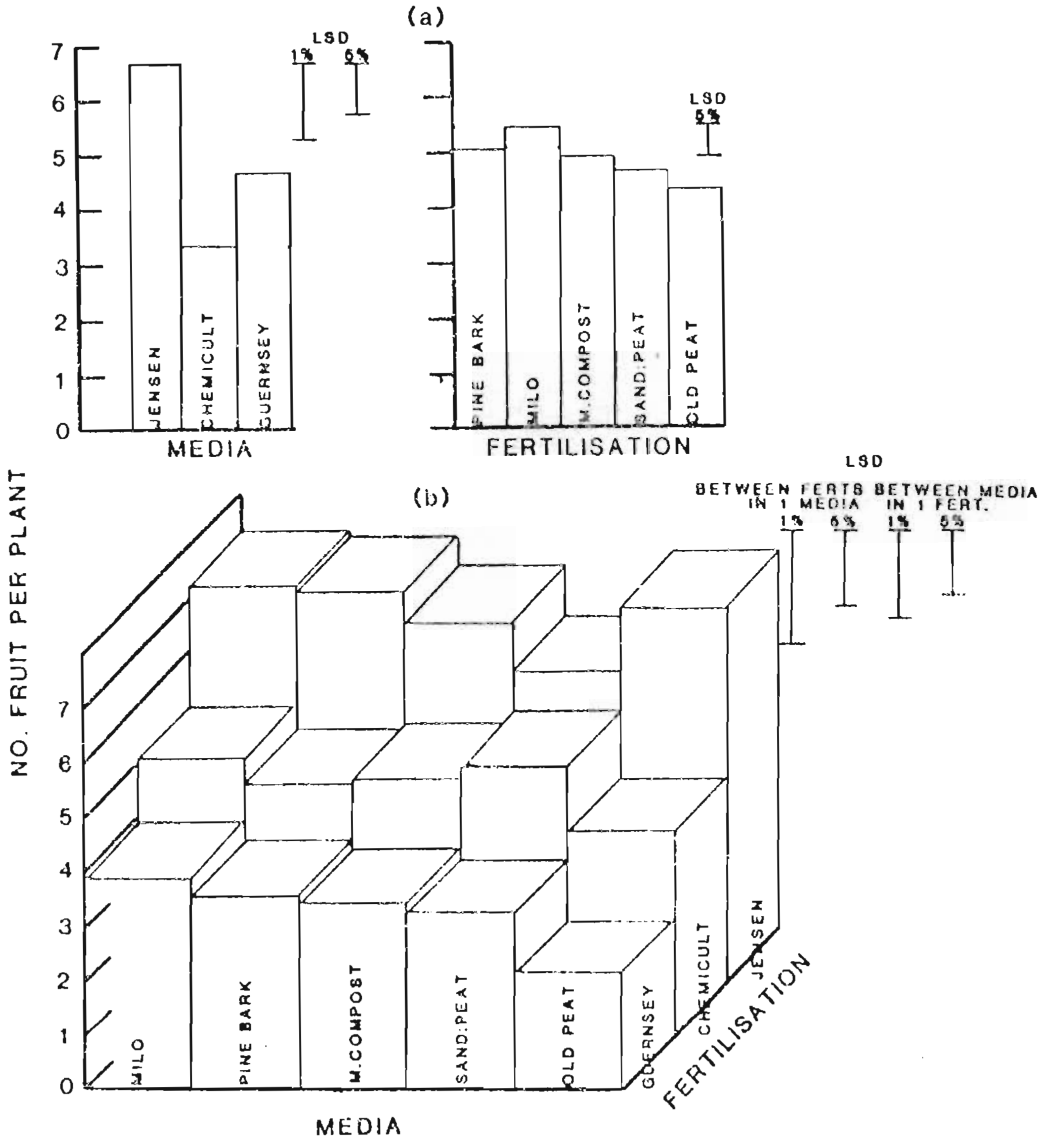


Fig. 3.18 Mean no. fruit per cucumber plant grown in different media and receiving different fertilisation treatments

a) main effects

b) individual treatment effects

The proportion of Class 3 fruit was highest in the worst yielding treatment viz. Guernsey/old peat. In pine bark and mushroom compost only between 10 and 20 per cent. of the fruit were in this size class. The average diameter of fruit in this size class was 51-52 mm with no significant differences between treatments. The percentage of Class 2 fruit was fairly uniform, and not significantly different in all treatments (Fig. 3.19), averaging from 30 to 50 per cent. Within this length class, fruit from Jensen's treatment had a significantly smaller fruit diameter (Fig. 3.20a and b) than in the Guernsey treatment. The trend was evident, therefore, that Jensen's treatment resulted in more, longer and thinner fruit.

Best quality fruit (Class 1) was produced in significantly greater proportions in mushroom compost, pine bark and sand:peat as compared to milo and old peat (Fig. 3.19). In all media, except milo, there were also significantly fewer Class 1 fruit in the Guernsey treatment. The two best individual treatments were ® Chemicult with pine bark and mushroom compost, which resulted in over 50 per cent. Class 1 fruit.

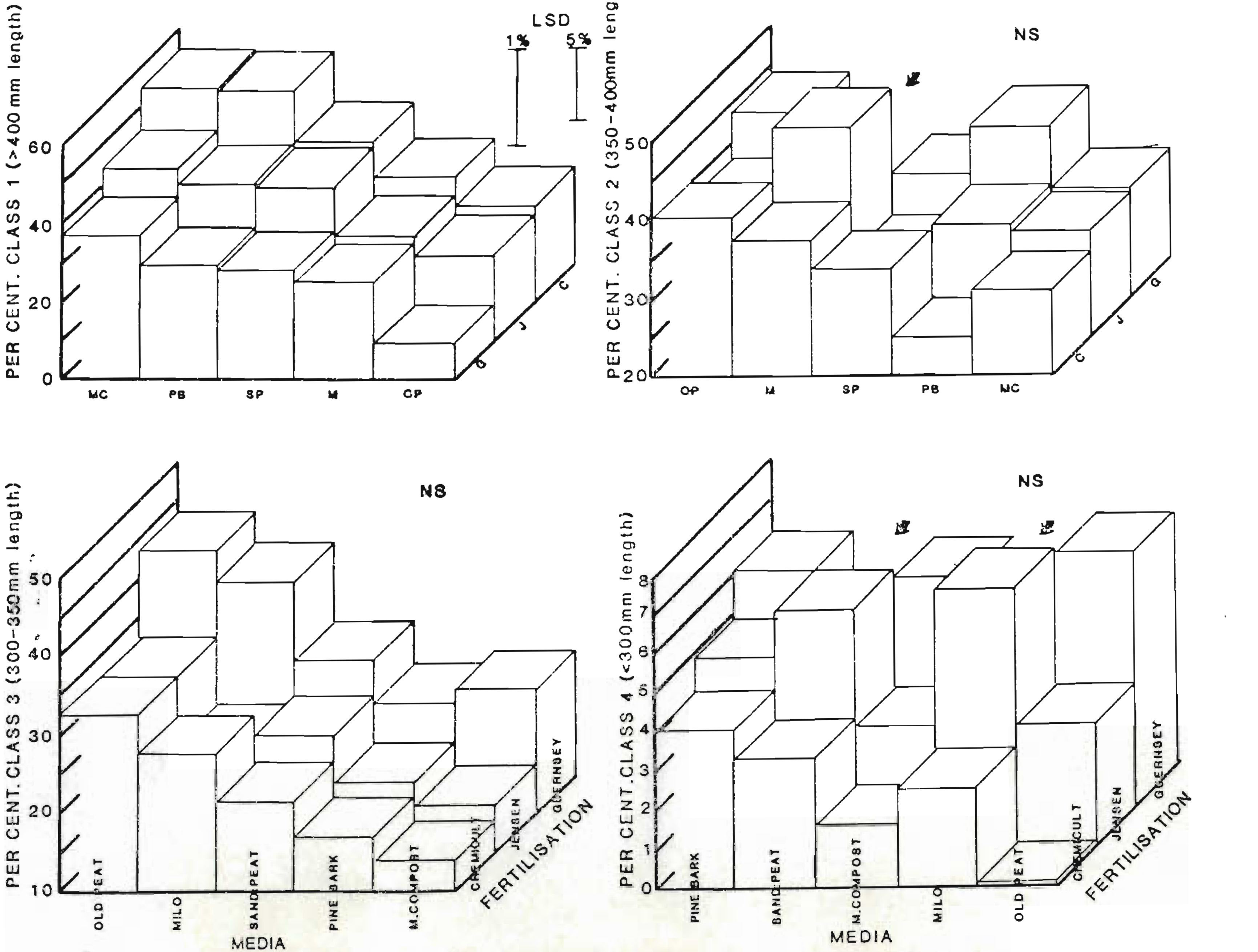
Class 1 fruit in the ® Chemicult treatment was notably, but not significantly, narrower (Fig. 3.21), having a diameter of 52-53 mm, compared to fruit in the Guernsey/pine bark which had an average diameter of 62 mm.

In the above discussion it must be noted that time from anthesis can affect fruit size at harvest in cucumbers. Although at each weekly harvest fruit of a similar stage of maturity was harvested as far as possible,fruit size measurements are obviously somewhat subjective.

3.6.4 Conclusions All the media tested gave equally good results on average except for a lower yield in used sand:peat. On average pine bark was the best medium although this was not significant.

Total liquid feeding was superior to the Guernsey pre-enrichment used. Jensen's solution with 259 ppm N resulted in better yields than an adjusted commercial mixture containing 194 ppm N.

The highest yielding single treatment combination was Jensen's nutrient solution with pine bark or mushroom compost. These treatments resulted in the most fruit per plant with 50 per cent. Class 1 fruit which, on average, had a smaller diameter.



PER CENT. CLASS 1 (>400 mm length)
0
20
40
60
MC
PB
SP
M
CP
G
J
C
LSD
1%
5%
PER CENT. CLASS 2 (350-400mm length)
20
30
40
50
NS
OP
M
SP
PB
MC
C
J
G
PER CENT. CLASS 3 (300-350mm length)
10
20
30
40
50
NS
OLD PEAT
MILO
SAND PEAT
PINE BARK
M.COMPOST
CHEMICULT
JENSEN
GUERNSEY
MEDIA
FERTILISATION
PER CENT. CLASS 4 (<300mm length)
0
1
2
3
4
5
6
7
8
NS
PINE BARK
SAND PEAT
M.COMPOST
MILO
OLD PEAT
CHEMICULT
JENSEN
GUERNSEY
MEDIA
FERTILISATION

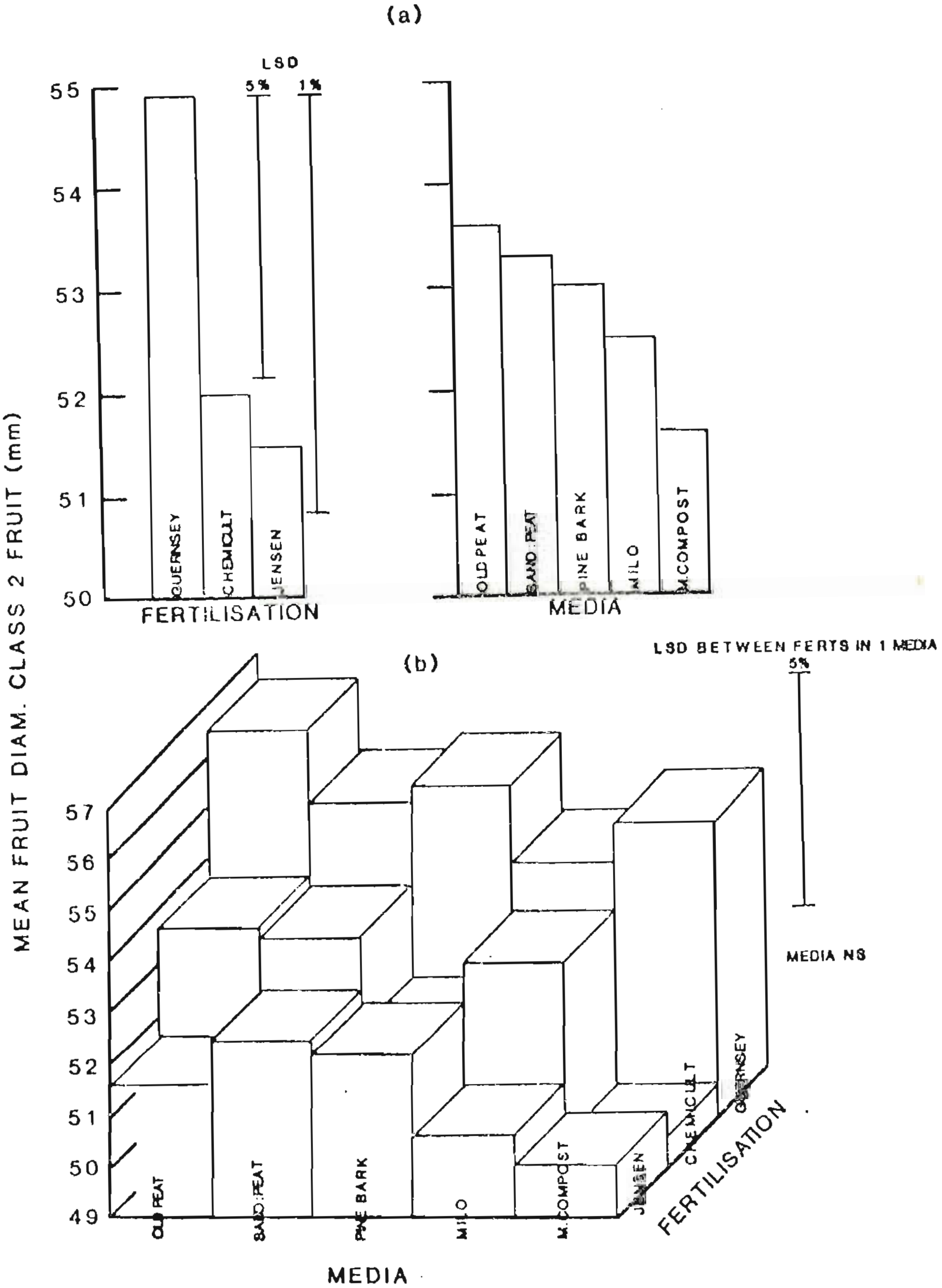


Fig. 3.20 Mean fruit diameter of Class 2 fruit on cucumber plants grown in different media and receiving different fertilisation treatments

a) main effects

b) individual treatment effects

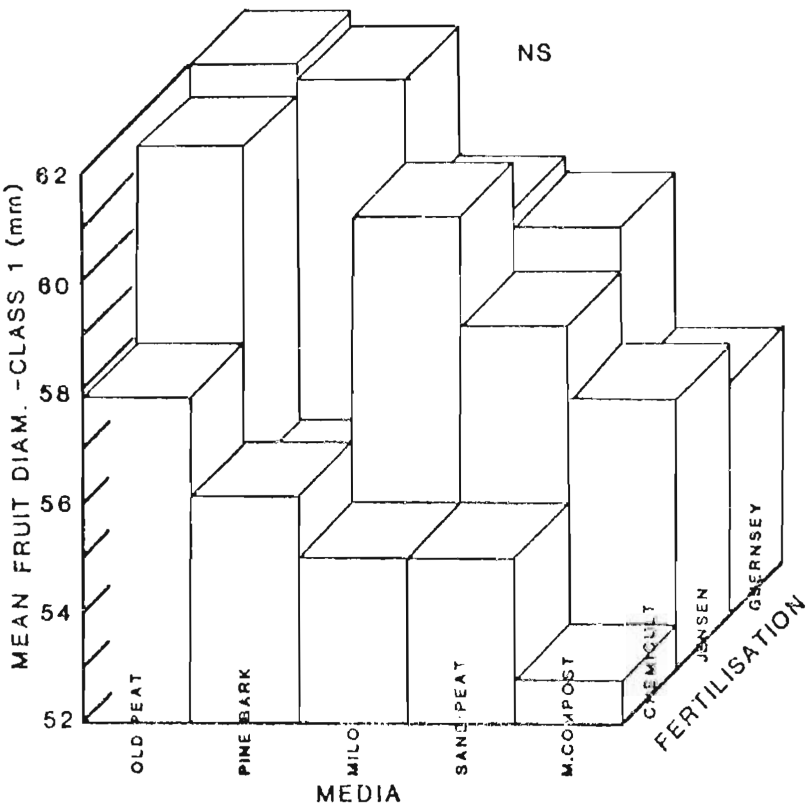


Fig. 3.21 Mean fruit diameter of Class 1 fruit in different treatment combinations

3.8 GENERAL DISCUSSION AND CONCLUSIONS (Chapter 3)

The nutrient solution recommendations of Ellis *et al.* (1974) and Jensen (1980) have proved suitable under local conditions for tomatoes and cucumbers and can be recommended to growers. Although no significant differences in yield were formed where fairly wide ranges of N and K especially were used for tomatoes it is the author's opinion that commercial mixtures should be balanced with added nutrients to approximate Jensen's formula. Thus ® Chemicult, at the rates shown in Table 3.16, is low in N, Ca and Mg for cucumbers by comparison, and ® Aquapon is almost the same as recommendations. These rates (Table 3.16) are not, however, the recommended rates on the labels of the commercial products, but are suggested by the author for cucumber growing, and are used in practice. Where an element is at a lower level than recommended straight fertilisers can be added to the commercial mix e.g. $Ca(NO_3)_2$ and $MgNO_3$ to ® Chemicult in Table 3.16.

The cost of the different nutrient solutions, balanced to approximately equal concentrations for cucumbers (Table 3.16), shows that it is cheaper for a grower to mix his own solution from straight chemicals all of which are now available in South Africa. Jensen's mix (Table 3.14) for cucumbers cost R1,20 1 000 ℓ^{-1} (Table 3.16) in comparison to the cheapest commercial product balanced to the same nutrient level which was ® Chemicult at R1,51 1 000 ℓ^{-1}. The most expensive was ® Aquafert at R2.39 1 000 ℓ^{-1}. Further research similar to that of Fontes (1980) must be carried out to work out least cost combinations of fertilisers in solution for local growers.

Where a medium had a relatively good CEC e.g. peat, bark, then the pre-enrichment system tended to give better results in tomatoes. In cucumbers a complete nutrient solution without pre-enrichment has given better results. This appears to be due to a too high salt concentration where pre-enrichment was applied to a medium which naturally had a high level of Ca, Mg and K. A pre-plant medium analysis with supplementary nutrients added to bring the medium levels up to recommended amounts is essential, especially for cucumbers.

Further research is required on how much pre-enrichment should be added to bark and sawdust. In certain crops Gartner's (1981) assertion that no Ca and Mg should be added appears to be correct. Differences between hardwood and softwood barks need to be examined in more detail.

Table 3.16 The costs (cents) and chemical composition (mg ℓ^{-1}) when diluted of commercial products suitable complete nutrient solution feeding programmes, in comparison to Jensen's (1980) recomendations for cucumbers

Element	Recommended Jensen (1980) (cucumbers) Table 3.14	COMMERCIAL PRODUCTS AND RECOMMENDED RATES			
		Ⓟ Chemicult 1,15 g ℓ^{-1}	Ⓟ Aquapon (AQ) 3,56 ml ℓ^{-1} AQ.1 +1,34 ml ℓ^{-1} AQ.2	Ⓟ Aquafert (AF) 2 ml ℓ^{-1} AF 1 +2 ml ℓ^{-1} AF 2	Ⓟ Speedling 1,23 g ℓ^{-1}
N	259	75	260	180	112
P	36	31	26	42	32
K	156	150	150	210	150
Ca	330	86	256	120	118
Mg	49	29	68	30	32
S	6,5	81	52	2,8	54
Fe	2,5	1,73	2,68	3,4	3,69
Mn	0,62	0,28	0,98	1,4	0,3
B	0,44	0,28	1,0	1,3	1,3
Cu	0,05	0,23	0,05	0,08	0,06
Zn	0,09	0,06	0,24	0,02	0,33
Mo	0,03	0,01	0,05	0,10	1,23
		ADDITIVES REQUIRED TO APPROXIMATE JENSEN (1980)			
		$Ca(NO_3)_2$ 1,0 g ℓ^{-1} Mg NO_3 0,25 g ℓ^{-1}	Nil	$Ca(NO_3)_2$ 0,5 g ℓ^{-1}	$Ca(NO_3)_2$ 0,73 g ℓ^{-1}
		TOTAL COST 1 000 ℓ^{-1} (January,1982)			
		CHEM. 79,4 $Ca(NO_3)_2$ 46,0 $MgNO_3$ 26,0	AQ 1 135,3 AQ 2 50,9	AF 1 108,0 AF 2 108,0 $Ca(NO_3)_2$ 23,0	SPEED. 145,0 $Ca(NO_3)_2$ 33,6
	119,5	151,4	186,2	239,0	178,6

In comparing the two systems for tomatoes it was notable that earlier flowering, flowering at a lower first truss height, and higher early yield was associated with pre-enrichment, consistent with European findings (Moorat, 1981).

Cost wise the pre-enrichment system is cheaper. Pre-enrichment costs R1,60 m^{-3} (Table 3.17) or 1,6 cents per 10 ℓ pot for tomatoes, which is extremely cheap. The nutrient solution for tomatoes using this method (Table 3.18) costs from 55 cents 1 000 ℓ^{-1} (Scottish) to 78 cents 1 000 ℓ^{-1} (Guernsey) in comparison to Jensen's at 94 cents 1 000 ℓ^{-1}.

In the author's opinion the pre-enrichment system is the easier for producers to use as only three fertilisers, which do not precipitate when mixed together are used in the nutrient solution. In comparison precipitation can be a problem in a complete nutrient mix, and more expertise is required. In certain cases e.g. Experiment 13, tomato yields were better in a medium with a high initial nutrient level (mushroom compost) which was watered with a complete nutrient solution. This indicates that pre-enrichment plus a complete nutrient solution may have advantages in certain circumstances e.g. long term crops.

In all cases medium and plant analysis, and continuous salinity monitoring are essential to assess the nutrient status of the crop, and facilities for local growers need to be established.

With respect to media, it has been shown that bark, and sawdust, are suitable substitutes for local peat. Two commercial companies have recently started processing bark in the Natal area for growers of tomatoes and cucumbers, and for the raising of seedlings. Mushroom compost has also produced good results.

Results have shown that most media can be used successfully for tomato and cucumber production provided that management of the medium is correct, and the physical properties are reasonable. This management must include a knowledge of the physical and chemical composition of the medium. If there is little CEC e.g. sand or perlite, then best results have been obtained where a complete nutrient solution was used. Media with a relatively good CEC are suitable for pre-enrichment.

TABLE 3.17 Costs of fertiliser for pre-enrichment using the Guernsey and Scottish recommendations, and the fertiliser prices shown in Table 3.9

Ingredient	Scottish		Guernsey	
	kg m^{-3}	Cost c m^{-3}	kg m^{-3}	Cost c m^{-3}
KNO_3	0,541	18,9	0,88	30,8
LAN	1,468	31,4		
Singlesupers	1,313	14,8	1,75	19,8
Calcitic Lime	5,0	14,3		
Dolomitic Lime	5,0	14,3	5,35	15,3
FRIT 504	0,3	57,6	0,4	76,8
$FeSO_4$	0,2	8,4		
K_2SO_4			0,44	10,8
Ureaformaldehyde			0,44	
TOTALS	cents m^{-3}	159,7		154,5
	cents 10 ℓ^{-1}	1,60		1,55

Costs of the different media are compared in Table 3.19. Note that certain media which may be re-used several times may be cheaper than shown when averaged over several crops, as pointed out by Maree (1981c). Table 3.19 shows the excessively high price of imported peats. Vermiculite, perlite and polystyrene are the next highest priced media. Local peat, bark and mushroom compost are similarly priced at ± 16 c per plant in tomatoes (10 ℓ), but are not as cheap as softwood sawdusts which at present can be obtained for the cost of cartage, estimated at R5,00 m^{-3}.

TABLE 3.18 Chemical costs (cents) for different nutrient solutions used in experiments in Chapter 3

Fertiliser	Guernsey Table 3.11 Tomatoes	Jensen Table 3.12 Tomatoes	Jensen Table 3.14 Tomatoes	Scottish Table 3.13 Tomatoes	Jensen Table 3.14 Cucumbers
	TREATMENT				
$Ca(NO_3)_2$	13,8	42,7	16,9		78,6
KNO_3	24,9	6,2	14,7	12	14,7
Urea	2,2			17	
MAP	37,4			26	
K_2SO_4		7,2			
$MgSO_4$		13,9	13,6		13,6
H_3PO_4		22,2	11,5		11,5
$FeCl_3$		0,73	0,73		0,73
$MnSO_4$		0,07	0,07		0,07
H_3BO_4		0,12	0,12		0,12
$ZnSO_4$		0,03	0,03		0,03
$CuSO_4$		0,01	0,01		0,01
$(NH_4)_6 Mo_7O_4$		0,09	0,09		0,09
TOTAL COST/1 000 ℓ	78,3	94,2	57,8	55	119,5
ELEMENT (ppm)					
N	217	137	113	296	259
P	71	63	36	50	36
K	262	181	156	120	156
Ca	57	161	70		330
Mg		49	49		49
Fe		2,5	2,5		2,5
Mn		0,28	0,28		0,28
B		0,29	0,29		0,29
Cu		0,08	0,08		0,08
Zn		0,05	0,05		0,05
Mo		0,03	0,03		0,03

Sand is also relatively cheap and mixtures with sand have proved popular with growers as this reduces the cost of the local peat or bark. Adding an organic media to sand improves its water holding capacity and makes management easier where sophisticated watering systems are not in use, and unskilled labour is involved.

TABLE 3.19 Cost of individual media and mixtures used in experiments in Chapter 3

	Cost (R m^{-3})	Cost per 10 ℓ pot (Tomatoes) (Cents)	Cost per 13 ℓ pot (Cucumbers) (Cents)
1 Irish peat	147,1	147	191,1
2 Local peat	19,0	19	24,7
3 Vermiculite	30,0	30	39
4 Perlite	49,5	49,5	64,4
5 Sand	8,8	8,9	11,6
6 Polystyrene	60,0	60	78,0
7 Bark (milled)	16,0	16	20,8
8 Sawdust	5,0	5	6,5
9 Mushroom compost	16,0	16	20,8
Mixtures			
2 + 3 (1:1)		24,5	31,9
5 + 2 (2:1)		12,2	15,9
5 + 2 (3:1)		11,4	14,8
2 + 4 (1:1)		34,5	44,9
2 + 6 (1:1)		39,5	51,4
1 + 3 (1:1)		88,5	115,1
9 + 3 (1:1)		23,0	29,9

The excellent results of Maree (1981c) with fresh sawdust, based on the system of Maas & Adamson (1980) makes this a medium which should be examined in more detail. Perlite has also given good results but appears to be too expensive in comparison to cheaper organic materials. Yields were better in a coarser grade product, as found by Wilson (1980a), which unfortunately is also more expensive than finer grades (Anon., undated c).

Re-usability of a medium is also an important aspect to consider, and Jensen's (1975,1980) reasoning that sand holds an advantage over organic media in this respect holds true. Local growers have re-used sand:peat mixtures up to six times, although as has been shown here yields may decrease, presumably due to salt build up. Thorough leaching and sterilisation of media between crops is recommended together with chemical analysis. Results also showed that where a complete nutrient solution was used with an old medium yields were still reasonable. Other inorganic media have also been re-used successfully several times e.g. rockwool (Maree, 1981a). In vermiculite, however, the lattices collapse, and topping up with new medium is required, thus increasing the cost.

Of the organic materials the rate of composting is slowest in pine bark (Gartner, 1981) followed by hardwood bark and sawdust. Adamson (1977) re-uses sawdust twice in one season. There has only recently been interest in Europe in re-using peat modules to reduce costs, and this has been done with success (Johnstone, 1980; Moorat, 1981).

In conclusion local growers are presently recommended to use bark which has been pre-enriched for tomatoes, and without enrichment using a complete nutrient solution, with the nutrient levels recommended by Jensen (1980), for cucumbers.

OVERALL DISCUSSION AND CONCLUSIONS

Soilless cultivation of tomatoes and cucumbers under protection in Natal and in other parts of South Africa has advanced considerably since the first tunnels were erected nearly 10 years ago. Initially there was a somewhat hasty erection of tunnels in different areas during a seller's market, based on glossy photographs and high-power advertising. This was followed by a period when many empty abandoned 'shells' dotted the countryside. A lack of grower and research knowledge was the major problem. Adverse climate, yield failure and marketing also combined to cause financial problems for growers.

The importation of more suitable cultivars by seedsmen, and increased research output, resulted in a small but stable industry. A few persistent and successful growers became established in selected climatic areas. With better advice available and the establishment of an Association for growers, the industry recently entered an expansion phase.

Climatic factors play an important role. The most successful growers, and the back-up research units, are in marginal climates where outside growers are sometimes adversely affected by weather. The modified tunnel environment enables a crop to grow during what is then a high priced period for tomatoes and cucumbers. Pietermaritzburg in Natal, and Stellenbosch in the Cape, are two such areas around which tunnel growing has gained a secure foothold, perhaps significantly also because research advice is easily available.

Research reported in this thesis, and by Maree at Stellenbosch, has shown that in summer, maximum irradiance levels are in excess of 1000 W m^{-2}. This may be more of a problem in the Cape which experiences a Mediterranean climate and has little cloud cover in summer. In Natal, frequent cloud cover reduces the total radiant density. Levels, however, are still far higher than in Europe in summer (25 MJ m^{-2} versus 16 MJ m^{-2}). Associated with this are very high tunnel temperatures with associated fruit set and yield problems.

These conditions have resulted in interest in shading, both to reduce tunnel temperatures and radiation intensity. The amount and timing of shading, however, requires further research. Hammes *et al.* (1980) showed that 60 per cent reduced tomato yields in summer. Cucumber dry matter yields in Pietermaritzburg were reduced at 300 W m^{-2} under 30 per cent shade cloth, as compared with 450 W m^{-2} under plastic alone.

Photosynthesis data in the literature sugg est that 700 W m^{-2} may be optimum for field cucumbers (Sale, 1977), but that lower levels of 400 W m^{-2} are sufficient for tomatoes (Calvert, 1973). Optimum irradiation intensities for photosynthesis in specific tomato and cucumber cultivars should be studied under local conditions. At the same time experiments with different degrees of shading at different times of the year must be carried out, and especially in the hotter months. Several local growers have already erected shade houses in preference to plastic tunnels for tomatoes, using nutriculture systems in summer.

It has also been shown that spacing and layout affect radiation interception. Further research is justified to determine the best plant arrangement and trellising system (e.g. single rows or double rows) in respect of yield, quality, management and disease control in Natal. To date trellising systems have been poorly researched. Most growers prefer short term crops (plants topped at the wire) as disease and insect control are serious problems locally.

Winter heating of tunnels to maintain optimum growth temperatures for tomatoes and cucumbers has generally not succeeded in South Africa, mainly for financial reasons. The price structure, in tomatoes especially, does not justify the investment. Outside growers in frost-free areas can compete with very low costs. The greenhouse cucumber price, however, has improved recently. With no chance of outside competition, winter heating may now be a proposition for this crop.

Polystyrene seedling trays have been used successfully for seedling establishment in a wide range of media. Recently, however, pine bark milled through a 6 mm screen has given excellent results. Although some growers still prefer imported Canadian and Finnish peats at higher costs, research has shown no justification for this in terms of seedling growth, and the formation of a compact root plug.

More research is required on the optimum particle size distribution in bark. Air capacity, water holding capacity and CEC need to be determined in bark which as been milled through different mesh screens. These properties must then be related to seedling growth. A difference may also exist between bark which has been milled or sieved to a particular particle size.

Best tomato seedling growth was obtained in pre-enriched bark which was watered with a total nutrient solution containing 184ppm N, 27ppm P and 130ppm K. Cucumber seedlings grew better without pre-enrichment, but with the same nutrient solution. Future experiments must determine more accurately the optimum and changing levels of N, P and K in the nutrient solution. They must also test whether a total nutrient solution is better than a solution containing only N or K, or N and P, N and K or N, P and K in a pre-enriched medium. Further, it is also necessary to know whether the levels or N, P and K should be changed just before transplanting to harden seedlings.

Tomato seedlings were not grown to first flowering to measure the height and number of flowers in the first truss, nor were they critically compared with seedlings grown in small pots. Where earliness in spring is important this comparision would be worthwhile.

A wide range of media were also tested for tomato and cucumber growing after transplanting. Although good results were obtained earlier in local peat and sand, growers were forced to seek an alternative as the supply of local peat diminished. Of a range of locally obtainable media, best results have been obtained with pine bark. Other media such as sawdust have also proved adequate provided the nutrition programme is adjusted to overcome the increased nitrogen demand.

A uniform nutrition programme was always used in medium comparison experiments. Under these programmes pine bark generally performed better than sawdust. Improved nutrition/media results could be obtained using smaller plots with individual nutrition programmes, as used by Paterson & Hall (1981) and Wilson (1981).

As in seedlings, the particle size distribution in bark and sawdust must be further researched. Thus far,larger particle mixes have been best in tomatoes and cucumbers. As shown by Brown & Pokorny (1975) these have a higher CEC and better aeration, but lower water holding capacity. These characteristics need to be determined for sawdust.

The overall choice of medium, providing that its physical characteristics are suitable, then depends mainly on local availability, price and reusability. Nutrition should then be adjusted accordingly.

The CEC of the medium is an important consideration when choosing the type of management and equipment to use. The simplest system is to use a medium with sufficient CEC for pre-enrichment to be feasible. To date this has worked better with tomatoes than cucumbers. In cucumbers better results were obtained with a total nutrient solution based on Jensen (1980). Further research to overcome this problem is being undertaken on the level of pre-enrichement for cucumbers.

Where a medium has little or no CEC, e.g. sand, perlite, a complete nutrient solution system must be considered. This requires greater management, more technical knowledge and more equipment. In terms of nutrient cost per 1 000ℓ of solution this system is also the more expensive.

The levels of the specific nutrients in Jensen's solution have worked well for tomatoes and cucumbers in Natal, as have European recommendations. The main difference lies in the levels of potassium for tomatoes. Although the lower levels in Jensen's recommendation result in equally good yields there may be a case for higher levels to improve keeping quality, as recommended by European workers.

Commercially available total nutrient mixtures have proved suitable for cucumber and tomato growing. These contain different percentage nutrient amounts, and at recommended rates contain different levels of the major nutrients. Preferably they should be balanced with added nutrients so that the final solution approximates Jensen's recommendations.

In pre-enrichment comparisons Wilson's (1981) recommendations for bark have also proved suitable. Some refinements for local conditions could be suggested by further research, especially where Fe, Mn and Mg deficiencies have occurred during later stages of growth.

The nutrition research in this thesis could have been more meaningful had leaf and medium analysis facilities been available at the time. Generall growers in Natal require more technical back-up, and facilities for leaf and medium analysis must be provided. This, with constant conductivity monitorin would improve their management capabilities considerably.

In conclusion, research has shown that tomatoes and cucumbers can be grown successfully in areas with mild winter frosts, using nutriculture methods in tunnels which provide a limited form of climate control. Good management of the crop environment, emphasizing ventilation aided by improved tunnel designs e.g. roll up sides, can give good yields. This has resulted in a now firmly established, and presently expanding, protected environment vegetable industry. Further, bark as a growing medium is now being processed commercially by two local companies and will soon be marketed countrywide.

The research reported here has reflected changing conditions and needs, and varying economic considerations. Tunnel growing is a high-technology, high risk, intensive farming enterprise which must respond quickly to changin circumstances. The author is fully aware that this will continue to be the case, and today's recommendations will inevitably soon be obsolete or inadequate. Although a measure of "responding to brush fires" has been involved in his research, underlying principles have nevertheless been clearly established and will serve as a sound foundation for future work.

SUMMARY

Research into aspects of tomato and cucumber production under protection in Natal has shown that good crops can be obtained using soilless media and nutriculture methods.

Tomato and cucumber seedlings were grown in polystyrene seedling trays with cone shaped cavities. A standard tray (675 x 343 mm) with 72 cavities resulted in better seedling growth than 128 and 228 cavities per tray. Seedling growth was reduced in the smallest cavities, but was acceptable in the 128 trays considering cost of media and transport, provided the seedlings were not left too long in the trays.

Seedlings grown in these trays in local peat adjusted to pH 6,3 grew better than in local peat:vermiculite, or vermiculite only adjusted to the same pH. In comparing different commercially formulated media with local peat, better seedlings were obtained in Finnish and Canadian peat which was pH stabilised and pre-enriched. Subsequently, pine bark milled through a 6 mm screen and with added nutrients gave equally good results as the imported peats.

Commercially available complete nutrient solutions watered onto seedlings in these media were equally good provided that they were adjusted to contain equal levels of N, P and K. At label recommendations ® Aquapon was better than ® Chemicult and ® Speedling. Best results were obtained where a nutrient solution containing 184 ppm N, 27 ppm P and 130 ppm K was used at every watering. Applying the same total amount of nutrient, but only on alternate days with water only in between, or applying solids once a week was not as good as the best treatment.

For growing tomatoes and cucumbers optimum temperature recommendations worldwide are 18-23/15-18 ^{o}C (day/night) and 21/19 ^{o}C respectively. In plastic tunnels in Natal temperatures ranging from 1 to 30 ^{o}C, and from 18-40 ^{o}C were measured in winter and summer respectively.

Associated rooting medium temperatures in pots varied from a minimum of 6 ^{o}C to a maximum of 15 ^{o}C in winter, rising to 24 ^{o}C on the warm northern side of the E-W orientated tunnel. In summer these temperatures fluctuated between 18 and 28 ^{o}C. Although recommended temperatures for tomatoes are 23 ^{o}C plants still grew and yielded relatively well in spring, summer and autumn. Fruit set was a problem in winter.

Differences in the temperatures of different potting media were also recorded. Peat:sand mixtures became the warmest during the day, but cooled to a greater extent than other media at night. Mixtures with good insulative properties e.g. vermiculite, were cooler in the day, but remained relatively warmer at night.

Irradiance levels measured in summer were typically 1 000 W m^{-2}, reducing to 600 W m^{-2} under plastic. At a 600 x 400 mm spacing in tomatoes 100 - 200 W m^{-2} reached the lowest canopy levels compared with only 50 W m^{-2} at a spacing of 300 x 200 mm. In autumn/winter, outside irradiance levels were 700 W m^{-2}, reducing to 450 W m^{-2} under plastic, and to 300 W m^{-2} under a 30 per cent. shadecloth inside the plastic. At these irradiance levels cucumber plants grew taller and had a larger leaf area, but accumulated less total dry matter than unshaded plants.

Cucumber fruit growth curves were typically sigmoid shaped and were affected by leaf area and temperature. Plants growing at 22/17 ^{O}C produced larger fruit than those growing at 18/15 ^{O}C with the same leaf area. A leaf area of 0,6475 m^2 resulted in larger fruit than 0,2625 m^2.

Spacing trials with tomatoes showed that the yield was 0,5 kg lower per plant at 0,2 m between plants compared with 0,4 m. Although yield per square meter was higher at the close spacing, fruit size was smaller, and management and disease control were problematical. Thus an overall population of 2,7-3,1 plants m^{-2} was considered optimum. In cucumbers a spacing of 0,5 m x 0,5 m was considered optimum in a double row system.

An examination of volume of medium in individual black plastic bags indicated that 10 ℓ per plant was optimum for tomatoes and 13 ℓ per plant for cucumbers. In Europe 13 ℓ is used for both, although there is a trend to use a larger volume for cucumbers.

A wide range of media were tested for tomatoes and cucumbers grown in containers. In early trials local peat:sand resulted in equally good yields as imported peat:sand, where such plants were watered with a total nutrient solution. Sand, perlite and vermiculite were not as good.

A comparison between the Guernsey pre-enrichemnt system and Jensen's Arizona nutriculture system with different media indicated that tomato yields were highest on average in pre-enriched local peat:sand mixtures. Mushroom compost:vermiculite also worked well, presumably due to the initially high nutrient status of the mushroom compost. In this particular experiment the Guernsey treatment had higher levels of N (217 ppm versus 137 ppm) and K (262 ppm versus 181 ppm) than the modified Jensen's solution used.

A further trial compared a Scottish pre-enrichment recommendation for bark with Jensen's solution and a commercial product. Tomato yields were, on average, equally good with ® Chemicult and Jensen's solution, which were better than the Scottish pre-enrichment system. This lower yield in the pre-enrichment treatment was a result of low yields in the media which had little CEC, resulting in all the pre-enrichment being leached out early on. Such media, however, were equally good where a total nutrient solution was applied. Of the media tested pine bark resulted in higher yields than local peat:sand, sawdust and perlite.

Similar trials with cucumbers indicated that a Jensen's solution with 260 ppm N resulted in higher yields than a pre-enrichment treatment in which the nutrient solution contained only 180 ppm N. The pine bark medium in this trial was better than milo, mushroom compost, local peat;sand and previously used local peat;sand.

As a result of this research most local growers are changing to pine bark with pre-enrichment for tomatoes. No pre-enrichment and total nutrient solution feeding, based on Jensen's recommendations is recommended for cucumbers.

Further research on pre-enrichment levels of Ca, Mg and P is being undertaken in cucumbers as this system is cheaper and easier to use with local labour than total nutrient solution feeding.

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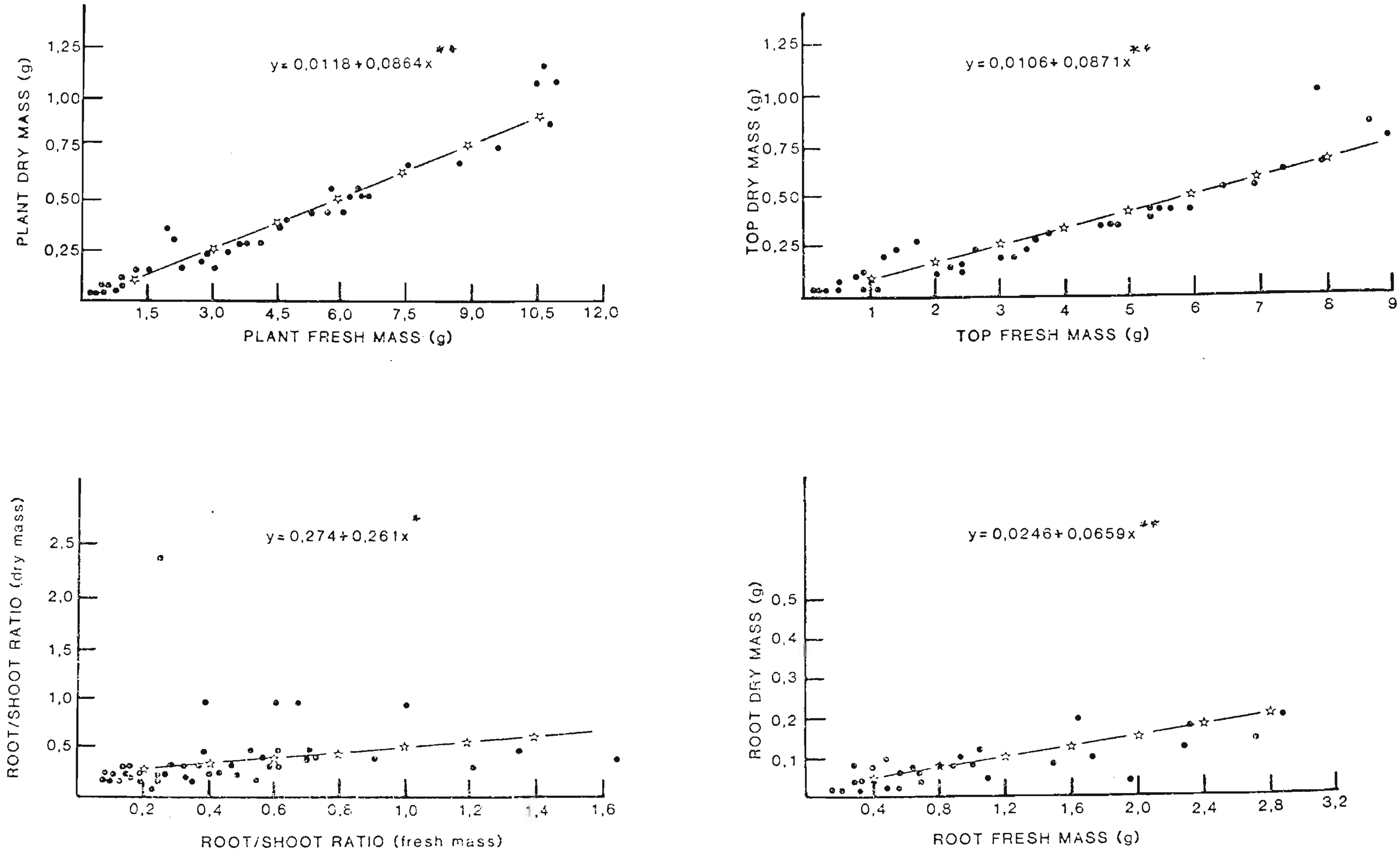
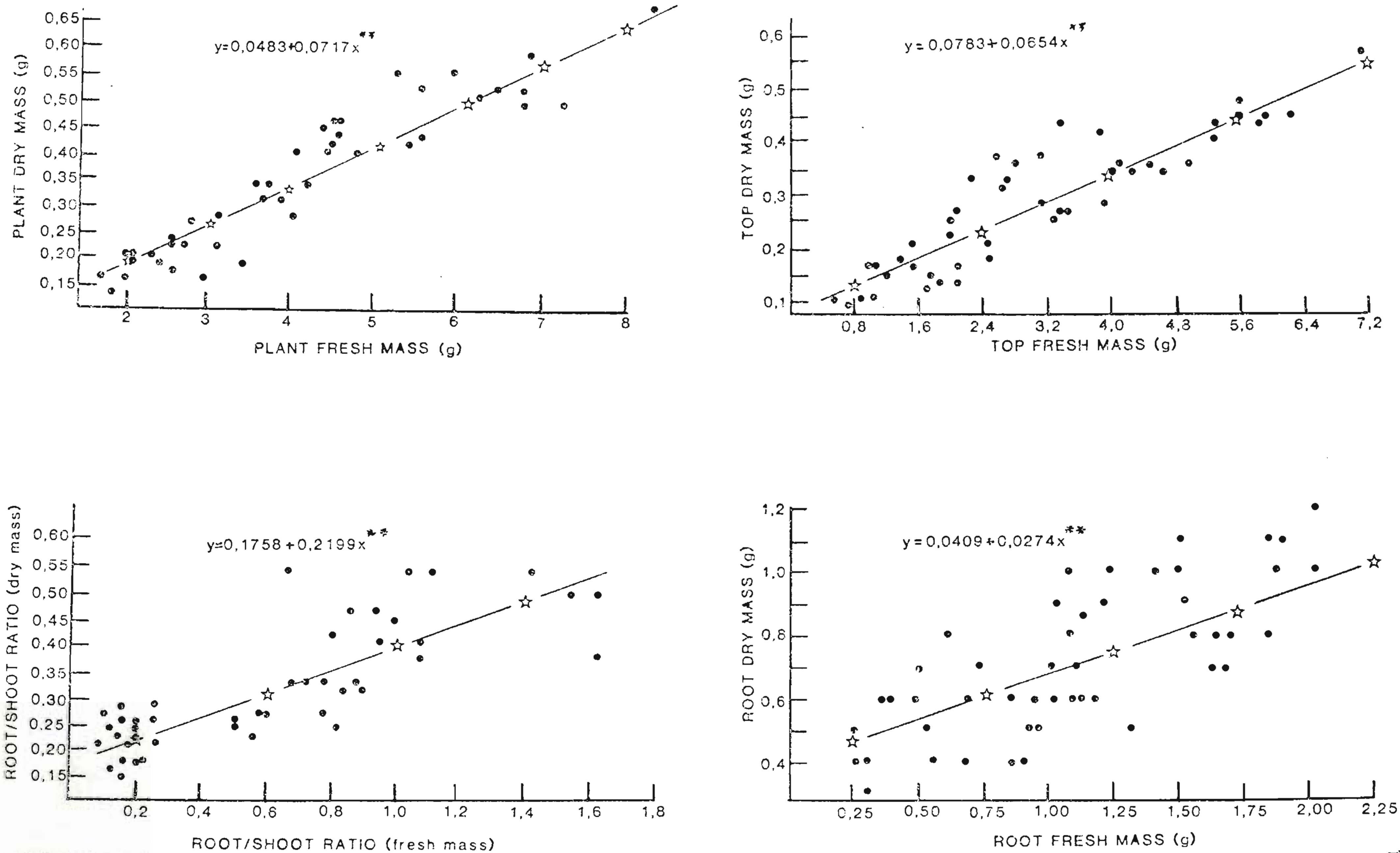


APPENDIX FIGURE 1. Correlations and regression lines between different plant growth characteristics in



APPENDIX FIGURE 2 Correlations, and regression lines, between different plant growth characteristics in cucumber

APPENDIX TABLE 1 Percentage nutrient content of commercially available nutrient mixtures

Element	Nutrient mixture					
	® Chemicult	® Speedling	® Aquapon		® Aquafert	
			Soln 1	Soln 2	Soln 1	Soln 2
N	6,5	9,1	7,3		9,0	
P	2,7	2,6		2,0		2,17
K	13,0	12,2		11,2	8,0	2,97
Ca	7,5	9,6	7,2		6,0	
Mg	2,5	2,6	1,9		1,5	
S	7,0	4,4		3,9		0,144
Fe	0,15	0,3		0,20		0,17
Mn	0,024	0,124		0,08		0,20
B	0,024	0,10		0,08		0,065
Cu	0,002	0,005		0,004		0,004
Zn	0,005	0,027		0,018		0,001
Mo	0,001	0,100		0,004		0,004

APPENDIX TABLE 2 Data for Experiment 1, first time of sampling (4 weeks from sowing)*

1	1	1	016.2	03.6	02.2	0.3	00.6	1.1	0.02	0.04	0.06
2	1	1	017.7	04.3	03.6	0.3	00.5	2.3	0.08	0.04	0.22
3	1	1	019.4	04.5	03.5	0.4	00.7	2.2	0.06	0.08	0.14
1	2	1	019.6	03.4	03.8	0.3	00.7	2.4	0.04	0.08	0.12
2	2	1	016.2	03.3	04.1	0.3	00.6	2.6	0.02	0.06	0.18
3	2	1	024.9	03.7	05.3	0.4	00.8	3.5	0.02	0.10	0.36
1	3	1	035.6	04.0	06.0	0.4	01.0	4.2	0.02	0.10	0.24
2	3	1	035.7	04.4	05.6	0.5	01.1	3.8	0.02	0.10	0.26
3	3	1	025.3	03.4	05.1	0.3	00.8	3.7	0.02	0.10	0.24
1	1	2	019.3	07.1	02.3	0.4	00.8	0.9	0.02	0.08	0.02
2	1	2	027.2	08.0	03.0	0.6	01.2	1.1	0.02	0.10	0.06
3	1	2	026.6	07.8	02.8	0.5	01.0	1.1	0.02	0.12	0.06
1	2	2	031.6	07.5	03.5	0.6	01.4	1.3	0.06	0.14	0.08
2	2	2	027.4	08.3	03.7	0.6	01.2	1.7	0.06	0.14	0.12
3	2	2	033.1	08.9	04.0	0.6	01.4	1.7	0.06	0.14	0.12
1	3	2	057.8	08.2	06.2	0.9	02.6	2.5	0.06	0.28	0.16
2	3	2	065.5	10.1	07.3	1.3	03.0	2.8	0.10	0.30	0.18
3	3	2	052.7	09.6	06.2	1.1	02.4	2.3	0.01	0.26	0.16
1	1	3	025.5	08.7	02.4	0.0	01.2	1.0	0.00	0.06	0.06
2	1	3	023.6	08.8	02.1	0.0	01.2	0.9	0.00	0.08	0.08
3	1	3	021.1	08.1	01.8	0.0	00.9	0.9	0.00	0.08	0.06
1	2	3	053.3	11.9	04.7	0.0	02.5	2.1	0.00	0.20	0.10
2	2	3	038.2	10.0	03.6	0.0	01.8	1.8	0.00	0.16	0.10
3	2	3	037.6	11.0	03.5	0.0	01.7	1.7	0.00	0.12	0.06
1	3	3	052.6	12.0	04.8	0.0	02.3	2.3	0.00	0.18	0.12
2	3	3	047.4	11.3	04.8	0.0	02.2	2.4	0.00	0.16	0.08
3	3	3	059.9	13.2	05.5	0.0	02.8	2.6	0.00	0.22	0.14
1	1	4	021.3	05.7	01.3	0.0	00.8	0.5	0.00	0.06	0.01
2	1	4	019.5	05.8	01.6	0.0	00.9	0.7	0.00	0.01	0.01
3	1	4	021.9	06.4	01.3	0.0	00.1	0.3	0.00	0.08	0.02
1	2	4	033.0	06.4	02.7	0.0	01.3	1.2	0.00	0.01	0.01
2	2	4	022.8	05.6	02.3	0.0	01.2	1.0	0.00	0.01	0.01
3	2	4	019.5	05.2	01.9	0.0	01.1	0.7	0.00	0.02	0.01
1	3	4	050.1	07.5	03.6	0.0	02.4	1.0	0.00	0.14	0.06
2	3	4	038.3	07.2	03.2	0.0	01.7	1.2	0.00	0.10	0.06
3	3	4	054.4	07.9	04.4	0.0	02.5	1.7	0.00	0.20	0.08

*Variates in column order are blocks, sizes (1 = 228 compartments/tray; 2 = 128 compartments/tray; 3 = 78 compartments/tray), kinds (1 = cucumbers; 2 = tomatoes; 3 = cabbages; 4 = lettuce), leaf area (cm^2), height (cm), whole plant fresh mass (g), stem fresh mass (g), leaf fresh mass (g), root fresh mass (g), stem dry mass (g), leaf dry mass (g), root dry mass (g)

APPENDIX TABLE 3 Analysis of Variance for Experiment 1, four weeks after sowing

Source of Variation	DF	M.S. Leaf area	Height	Fresh Mass Whole plant	Shoot	Roots	Leaves	Dry Mass Shoot $\times 10^{-4}$	Leaves $\times 10^{-3}$	Roots $\times 10^{-3}$
Blocks	2	28	0,30	0,07	0,01	0,10	0,04	2,7	2,4	3,9
Sizes	2	2181**	8,69**	25,36**	0,10**	6,38**	4,70**	0,4	38,3**	20,0**
Kinds	3	502**	73,54**	6,97**	1,10**	5,76**	2,07**	48,9**	22,3**	45,9**
S.K	6	103	2,32	0,66	0,07**	0,22	0,36	7,9	5,0*	1,6
Error	22	31	0,41	0,29	0,01	0,11	0,08	2,6	0,6	1,9
CV %		16,9	8,8	14,6	26,3	18,2	20,0	81,3	21,6	41,1

APPENDIX TABLE 4 Data for Experiment 1, second time of sampling (6 weeks from sowing)*

1	1	1	042.7	09.4	04.7	1.0	01.5	2.1	0.06	0.18	0.10
2	1	1	047.8	11.7	04.8	1.2	01.6	1.9	0.06	0.20	0.10
3	1	1	059.5	16.2	05.5	1.8	01.9	1.8	0.14	0.26	0.08
1	2	1	071.4	11.3	06.9	1.7	02.6	2.6	0.10	0.32	0.14
2	2	1	062.8	10.9	06.7	1.4	02.3	3.0	0.06	0.28	0.12
3	2	1	057.3	10.0	06.0	1.2	02.1	2.8	0.10	0.24	0.14
1	3	1	101.9	13.3	10.7	2.0	03.8	5.0	0.14	0.46	0.24
2	3	1	116.7	15.2	11.0	2.3	04.0	4.6	0.12	0.50	0.18
3	3	1	099.4	13.7	10.1	1.8	03.5	4.6	0.12	0.40	0.20
1	1	2	044.4	14.4	04.5	1.1	01.6	1.4	0.14	0.02	0.12
2	1	2	049.5	15.2	05.3	1.4	02.0	1.9	0.18	0.28	0.14
3	1	2	045.6	15.4	05.2	1.5	02.0	1.8	0.16	0.24	0.16
1	2	2	043.7	11.8	05.3	1.2	02.1	1.9	0.18	0.26	0.12
2	2	2	063.2	15.5	06.7	1.8	02.6	2.3	0.18	0.34	0.14
3	2	2	051.9	14.7	06.2	1.5	02.4	2.2	0.16	0.28	0.14
1	3	2	121.4	14.4	12.9	3.1	05.3	4.2	0.36	0.66	0.30
2	3	2	124.4	21.6	13.4	3.5	05.4	4.2	0.36	0.60	0.28
3	3	2	112.5	20.8	12.6	3.3	05.1	4.1	0.36	0.60	0.26
1	1	3	058.2	12.2	05.2	0.0	02.8	2.4	0.00	0.34	0.16
2	1	3	067.8	15.9	05.0	0.0	03.2	1.8	0.00	0.28	0.12
3	1	3	043.6	14.0	03.2	0.0	01.9	1.2	0.00	0.18	0.08
1	2	3	061.8	12.6	06.4	0.0	03.5	2.6	0.00	0.46	0.16
2	2	3	063.4	13.0	06.6	0.0	03.9	2.6	0.00	0.46	0.18
3	2	3	082.2	11.7	06.7	0.0	03.6	2.9	0.00	0.40	0.16
1	3	3	121.9	20.8	10.8	0.0	07.2	3.0	0.00	0.64	0.22
2	3	3	101.1	19.0	09.5	0.0	06.3	3.1	0.00	0.54	0.20
3	3	3	146.9	16.8	10.2	0.0	06.7	3.4	0.00	0.64	0.22
1	1	4	081.5	17.3	07.1	0.0	05.1	1.7	0.00	0.30	0.10
2	1	4	056.7	13.7	05.1	0.0	03.9	1.0	0.00	0.24	0.06
3	1	4	072.4	16.0	06.0	0.0	04.7	1.0	0.00	0.30	0.01
1	2	4	099.2	10.4	06.1	0.0	04.0	1.9	0.00	0.32	0.12
2	2	4	084.6	08.6	05.2	0.0	03.5	1.6	0.00	0.30	0.14
3	2	4	112.6	08.4	07.0	0.0	04.5	2.4	0.00	0.42	0.22
1	3	4	176.6	14.1	11.2	0.0	07.5	3.5	0.00	0.58	0.24
2	3	4	227.3	12.4	14.7	0.0	10.5	4.0	0.00	0.74	0.28
3	3	4	248.4	14.2	16.0	0.0	12.1	3.7	0.00	0.84	0.26

*Variates in column order are blocks, sizes (1 = 228 compartments/tray; 2 = 128 compartments/tray; 3 = 78 compartments/tray), kinds (1 = cucumbers; 2 = tomatoes; 3 = cabbages; 4 = lettuce), leaf area (cm^2), height (cm), whole plant fresh mass (g), stem fresh mass (g), leaf fresh mass (g), root fresh mass (g), stem dry mass (g), leaf dry mass (g), root dry mass (g)

APPENDIX TABLE 5 Analysis of Variance for Experiment 1, six weeks after sowing

Source of Variation	DF	M.S.								
		Leaf area	Height	Fresh Mass						
				Whole plant	Shoot	Roots	Leaves	Shoot x 10^3	Leaves x 10^3	Roots x 10^3
Blocks	2	246	2,96	0,20	0,05	0,004	0,26	0,14	1,6	0,2
Sizes	2	25075**	69,04**	157,96**	1,62**	16,31**	51,27**	136,4**	423,7**	58,8**
Kinds	3	6374**	27,35**	4,77*	10,26**	1,13**	22,87**	1080,1*	35,8**	2,5
S.K.	6	1476*	8,91*	3,45	0,79	0,49*	3,08	8,5**	11,4	3,1
Error	22	239	3,96	0,99	0,04	0,10	0,62	0,3	5,5	0,8
CV %		17,3	14,1	12,8	21,6	11,6	19,3	20,6	18,9	17,5

APPENDIX TABLE 6 Data for Experiment 1, third time of sampling (8 weeks from Sowing)*

1	1	1	069.0	19.3	07.9	2.4	02.5	2.7	0.20	0.34	0.14
2	1	1	066.7	17.2	06.1	1.8	02.1	1.9	0.14	0.28	0.12
3	1	1	115.3	21.7	09.6	3.4	02.6	3.3	0.26	0.36	0.18
1	2	1	114.3	20.4	11.8	3.3	04.4	3.8	0.28	0.58	0.18
2	2	1	111.0	20.8	10.9	3.2	03.9	3.5	0.26	0.54	0.18
3	2	1	106.8	19.0	11.2	3.3	03.9	3.6	0.28	0.56	0.16
1	3	1	194.3	28.8	17.2	5.2	06.5	5.3	0.42	0.80	0.32
2	3	1	117.6	28.1	16.8	5.5	05.8	5.6	0.46	0.70	0.30
3	3	1	172.6	27.0	16.2	4.7	05.5	5.7	0.40	0.70	0.28
1	1	2	064.9	22.0	08.2	2.5	03.4	2.2	0.36	0.42	0.20
2	1	2	070.5	23.7	08.7	2.7	03.5	2.4	0.34	0.42	0.24
3	1	2	073.2	22.9	08.4	2.6	03.5	2.1	0.36	0.40	0.18
1	2	2	082.2	21.7	11.0	3.2	04.8	3.0	0.42	0.58	0.28
2	2	2	069.0	20.4	10.0	2.9	04.0	3.0	0.36	0.46	0.30
3	2	2	092.5	24.5	13.8	4.1	05.3	4.1	0.54	0.62	0.34
1	3	2	178.6	34.6	23.1	7.2	10.0	5.7	0.94	1.18	0.56
2	3	2	167.2	36.0	24.6	7.3	09.5	7.8	0.98	1.10	0.88
3	3	2	136.3	35.0	23.5	7.2	08.0	7.9	1.02	1.00	0.82
1	1	3	070.4	17.5	05.6	0.0	03.6	2.0	0.00	0.42	0.44
2	1	3	085.9	18.7	07.4	0.0	04.7	2.7	0.00	0.58	0.30
3	1	3	077.2	17.2	06.1	0.0	04.1	1.9	0.00	0.48	0.36
1	2	3	090.1	14.2	10.2	0.0	05.6	4.5	0.00	0.74	0.56
2	2	3	088.5	14.2	08.6	0.0	05.3	3.2	0.00	0.62	0.30
3	2	3	100.5	11.9	08.2	0.0	05.3	2.8	0.00	0.64	0.32
1	3	3	199.5	22.0	22.1	0.0	13.5	8.5	0.00	1.88	1.28
2	3	3	197.6	22.8	19.6	0.0	12.3	7.2	0.00	1.70	0.94
3	3	3	204.5	21.0	23.0	0.0	13.3	9.7	0.00	1.98	1.50
1	1	4	185.7	14.5	12.2	0.0	09.5	2.5	0.00	0.56	0.20
2	1	4	214.1	16.0	13.6	0.0	10.4	2.9	0.00	0.74	0.24
3	1	4	176.0	13.7	13.5	0.0	09.4	3.6	0.00	0.56	0.24
1	2	4	172.0	13.2	12.5	0.0	08.8	3.2	0.00	0.60	0.34
2	2	4	196.8	11.8	15.2	0.0	09.8	5.0	0.00	0.70	0.48
3	2	4	229.5	13.5	16.6	0.0	11.6	4.3	0.00	0.82	0.36
1	3	4	503.1	18.5	38.4	0.0	31.0	7.0	0.00	1.86	0.70
2	3	4	471.5	16.6	35.7	0.0	27.9	7.5	0.00	1.70	0.70
3	3	4	531.2	17.5	36.0	0.0	28.0	7.4	0.00	1.58	0.62

*Variates in column order are blocks, sizes (1 = 228 compartments/tray); 2 = 128 compartments/tray; 3 = 78 compartments/tray), kinds (1 = cucumbers; 2 = tomatoes; 3 = cabbages; 4 = lettuce), leaf area (cm^2), height (cm), whole plant fresh mass (g), stem fresh mass (g), leaf fresh mass (g), root fresh mass (g), stem dry mass (g), leaf dry mass (g), root dry mass (g)

APPENDIX TABLE 7 Analysis of variance for Experiment 1, eight weeks after sowing

Source of Variation	DF	M.S.								
		Leaf area	Height	Fresh Mass				Dry Mass		
				Whole plant	Shoot	Roots	Leaves	Shoots x 10^{-}	Leaves x 10^{-3}	Roots x 10^{-3}
Blocks	2	532	0,07	1,7	0,1	0,8	0,4	0,2	0,4	0,3
Sizes	2	82213**	247,1**	849,3**	10,9**	68,5**	311,7**	15,4**	267,3**	88,4**
Kinds	3	75462**	241,9**	177,3**	49,6**	1,6	263,2**	72,3**	50,1**	31,8**
S.K	6	12369**	17,6**	41,6**	4,3**	1,8	52,4**	7,7**	19,7**	9,4*
Error	22	424	1,7	1,7	0,1	0,5	0,7	0,1	0,8	1,3
CV %		12,8	6,4	8,6	16,0	16,0	9,9	15,1	11,2	26,4

APPENDIX TABLE 8 Data for Experiment 2*

1	1	1	1	4.07	2.73	1.32	0.341	0.127
1	1	1	2	5.38	3.71	1.63	0.450	0.150
1	1	1	3	3.57	2.11	1.41	0.268	0.104
1	1	2	1	4.44	2.92	1.46	0.361	0.108
1	1	2	2	3.07	1.94	1.11	0.226	0.108
1	1	2	3	3.95	2.23	1.65	0.255	0.095
1	1	3	1	6.04	4.43	1.55	0.509	0.138
1	1	3	2	6.47	4.61	1.84	0.500	0.239
1	1	3	3	5.50	3.82	1.66	0.489	0.158
1	2	1	1	2.01	1.47	0.52	0.161	0.078
1	2	1	2	2.68	1.89	0.75	0.211	0.139
1	2	1	3	1.68	1.16	0.50	0.136	0.100
1	2	2	1	2.72	1.99	0.69	0.230	0.110
1	2	2	2	2.69	2.02	0.66	0.225	0.140
1	2	2	3	2.51	1.73	0.75	0.160	0.113
1	2	3	1	2.62	1.92	0.68	0.184	0.113
1	2	3	2	3.61	2.72	0.87	0.241	0.145
1	2	3	3	2.02	1.39	0.61	0.116	0.092
2	1	1	1	4.58	3.21	1.34	0.314	0.104
2	1	1	2	4.93	3.32	1.59	0.366	0.147
2	1	1	3	3.09	1.77	1.27	0.200	0.106
2	1	2	1	4.40	2.48	1.79	0.266	0.114
2	1	2	2	9.91	1.88	1.01	0.204	0.078
2	1	2	3	3.86	2.25	1.59	0.237	0.105
2	1	3	1	6.10	4.62	1.45	0.524	0.133
2	1	3	2	7.59	5.09	2.47	0.519	0.319
2	1	3	3	4.65	3.37	1.24	0.376	0.114
2	2	1	1	2.22	1.65	0.54	0.187	0.100
2	2	1	2	2.67	1.96	0.70	0.212	0.141
2	2	1	3	1.52	1.11	0.39	0.125	0.100
2	2	2	1	2.28	1.68	0.58	0.195	0.127
2	2	2	2	2.41	1.74	0.67	0.177	0.115
2	2	2	3	2.35	1.68	0.70	0.139	0.100
2	2	3	1	2.56	1.87	0.66	0.163	0.100
2	2	3	2	3.37	2.51	0.85	0.237	0.133
2	2	3	3	2.13	1.49	0.63	0.127	0.100
3	1	1	1	6.26	4.52	1.71	0.495	0.140
3	1	1	2	4.28	2.57	1.69	0.309	0.159
3	1	1	3	3.25	2.17	1.04	0.250	0.150
3	1	2	1	4.41	2.61	1.66	0.289	0.100
3	1	2	2	3.34	2.16	1.13	0.247	0.100
3	1	2	3	3.84	2.35	1.44	0.250	0.110
3	1	3	1	6.27	4.54	1.70	0.542	0.116
3	1	3	2	5.55	3.96	1.57	0.441	0.154
3	1	3	3	4.38	3.35	1.00	0.350	0.094
3	2	1	1	2.72	2.04	0.60	0.233	0.128
3	2	1	2	3.08	2.38	0.68	0.295	0.141
3	2	1	3	1.62	1.19	0.43	0.120	0.080
3	2	2	1	2.42	1.74	0.68	0.173	0.140
3	2	2	2	2.16	1.56	0.59	0.161	0.115
3	2	2	3	1.49	1.03	0.44	0.091	0.061
3	2	3	1	2.76	2.12	0.63	0.221	0.116
3	2	3	2	3.69	2.70	0.96	0.270	0.150
3	2	3	3	3.13	2.29	0.83	0.191	0.154

*Variates in column order are blocks, kinds (1 = cucumbers, 2 = tomatoes), media (1 = peat : vermiculite; 2 = vermiculite; 3 = local peat), pH (1 = 5,5 2 = 6,5; 3 = 7,5), total plant fresh mass (g), top fresh mass (g), root fresh mass (g), top dry mass (g), root dry mass (g)

APPENDIX TABLE 9 Analysis of Variance for Experiment 2

Source of Variation	DF	M.S.				
		Fresh Mass			Dry Mass	
		Whole plant	Shoot	Root x 10^{-1}	Shoot x 10^{-2}	Root x 10^{-3}
Blocks	2	0,6	0,4	0,1	0,4	0,03
Kinds	1	80,8**	23,7**	95,7**	39,1**	3,6*
Media	2	5,8**	6,6**	1,5**	6,3**	5,6*
pH	2	7,1**	2,8**	1,4**	4,0**	8,4**
Kinds. Med	2	0,9	2,4**	0,1	4,3**	3,1*
Kinds. pH	2	0,8	0,6	0,3	0,6	0,4
Med. pH	4	0,3	0,6	2,3**	0,5	2,5
Kinds. Med. pH	4	0,3	0,1	1,0**	0,1	1,9
Error	34	1,1	0,1	0,3	0,2	0,7
CV %		28,1	14,9	16,2	16,2	21,9

APPENDIX TABLE 10   Data for Experiment 3*

1	1	1	10.8	7.4	4.42	2.94	0.42	0.29
1	1	2	12.8	8.2	4.94	3.26	0.50	0.26
1	1	3	14.2	8.7	5.30	3.42	0.55	0.27
1	1	4	09.8	5.5	3.47	1.97	0.27	0.17
1	1	5	11.5	7.6	4.70	2.87	0.45	0.27
1	1	6	10.6	6.9	4.46	2.41	0.41	0.04
1	2	1	12.0	3.5	2.40	1.07	0.24	0.09
1	2	2	13.5	4.6	3.07	1.51	0.35	0.12
1	2	3	13.5	4.1	2.75	1.26	0.27	0.10
1	2	4	14.6	3.8	2.46	1.34	0.26	0.11
1	2	5	15.3	4.8	3.18	1.56	0.27	0.14
1	2	6	13.1	3.9	2.72	1.19	0.25	0.11
1	3	1	13.0	4.3	3.11	1.16	0.30	0.15
1	3	2	12.7	4.6	3.37	1.27	0.29	0.14
1	3	3	11.7	3.8	2.55	1.19	0.29	0.15
1	3	4	11.8	3.9	2.74	1.07	0.31	0.18
1	3	5	12.4	3.7	2.70	1.02	0.25	0.14
1	3	6	11.0	3.8	2.96	0.90	0.30	0.16
2	1	1	06.2	3.6	2.40	1.18	0.32	0.10
2	1	2	07.3	4.2	2.54	1.70	0.30	0.10
2	1	3	08.2	5.0	2.98	2.03	0.36	0.17
2	1	4	07.7	4.5	2.70	1.83	0.31	0.15
2	1	5	06.2	2.9	1.81	1.06	0.16	0.10
2	1	6	07.5	3.2	2.01	1.18	0.23	0.08
2	2	1	04.6	1.0	0.57	0.48	0.06	0.04
2	2	2	04.7	1.1	0.66	0.50	0.07	0.04
2	2	3	05.0	1.5	0.81	0.66	0.11	0.06
2	2	4	05.4	1.7	0.96	0.71	0.10	0.04
2	2	5	06.3	1.4	0.84	0.53	0.08	0.03
2	2	6	07.5	1.5	0.99	0.54	0.10	0.04
2	3	1	07.6	1.8	1.33	0.56	0.16	0.06
2	3	2	07.9	2.2	1.45	0.78	0.18	0.08
2	3	3	08.7	2.3	1.61	0.71	0.20	0.09
2	3	4	09.3	2.6	1.83	0.74	0.21	0.08
2	3	5	09.1	2.1	1.58	0.51	0.16	0.07
2	3	6	10.5	1.9	1.50	0.50	0.14	0.06
3	1	1	09.0	4.6	2.77	1.82	0.27	0.17
3	1	2	12.0	5.5	3.93	2.08	0.33	0.13
3	1	3	06.6	6.0	4.12	1.98	0.30	0.12
3	1	4	09.8	4.9	3.38	1.58	0.26	0.11
3	1	5	08.6	5.1	2.73	2.20	0.23	0.10
3	1	6	09.6	5.5	3.66	1.73	0.26	0.06
3	2	1	07.1	2.2	1.28	0.92	0.14	0.08
3	2	2	06.9	2.2	1.32	0.85	0.14	0.07
3	2	3	06.0	2.1	1.24	0.84	0.15	0.05
3	2	4	06.7	2.0	1.19	0.77	0.12	0.06
3	2	5	06.9	2.3	1.35	0.94	0.15	0.06
3	2	6	06.4	2.0	1.19	0.86	0.15	0.06
3	3	1	10.4	3.2	2.38	0.77	0.30	0.10
3	3	2	09.5	2.9	2.29	0.69	0.26	0.09
3	3	3	12.1	3.5	2.54	1.00	0.27	0.13
3	3	4	12.3	3.4	2.55	0.80	0.27	0.11
3	3	5	11.4	3.2	2.36	0.82	0.21	0.09
3	3	6	11.4	3.4	2.41	0.92	0.25	0.14

*Variates in column order are media (1 = ® Finnpeat; 2 = local peat; 3 = Newcastle peat; 4 = Amberglo medium; 5 = ® Roode-Lyon medium; 6 = Biggs' medium), kinds (1 = cucumbers; 2 = tomatoes; 3 = cabbages), blocks, height (cm), total plant mass (g), tops fresh mass (g), root fresh mass (g), top dry mass (g), root dry mass (g)

APPENDIX TABLE 10 Continued

4	1	1	09.4	4.1	2.75	1.33	0.25	0.11
4	1	2	09.2	5.7	3.56	2.11	0.36	0.20
4	1	3	08.9	4.9	3.07	1.80	0.29	0.15
4	1	4	08.9	4.5	2.90	1.53	0.27	0.10
4	1	5	09.1	4.6	3.04	1.56	0.33	0.14
4	1	6	08.8	4.9	3.04	1.78	0.34	0.11
4	2	1	10.0	2.4	1.53	0.88	0.16	0.10
4	2	2	09.9	2.6	1.63	0.91	0.16	0.08
4	2	3	08.2	2.7	1.64	1.04	0.18	0.07
4	2	4	07.9	2.3	1.44	0.84	0.17	0.06
4	2	5	07.8	2.4	1.53	0.90	0.18	0.08
4	2	6	06.5	1.6	0.90	0.69	0.11	0.06
4	3	1	09.9	2.3	1.56	0.76	0.20	0.11
4	3	2	09.9	2.3	1.77	0.58	0.21	0.10
4	3	3	10.9	2.5	2.05	0.38	0.21	0.08
4	3	4	10.7	2.8	2.24	0.53	0.24	0.06
4	3	5	**.*	*.*	*.**	*.**	*.**	*.**
4	3	6	**.*	*.*	*.**	*.**	*.**	*.**
5	1	1	05.1	3.5	1.83	1.64	0.24	0.13
5	1	2	06.3	3.4	1.96	1.37	0.24	0.08
5	1	3	06.9	4.1	2.18	1.90	0.27	0.13
5	1	4	06.7	3.8	2.25	1.54	0.26	0.11
5	1	5	06.9	3.5	2.14	1.31	0.26	0.07
5	1	6	08.4	4.7	2.81	1.81	0.33	0.16
5	2	1	06.7	1.8	1.04	0.79	0.14	0.05
5	2	2	06.6	1.8	0.96	0.76	0.14	0.06
5	2	3	06.5	1.8	1.01	0.81	0.14	0.04
5	2	4	06.2	1.7	0.97	0.74	0.12	0.05
5	2	5	06.2	1.7	0.90	0.75	0.12	0.06
5	2	6	05.7	1.5	0.89	0.66	0.11	0.04
5	3	1	10.0	2.1	1.38	0.78	0.16	0.08
5	3	2	09.4	2.3	1.45	0.85	0.16	0.08
5	3	3	09.3	2.2	1.45	0.76	0.20	0.08
5	3	4	08.7	2.0	1.34	0.71	0.17	0.10
5	3	5	07.9	1.9	1.20	0.74	0.14	0.08
5	3	6	07.8	1.8	1.10	0.67	0.13	0.08
6	1	1	06.2	4.4	2.42	1.95	0.25	0.12
6	1	2	07.4	4.2	2.43	1.70	0.23	0.10
6	1	3	06.1	5.8	2.85	2.86	0.33	0.20
6	1	4	06.5	4.4	3.02	1.26	0.30	0.10
6	1	5	07.6	4.9	3.52	1.36	0.36	0.10
6	1	6	09.9	6.7	4.25	2.31	0.41	0.20
6	2	1	05.4	1.9	0.90	1.00	0.30	0.10
6	2	2	06.2	2.1	1.50	0.62	0.18	0.08
6	2	3	07.1	2.0	1.43	0.53	0.16	0.05
6	2	4	06.3	1.8	1.30	0.50	0.15	0.05
6	2	5	07.6	2.1	1.47	0.60	0.17	0.05
6	2	6	07.1	2.1	1.37	0.67	0.17	0.07
6	3	1	08.8	2.4	1.88	0.51	0.20	0.11
6	3	2	09.3	2.1	1.66	0.46	0.16	0.06
6	3	3	09.7	2.8	1.73	1.23	0.23	0.13
6	3	4	09.0	2.1	1.80	0.24	0.22	0.04
6	3	5	08.3	1.7	1.41	0.33	0.13	0.06
6	3	6	07.7	1.7	1.35	0.33	0.08	0.03

APPENDIX TABLE 11 Analysis of Variance for Experiment 3

Source of Variation	DF	M.S.					
		Height	Fresh Mass			Dry Mass	
			Whole plant	Shoot	Root x 10^{-1}	Shoot x 10^{-2}	Root x 10^{-3}
Blocks	5	0,6	0,6	0,2	0,2	0,3	0,2
Media	5	72,0**	17,7**	8,6**	1,7**	5,4**	1,6**
Kinds	2	44,0**	80,2**	27,0**	15,1**	20,9**	4,5**
Med. Kinds	10	6,9**	0,9**	0,3	0,2**	0,5	0,1
Error	83	1,1	0,2	0,1	0,06	0,2	0,1
CV %		12,0	14,8	15,7	21,8	19,2	33,2

APPENDIX TABLE 12 Data for Experiment 4*

1	1	1	1	8.05	4.25	3.80	0.90	245	0
1	1	1	2	5.18	3.36	1.82	0.54	112	0
1	1	1	3	8.28	5.92	2.36	.40	162	0
1	1	1	4	7.19	4.89	2.30	0.47	189	0
1	1	2	1	3.04	2.20	0.84	0.39	165	0
1	1	2	2	4.33	2.77	1.56	0.56	172	0
1	1	2	3	3.86	2.32	1.54	0.66	142	0
1	1	2	4	3.15	2.00	1.15	0.58	146	0
1	1	3	1	4.65	2.60	2.05	0.79	116	0
1	1	3	2	2.88	1.98	0.90	0.46	128	0
1	1	3	3	4.66	3.56	1.10	0.31	173	0
1	1	3	4	4.14	2.52	1.62	0.65	107	0
1	1	4	1	11.67	7.02	4.65	0.67	260	0
1	1	4	2	9.00	4.78	4.22	0.88	183	0
1	1	4	3	12.30	8.82	3.48	0.40	254	0
1	1	4	4	10.54	5.52	5.02	0.91	177	0
1	1	5	1	11.97	6.42	5.55	0.87	201	13
1	1	5	2	8.00	4.02	3.98	0.98	143	0
1	1	5	3	12.84	9.47	3.37	0.36	243	0
1	1	5	4	8.85	4.52	4.33	0.96	187	0
1	2	1	1	9.47	6.20	3.27	0.53	215	88
1	2	1	2	6.55	4.40	2.15	0.49	137	50
1	2	1	3	10.29	7.79	2.50	0.52	223	25
1	2	1	4	8.80	4.69	3.31	0.71	155	15
1	2	2	1	7.15	4.42	2.73	0.62	178	100
1	2	2	2	6.47	4.89	1.58	0.32	186	88
1	2	2	3	8.34	5.78	2.56	0.45	176	63
1	2	2	4	5.32	3.45	1.87	0.55	126	13
1	2	3	1	7.32	4.49	2.83	0.63	124	50
1	2	3	2	6.59	4.85	1.74	0.36	194	13
1	2	3	3	7.15	5.05	2.10	0.42	181	0
1	2	3	4	6.96	47.02	2.60	4.81	33	00
1	2	4	1	13.54	10.43	3.11	0.30	230	100
1	2	4	2	12.89	9.30	3.56	0.39	233	37
1	2	4	3	19.85	11.98	7.87	0.40	261	88
1	2	4	4	12.97	8.62	4.35	0.51	187	38
1	2	5	1	16.39	11.56	4.83	0.42	219	88
1	2	5	2	17.10	8.57	8.53	0.99	207	88
1	2	5	3	18.17	12.20	5.97	0.49	236	75
1	2	5	4	12.73	6.33	6.40	1.02	142	75
1	3	1	1	7.60	4.44	3.16	0.72	72	100
1	3	1	2	7.02	3.90	3.12	0.80	58	63
1	3	1	3	8.46	5.38	3.08	0.58	81	50
1	3	1	4	5.00	2.37	2.63	1.11	53	13
1	3	2	1	6.44	3.82	2.62	0.69	80	100
1	3	2	2	4.39	2.64	1.75	0.67	87	63
1	3	2	3	6.10	4.16	1.94	0.47	83	75
1	3	2	4	4.60	2.24	2.36	1.06	55	63
1	3	3	1	4.30	2.20	2.10	0.96	50	75
1	3	3	2	4.02	2.50	1.52	0.61	69	0
1	3	3	3	7.90	5.42	2.48	0.46	91	25
1	3	3	4	5.98	3.30	2.68	0.82	46	0
1	3	4	1	10.17	5.95	4.22	0.71	91	100
1	3	4	2	5.79	3.69	2.01	0.57	79	88
1	3	4	3	9.40	5.87	3.53	0.61	107	100
1	3	4	4	8.47	4.44	4.03	0.91	73	63
1	3	5	1	8.08	5.76	2.32	0.41	68	88
1	3	5	2	6.39	3.32	3.07	0.93	62	100
1	3	5	3	6.52	4.62	1.90	0.42	73	88
1	3	5	4	7.67	3.94	3.73	0.95	62	63

*Variates in column order are blocks, kinds (1 = tomatoes; 2 = cucumbers; 3 = cabbage), media (1 = ® Roode-Lyon; 2 = local peat; 3 = bark; 4 = Canadian peat; 5 = ® Finn peat), fertilisers (1 = ® Aquapon; 2 = ® Chemicult; 3 = ® Chemicult Plus; 4 = ® Speedling), total plant mass (g), top mass (g), root mass (g), root/shoot ratio, length (cm), germination percentage

APPENDIX TABLE 12 Continued

2	2	4	1	12.93	9.74	3.19	0.33	248	100
2	2	4	2	16.55	10.03	6.52	0.65	261	37
2	2	4	3	19.43	11.23	8.20	0.73	266	37
2	2	4	4	10.69	6.65	4.04	0.61	181	25
2	2	5	1	17.52	12.20	5.32	0.44	242	100
2	2	5	2	13.79	7.04	6.75	0.96	195	100
2	2	5	3	18.73	11.68	7.05	0.61	254	100
2	2	5	4	12.12	6.04	6.08	1.01	168	88
2	3	1	1	5.78	3.44	2.34	0.68	78	88
2	3	1	2	5.38	2.84	2.54	0.90	51	88
2	3	1	3	8.80	5.90	2.90	0.50	92	75
2	3	1	4	5.84	3.26	2.58	0.80	51	38
2	3	2	1	7.44	4.70	2.74	0.59	88	100
2	3	2	2	5.47	2.97	2.50	0.85	80	50
2	3	2	3	5.54	3.69	1.85	0.51	83	100
2	3	2	4	4.35	2.40	1.95	0.82	52	63
2	3	3	1	4.82	2.52	2.30	0.92	66	50
2	3	3	2	4.02	2.40	1.62	0.68	72	13
2	3	3	3	6.49	4.50	1.99	0.45	87	13
2	3	3	4	7.93	4.55	3.38	0.75	55	13
2	3	4	1	6.22	3.74	2.48	0.67	88	100
2	3	4	2	6.92	4.38	2.54	0.58	77	75
2	3	4	3	10.50	7.66	2.84	0.37	112	75
2	3	4	4	8.72	4.35	4.37	1.01	81	63
2	3	5	1	6.80	3.87	2.93	0.76	71	100
2	3	5	2	6.89	3.79	3.10	0.82	62	75
2	3	5	3	7.47	5.27	2.20	0.42	88	100
2	3	5	4	5.09	3.12	1.97	0.64	51	63
2	1	1	1	8.64	6.27	2.37	0.38	247	0
2	1	1	2	6.42	4.37	2.05	0.47	138	0
2	1	1	3	10.28	7.73	2.55	0.33	203	0
2	1	1	4	6.57	4.27	2.30	0.54	185	0
2	1	2	1	2.90	2.07	0.83	0.40	159	0
2	1	2	2	3.93	2.63	1.25	0.47	167	0
2	1	2	3	3.06	2.06	1.00	0.49	120	0
2	1	2	4	2.74	1.82	0.92	0.51	140	0
2	1	3	1	7.26	4.62	2.64	0.58	176	0
2	1	3	2	3.92	2.37	1.55	0.66	142	0
2	1	3	3	5.38	3.98	1.40	0.35	151	0
2	1	3	4	4.19	2.70	1.49	0.56	149	0
2	1	4	1	12.75	7.35	5.40	0.74	257	25
2	1	4	2	9.35	5.12	4.41	0.86	178	0
2	1	4	3	11.35	8.18	3.17	0.39	217	0
2	1	4	4	10.72	5.47	5.25	0.96	177	0
2	1	5	1	12.29	7.70	4.59	0.60	236	0
2	1	5	2	8.13	4.71	3.42	0.72	169	0
2	1	5	3	14.12	9.87	4.25	0.43	275	13
2	1	5	4	7.30	4.14	3.16	0.77	164	0
2	2	1	1	8.54	5.94	2.60	0.44	208	88
2	2	1	2	8.09	5.90	2.19	0.38	163	13
2	2	1	3	9.25	6.98	2.27	0.33	205	13
2	2	1	4	6.89	4.12	2.77	0.68	129	25
2	2	2	1	7.10	4.64	2.46	0.53	184	100
2	2	2	2	6.07	4.50	1.57	0.35	187	50
2	2	2	3	7.73	5.42	2.31	0.43	184	63
2	2	2	4	4.29	2.52	1.77	0.71	106	13
2	2	3	1	7.28	4.78	2.50	0.53	163	75
2	2	3	2	5.73	4.12	1.61	0.39	177	0
2	2	3	3	7.65	5.28	2.35	0.45	187	25
2	2	3	4	5.97	3.91	2.06	0.53	105	25

APPENDIX TABLE 12 Continued

3	1	1	1	9.02	6.12	2.90	0.48	242	13
3	1	1	2	8.48	5.91	2.56	0.43	165	0
3	1	1	3	10.68	8.03	2.65	0.33	206	0
3	1	1	4	7.20	4.57	2.63	0.58	183	0
3	1	2	1	3.45	2.57	0.88	0.35	177	13
3	1	2	2	4.57	2.95	1.62	0.55	175	0
3	1	2	3	3.64	2.22	1.42	0.64	142	0
3	1	2	4	3.37	2.22	1.15	0.52	147	0
3	1	3	1	5.99	3.82	2.17	0.57	188	0
3	1	3	2	4.70	3.55	1.15	0.33	171	0
3	1	3	3	5.98	4.16	1.82	0.44	170	0
3	1	3	4	3.62	2.34	1.28	0.55	150	0
3	1	4	1	13.79	7.75	6.04	0.78	242	0
3	1	4	2	9.35	5.78	3.57	0.62	193	0
3	1	4	3	11.45	7.97	3.48	0.44	210	0
3	1	4	4	11.02	5.78	5.24	0.91	184	0
3	1	5	1	9.62	5.95	3.67	0.62	234	0
3	1	5	2	11.03	6.47	4.56	0.71	192	0
3	1	5	3	14.07	9.88	4.99	0.51	275	0
3	1	5	4	7.20	3.82	3.38	0.89	128	0
3	2	1	1	9.40	5.85	3.55	0.61	213	100
3	2	1	2	8.43	5.25	3.15	0.61	161	25
3	2	1	3	9.25	6.98	2.27	0.33	205	38
3	2	1	4	6.52	3.89	2.63	0.68	125	38
3	2	2	1	6.97	5.10	1.87	0.37	194	88
3	2	2	2	6.03	4.49	1.54	0.35	166	13
3	2	2	3	7.53	5.37	2.16	0.41	196	13
3	2	2	4	2.62	1.82	0.80	0.44	83	0
3	2	3	1	6.84	4.77	2.07	0.44	189	75
3	2	3	2	5.49	4.17	1.32	0.32	161	0
3	2	3	3	6.58	4.53	2.05	0.46	179	0
3	2	3	4	5.44	4.70	0.74	0.16	150	0
3	2	4	1	14.27	9.69	4.58	0.48	248	100
3	2	4	2	12.80	10.49	2.31	0.22	229	37
3	2	4	3	20.20	11.52	8.68	0.76	263	88
3	2	4	4	12.39	8.00	4.39	0.55	197	25
3	2	5	1	17.45	11.07	6.38	0.58	243	88
3	2	5	2	14.74	7.80	6.94	0.89	219	100
3	2	5	3	17.23	10.34	6.89	0.67	193	100
3	2	5	4	12.33	6.27	6.06	0.97	172	75
3	3	1	1	7.29	4.14	3.15	0.76	77	88
3	3	1	2	3.49	1.84	1.65	0.90	48	88
3	3	1	3	6.87	4.09	2.78	0.68	67	88
3	3	1	4	5.20	2.84	2.36	0.83	45	13
3	3	2	1	5.05	2.97	2.08	0.70	76	75
3	3	2	2	6.25	3.27	2.98	0.92	82	88
3	3	2	3	3.20	2.43	0.77	0.32	78	75
3	3	2	4	4.68	2.47	2.21	0.90	59	25
3	3	3	1	3.34	2.17	1.17	0.54	72	100
3	3	3	2	4.25	2.40	1.85	0.77	65	0
3	3	3	3	6.40	4.48	1.92	0.43	73	13
3	3	3	4	4.08	2.24	1.84	0.83	68	13
3	3	4	1	6.65	4.35	2.30	0.53	88	100
3	3	4	2	8.20	4.85	3.35	0.69	76	63
3	3	4	3	11.77	7.55	5.78	0.77	108	88
3	3	4	4	8.28	4.88	3.40	0.70	72	50
3	3	5	1	5.38	3.32	2.06	0.62	61	88
3	3	5	2	5.97	3.29	2.69	0.82	64	75
3	3	5	3	8.50	5.59	2.91	0.52	82	88
3	3	5	4	6.29	3.77	2.52	0.67	59	63

APPENDIX TABLE 13 Analysis of Variance for Experiment 4

Source of Variation	DF	M.S.					
		Height	Germ %	Fresh Mass			Root/Shoot ratio
		$\times 10^{-2}$	$\times 10^{-1}$	Whole plant	Shoot	Roots	$\times 10^{-1}$
Blocks	2	7,9	9,9	0,5	10,2	0,2	2,3
Kinds	2	2529**	6972,5**	248**	206,5**	18,5**	2,3
Media	4	167**	872,2**	321**	87,1*	59,2*	1,2
Fert.	3	218**	1117,3**	63**	31,8*	1,1*	9,4**
K.M	8	33	250,3	42	16,2	9,6	1,7
K.F	6	37**	248,7**	6,1**	4,0	2,1**	1,4
M.F	12	16**	61,3**	5,2**	19,7	1,4**	1,1
K.M.F	24	7**	39,8*	3,6**	13,9	1,7*	1,1
Error	118	2,6	15,1	1,0	10,6	0,4	1,2
CV %		11,1	30,8	12,4	60,5	20,5	55,3

APPENDIX TABLE 14 Data for Experiment 5*

1	1	1	1	04.5	00.40	00.30	00.10	00.06	00.05	0.01
1	1	1	2	06.0	02.05	01.07	00.97	00.21	00.16	0.05
1	1	1	3	03.1	00.96	00.86	00.32	00.17	00.16	0.01
1	1	2	1	02.8	00.10	00.06	00.0[illegible]	00.01	00.01	0.01
1	1	2	2	03.6	01.52	00.58	00.94	00.15	00.10	0.05
1	1	2	3	02.5	00.22	00.15	00.07	00.03	00.02	0.01
1	1	3	1	02.3	00.08	00.05	00.03	00.02	00.02	0.01
1	1	3	2	04.3	01.83	00.93	00.90	00.14	00.10	0.04
1	1	3	3	**.*	**.**	**.**	**.**	**.**	**.**	*.**
1	1	4	1	05.5	01.17	00.78	00.38	00.13	00.14	0.03
1	1	4	2	09.6	04.60	02.57	02.03	00.47	00.37	0.10
1	1	4	3	02.8	00.92	00.65	00.27	00.12	00.11	0.01
1	1	5	1	05.5	01.52	00.95	00.57	00.18	00.12	0.06
1	1	5	2	06.4	03.47	01.78	01.68	00.21	00.15	0.07
1	1	5	3	02.7	00.63	00.43	00.20	00.65	00.05	0.01
1	1	6	1	03.1	00.33	00.15	00.18	00.04	00.03	0.01
1	1	6	2	07.3	04.10	01.53	02.47	00.29	00.21	0.08
1	1	6	3	03.0	00.95	00.75	00.20	00.15	00.14	0.01
1	1	7	1	03.4	00.14	00.10	00.04	00.03	00.04	0.01
1	1	7	2	04.6	01.97	00.95	01.02	00.21	00.16	0.06
1	1	7	3	01.5	00.18	00.15	00.03	00.02	00.02	0.01
1	1	8	1	04.0	00.48	00.28	00.20	00.07	00.05	0.02
1	1	8	2	12.6	04.65	03.12	01.53	00.46	00.37	0.09
1	1	8	3	02.4	00.60	00.45	00.15	00.0[illegible]	00.05	0.01
1	1	9	1	05.[illegible]	02.03	01.22	00.80	00.31	00.22	0.09
1	1	9	2	12.9	05.70	03.80	01.90	00.53	00.42	0.11
1	1	9	3	03.8	01.60	01.2[illegible]	00.37	00.19	00.17	0.02
1	2	1	1	12.5	04.60	03.70	00.90	00.41	00.35	0.[illegible]
1	2	1	2	09.1	02.32	01.44	00.88	00.27	00.21	0.06
1	2	1	3	07.5	04.96	03.32	01.64	00.85	00.62	0.23
1	2	2	1	21.0	10.92	08.60	02.32	01.07	00.89	0.18
1	2	2	2	18.4	09.06	07.40	01.66	00.54	00.46	0.08
1	2	2	3	05.7	12.10	10.10	02.10	00.99	00.79	0.20
1	2	3	1	04.7	00.96	00.86	00.10	00.07	00.06	0.01
1	2	3	2	07.5	02.60	02.05	00.55	00.1[illegible]	00.1[illegible]	0.04
1	2	3	3	07.5	07.50	06.00	01.50	00.58	00.47	0.11
1	2	4	1	21.4	06.56	05.50	01.02	00.54	00.45	0.09
1	2	4	2	15.5	06.95	05.80	01.97	00.50	00.43	0.07
1	2	4	3	07.1	07.15	06.2[illegible]	00.9[illegible]	00.50	00.43	0.07
1	2	5	1	22.0	10.70	07.82	02.87	00.90	00.70	0.21
1	2	5	2	15.0	07.07	05.57	01.50	00.5[illegible]	00.4[illegible]	0.10
1	2	5	3	11.2	13.37	11.70	01.67	01.01	00.88	0.13
1	2	6	1	20.0	05.63	04.93	00.80	00.40	00.37	0.03
1	2	6	2	10.[illegible]	02.5[illegible]	02.2[illegible]	00.2[illegible]	00.2[illegible]	00.1[illegible]	0.0[illegible]
1	2	6	3	05.0	02.90	02.35	00.55	00.21	00.13	0.04
1	2	7	1	25.5	06.32	05.86	00.46	00.56	00.46	0.10
1	2	7	2	16.5	05.65	04.45	01.20	00.44	00.36	0.0[illegible]
1	2	7	3	15.0	10.95	09.45	01.53	00.75	00.65	0.10
1	2	8	1	15.0	06.03	04.57	01.47	00.4[illegible]	00.36	0.0[illegible]
1	2	8	2	14.7	03.90	03.43	00.47	00.33	00.27	0.06
1	2	8	3	10.3	11.04	10.44	01.5[illegible]	01.05	00.85	0.20
1	2	9	1	15.5	03.95	03.24	00.74	00.2[illegible]	00.2[illegible]	0.0[illegible]
1	2	9	2	11.0	03.90	03.38	00.55	00.32	00.27	0.05
1	2	9	3	07.5	07.25	06.55	00.70	00.59	00.49	0.10
2	1	1	1	04.5	00.32	00.22	00.10	00.0[illegible]	00.0[illegible]	0.01
2	1	1	2	05.9	02.53	01.35	01.18	00.23	00.19	0.04
2	1	1	3	02.8	00.80	00.53	00.27	00.11	00.10	0.01
2	1	2	1	03.1	00.10	00.05	00.05	00.02	00.01	0.01
2	1	2	2	04.1	01.68	01.02	00.67	00.17	00.11	0.06

*Variates in column order are blocks, fertilisation (1 = water only; 2 = '® Chemicult Plus'), media (1 = Amberglo; 2 = bark; 3 = ® Gromor; 4 = bark + nutrients; 5 = bark + ® Lewatit; 6 = Canadian peat; 7 = local peat; 8 = local peat + nutrients; 9 = local peat + ® Lewatit), kinds (1 = tomatoes; 2 = cucumbers; 3 = cabbages), height (cm), total fresh mass (g), top fresh mass (g), root fresh mass (g), total dry mass (g), top d

APPENDIX TABLE 14 Continued

2	1	2	3	02.2	00.12	00.08	00.03	00.02	00.02	0.01
2	1	3	1	02.3	00.08	00.05	00.03	00.01	00.01	0.01
2	1	3	2	04.2	01.37	00.63	00.68	00.13	00.09	0.04
2	1	3	3	03.0	00.07	00.05	00.02	00.01	00.01	0.01
2	1	4	1	05.6	01.16	00.78	00.38	00.17	00.14	0.03
2	1	4	2	11.0	04.40	02.60	01.88	00.41	00.31	0.10
2	1	4	3	02.9	00.78	00.94	00.12	00.12	00.11	0.01
2	1	5	1	04.3	00.68	00.45	00.23	00.06	00.04	0.02
2	1	5	2	07.4	03.44	01.84	01.60	00.19	00.13	0.06
2	1	5	3	02.4	00.45	00.34	00.14	00.04	00.03	0.02
2	1	6	1	04.4	00.70	00.30	00.40	00.09	00.06	0.03
2	1	6	2	08.4	03.73	02.03	01.70	00.35	00.26	0.08
2	1	6	3	02.9	00.63	00.43	00.20	00.09	00.07	0.01
2	1	7	1	03.5	00.18	00.13	00.05	00.03	00.02	0.01
2	1	7	2	04.4	02.06	01.17	00.92	00.20	00.15	0.05
2	1	7	3	02.1	00.18	00.15	00.03	00.03	00.02	0.01
2	1	8	1	03.3	00.22	00.14	00.03	00.04	00.03	0.01
2	1	8	2	12.7	04.38	02.82	01.56	00.45	00.36	0.08
2	1	8	3	02.1	00.60	00.48	00.13	00.09	00.07	0.02
2	1	9	1	06.0	01.98	01.72	00.26	00.36	00.26	0.03
2	1	9	2	11.3	04.56	02.70	01.86	00.44	00.33	0.11
2	1	9	3	04.2	02.23	02.00	00.23	00.34	00.32	0.02
2	2	1	1	16.5	05.67	05.27	00.40	00.55	00.45	0.09
2	2	1	2	12.0	04.60	04.00	00.60	00.42	00.34	0.08
2	2	1	3	08.5	11.27	10.15	01.12	00.89	00.75	0.14
2	2	2	1	18.9	06.20	05.30	00.92	00.52	00.42	0.10
2	2	2	2	20.0	08.55	07.15	01.40	00.67	00.57	0.10
2	2	2	3	05.5	03.97	03.67	00.30	00.31	00.25	0.05
2	2	3	1	14.3	03.00	02.43	00.57	00.15	00.13	0.03
2	2	3	2	09.6	02.75	02.45	00.30	00.22	00.18	0.04
2	2	3	3	**.*	**.**	**.**	**.**	**.**	**.**	*.**
2	2	4	1	25.9	08.63	06.92	01.72	00.67	00.56	0.11
2	2	4	2	16.5	06.95	05.95	01.00	00.55	00.45	0.07
2	2	4	3	07.4	10.45	09.60	01.35	00.72	00.60	0.12
2	2	5	1	22.9	[illegible]	07.32	02.27	00.76	00.63	0.13
2	2	5	2	16.2	05.52	04.68	00.84	00.42	00.35	0.06
2	2	5	3	11.2	14.92	12.42	02.50	01.06	00.94	0.12
2	2	6	1	14.6	02.32	02.02	00.30	00.16	00.14	0.04
2	2	6	2	11.3	02.35	02.05	00.25	00.21	00.17	0.04
2	2	6	3	07.8	05.17	04.73	00.42	00.37	00.32	0.05
2	2	7	1	22.1	05.30	04.68	00.62	00.45	00.37	0.08
2	2	7	2	16.5	04.90	04.87	01.03	00.45	00.36	0.09
2	2	7	3	11.5	07.68	07.90	00.90	00.55	00.53	0.06
2	2	8	1	16.3	05.75	04.00	01.75	00.20	00.16	0.04
2	2	8	2	14.7	04.28	03.93	00.35	00.35	00.29	0.06
2	2	8	3	10.9	11.83	09.88	01.95	00.94	00.73	0.21
2	2	9	1	14.4	04.56	03.52	00.96	00.35	00.28	0.08
2	2	9	2	15.6	04.92	04.20	00.72	00.40	00.34	0.07
2	2	9	3	05.5	07.28	06.45	00.83	00.55	00.45	0.09
3	1	1	1	04.3	00.47	00.30	00.17	00.06	00.05	0.02
3	1	1	2	06.5	02.02	00.95	01.07	00.17	00.11	0.06
3	1	1	3	02.2	00.33	00.23	00.10	00.05	00.04	0.01
3	1	2	1	02.6	00.10	00.08	00.03	00.02	00.01	0.01
3	1	2	2	04.4	01.86	00.76	01.10	00.17	00.11	0.06
3	1	2	3	02.3	00.20	00.13	00.07	00.03	00.02	0.01
3	1	3	1	02.3	00.05	00.03	00.02	00.01	00.01	0.01
3	1	3	2	04.0	01.48	00.55	00.93	00.12	00.08	0.04
3	1	3	3	**.*	**.**	**.**	**.**	**.**	**.**	*.**
3	1	4	1	04.7	00.85	00.53	00.32	00.11	00.09	0.03
3	1	4	2	09.5	04.10	02.26	01.84	00.41	00.33	0.08

APPENDIX TABLE 14 Continued

3	1	4	3	02.8	00.85	00.70	00.15	00.13	00.12	0.01
3	1	5	1	04.6	00.74	00.28	00.46	00.07	00.05	0.02
3	1	5	2	07.0	02.96	01.66	01.32	00.17	00.12	0.05
3	1	5	3	02.6	00.60	00.40	00.20	00.05	00.04	0.02
3	1	6	1	03.9	00.55	00.28	00.25	00.07	00.05	0.02
3	1	6	2	03.2	03.12	01.50	01.62	00.24	00.17	0.07
3	1	6	3	02.9	00.80	00.65	00.15	00.13	00.12	0.01
3	1	7	1	03.2	00.17	00.10	00.07	00.03	00.02	0.01
3	1	7	2	04.5	01.83	00.90	00.93	00.17	00.11	0.06
3	1	7	3	01.9	00.17	00.15	00.03	00.02	00.02	0.01
3	1	8	1	04.1	00.48	00.32	00.17	00.07	00.06	0.01
3	1	8	2	10.1	03.10	01.97	01.13	00.28	00.22	0.06
3	1	8	3	02.3	00.83	00.63	00.20	00.13	00.12	0.01
3	1	9	1	07.1	02.12	01.45	00.63	00.33	00.26	0.07
3	1	9	2	13.7	05.33	03.32	02.02	00.56	00.44	0.12
3	1	9	3	04.6	03.03	02.63	00.40	00.41	00.37	0.08
3	2	1	1	17.0	07.47	06.43	01.03	00.67	00.55	0.12
3	2	1	2	13.3	06.12	05.28	00.83	00.55	00.44	0.11
3	2	1	3	06.0	14.40	12.43	01.97	01.25	00.94	0.31
3	2	2	1	19.8	10.57	08.93	01.63	01.07	00.80	0.21
3	2	2	2	19.4	09.02	07.52	01.50	00.70	00.59	0.11
3	2	2	3	06.5	06.57	05.93	00.63	00.57	00.46	0.11
3	2	3	1	13.7	02.67	02.40	00.27	00.21	00.17	0.04
3	2	3	2	10.0	02.40	02.10	00.30	00.20	00.27	0.03
3	2	3	3	03.5	07.30	06.40	00.90	00.56	00.49	0.07
3	2	4	1	23.8	06.42	05.38	01.03	00.52	00.45	0.07
3	2	4	2	17.1	07.48	06.27	01.22	00.50	00.45	0.10
3	2	4	3	07.0	06.35	05.80	00.55	00.47	00.41	0.06
3	2	5	1	22.1	10.58	07.85	02.73	01.18	01.04	0.14
3	2	5	2	17.0	06.65	05.58	01.08	00.53	00.45	0.08
3	2	5	3	09.6	16.40	13.80	02.62	01.29	01.14	0.14
3	2	6	1	18.7	03.27	02.97	00.30	00.26	00.21	0.05
3	2	6	2	10.9	03.60	03.10	00.50	00.35	00.29	0.07
3	2	6	3	07.3	03.73	03.23	00.50	00.26	00.23	0.04
3	2	7	1	21.1	03.72	03.40	00.32	00.30	00.25	0.05
3	2	7	2	15.0	06.37	05.27	01.06	00.51	00.41	0.10
3	2	7	3	11.0	10.82	09.78	01.04	00.93	00.79	0.11
3	2	8	1	15.4	03.71	02.63	01.09	00.27	00.23	0.05
3	2	8	2	11.9	03.65	03.25	00.40	00.32	00.28	0.04
3	2	8	3	11.3	14.24	11.80	02.44	01.12	00.90	0.21
3	2	9	1	12.1	02.84	02.16	00.65	00.23	00.17	0.05
3	2	9	2	15.7	04.65	04.10	00.50	00.43	00.36	0.06
3	2	9	3	07.9	07.20	06.52	00.65	00.55	00.49	0.09

APPENDIX TABLE 15 Analysis of Variance for Experiment 5

Source of Variation	DF	M.S.								
		Height	Fresh Mass				Dry Mass			
			Whole Plant	Shoot	Root	Root/Shoot Ratio x 10^{-1}	Whole Plant x 10^{-1}	Shoot x 10^{-1}	Root x 10^{-2}	Root/Shoot Ratio x 10^{-1}
Blocks	2	2	0,5	0,3	0,2	0,7	0,3	0,2	0,6	0,03
Fert.	1	3201**	1137,0**	944,3*	8,8**	82,5**	58,0*	43,4*	16,7**	11,0**
Med.	8	36**	23,1**	14,6**	1,2**	1,1**	1,9**	1,1**	1,1*	1,9**
Kinds	2	522**	41,7**	42,4**	3,0**	13,2**	2,4**	1,7**	0,02	2,1**
F.M.	8	42**	27,3**	17,0**	1,3**	1,3**	2,3**	4,7**	1,5**	2,7**
F.K.	2	273**	142,5**	79,1**	11,4**	11,1**	7,4**	0,4**	4,1**	0,05
M.K.	16	14**	6,3**	4,3**	0,4**	0,6*	0,6**	0,3*	0,4	0,5
F.M.K	16	11**	6,5**	4,4**	0,3**	0,3	0,5*	0,3**	0,4	0,7
Error	103	1	1,2	0,8	0,08	0,3	0,1	0,07	0,3	0,4
CV %		11,4	26,2	26,3	34,7	39,5	32,5	30,0	84,6	60,1

APPENDIX TABLE 16 Data for Experiment 6*

1	1	1	1	03.78	02.44	01.34	00.26	00.19	0.07
1	1	1	2	05.18	03.90	01.28	00.42	00.32	0.10
1	1	1	3	09.13	06.10	03.03	00.52	[illegible]	0.22
1	1	2	1	08.40	07.22	01.17	[illegible]	00.07	0.05
1	1	2	2	08.68	07.38	01.30	00.63	[illegible]	0.13
1	1	2	3	11.18	07.26	03.92	00.96	00.70	0.26
1	1	3	1	06.97	05.22	01.75	00.39	00.33	0.07
1	1	3	2	08.90	06.96	01.94	00.70	00.60	0.10
1	1	3	3	12.89	08.69	04.20	00.98	00.77	0.21
1	2	1	1	04.80	03.33	01.48	00.35	00.27	0.08
1	2	1	2	04.59	03.52	01.30	00.30	00.24	0.06
1	2	1	3	09.00	06.83	02.13	00.77	00.64	0.14
1	2	2	1	07.40	06.47	00.93	00.34	00.29	0.05
1	2	2	2	07.86	05.46	02.40	00.69	00.52	0.17
1	2	2	3	10.73	08.78	02.00	00.85	00.71	0.13
1	2	3	1	08.08	06.66	01.42	00.40	00.32	0.08
1	2	3	2	08.68	06.94	01.74	00.60	00.48	0.12
1	2	3	3	14.20	11.60	02.60	01.07	00.82	0.25
1	3	1	1	07.20	[illegible]	02.32	00.55	[illegible]	[illegible]
1	3	1	2	05.30	04.04	01.26	[illegible]	[illegible]	0.06
1	3	1	3	12.33	08.58	03.75	00.97	00.77	0.20
1	3	2	1	[illegible]	07.74	[illegible]	00.43	[illegible]	[illegible]
1	3	2	2	06.47	05.33	01.13	00.45	00.37	[illegible]
1	3	2	3	[illegible]	12.27	02.37	01.11	00.93	[illegible]
1	3	3	1	07.83	06.30	01.53	00.38	00.31	0.07
1	3	3	2	[illegible]	[illegible]	[illegible]	00.75	[illegible]	[illegible]
1	3	3	3	[illegible]	[illegible]	02.90	01.25	[illegible]	[illegible]
2	1	1	1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	1	1	2	[illegible]	[illegible]	01.72	[illegible]	[illegible]	[illegible]
2	1	1	3	[illegible]	[illegible]	02.97	[illegible]	[illegible]	0.17
2	1	2	1	06.90	04.15	02.75	[illegible]	[illegible]	0.07
2	1	2	2	08.72	07.17	01.55	[illegible]	[illegible]	0.12
2	1	2	3	09.15	07.07	02.08	[illegible]	[illegible]	0.17
2	1	3	1	08.70	07.24	01.45	[illegible]	[illegible]	0.07
2	1	3	2	[illegible]	[illegible]	[illegible]	00.54	[illegible]	[illegible]
2	1	3	3	[illegible]	[illegible]	01.60	00.54	[illegible]	[illegible]
2	2	1	1	04.13	[illegible]	01.30	[illegible]	[illegible]	0.07
2	2	1	2	06.40	04.73	[illegible]	00.33	[illegible]	[illegible]
2	2	1	3	[illegible]	[illegible]	[illegible]	00.64	[illegible]	[illegible]
2	2	2	1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	2	2	2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	2	2	3	[illegible]	11.33	[illegible]	01.11	[illegible]	[illegible]
2	2	3	1	[illegible]	06.42	[illegible]	00.34	[illegible]	[illegible]
2	2	3	2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.11
2	2	3	3	[illegible]	12.10	01.74	01.11	00.78	[illegible]
2	3	1	1	05.90	04.54	[illegible]	00.40	00.33	[illegible]
2	3	1	2	06.28	[illegible]	01.72	[illegible]	[illegible]	0.10
2	3	1	3	[illegible]	[illegible]	03.40	[illegible]	00.79	0.22
2	3	2	1	[illegible]	[illegible]	[illegible]	00.54	[illegible]	[illegible]
2	3	2	2	07.28	[illegible]	01.20	[illegible]	[illegible]	0.12
2	3	2	3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	3	3	1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	3	3	2	[illegible]	09.37	[illegible]	[illegible]	00.73	0.17
2	3	3	3	12.55	[illegible]	[illegible]	01.11	00.76	[illegible]

*Variates in column order are blocks, concentrations (1 = 0,7 g; 1,4 g; 3 = 2,1 g), times (1 = once per day= 2 = once every second day; 3 = once per week as solid), kinds (1 = lettuce; 2 = tomatoes; 3 = cabbages), total fresh mass (g), top fresh mass (g), root fresh mass (g), total dry mass (g), top dry mass (g), root dry mass (g)

APPENDIX TABLE 16 Continued

3	1	1	1	05.57	03.92	01.65	00.37	00.35	0.02
3	1	1	2	03.73	02.68	01.05	00.25	00.20	0.05
3	1	1	3	07.80	05.28	02.53	00.65	00.52	0.14
3	1	2	1	07.10	05.96	01.14	00.38	00.34	0.04
3	1	2	2	07.07	05.73	01.33	00.50	00.40	0.10
3	1	2	3	08.25	06.36	02.16	00.70	00.59	0.11
3	1	3	1	12.42	09.37	03.05	00.61	00.51	0.11
3	1	3	2	07.08	05.45	01.63	00.43	00.40	0.03
3	1	3	3	11.32	08.33	02.98	00.99	00.73	0.27
3	2	1	1	07.14	04.90	02.24	00.40	00.32	0.09
3	2	1	2	05.49	04.17	01.32	00.40	00.32	0.08
3	2	1	3	10.28	07.62	02.65	00.50	00.57	0.13
3	2	2	1	10.90	09.60	01.30	00.45	00.39	0.06
3	2	2	2	07.20	05.27	01.93	00.57	00.45	0.12
3	2	2	3	12.00	09.13	02.87	00.79	00.60	0.19
3	2	3	1	11.53	09.63	01.90	00.63	00.46	0.17
3	2	3	2	07.36	06.13	01.23	00.60	00.42	0.18
3	2	3	3	10.40	08.90	01.50	00.83	00.70	0.13
3	3	1	1	10.46	07.14	03.32	00.57	00.42	0.15
3	3	1	2	05.13	03.93	01.20	00.30	00.23	0.07
3	3	1	3	14.02	09.92	04.10	01.12	00.86	0.26
3	3	2	1	12.77	10.42	02.35	00.59	00.47	0.12
3	3	2	2	08.98	07.43	01.55	00.65	00.55	0.10
3	3	2	3	14.44	12.02	02.42	01.06	00.91	0.15
3	3	3	1	09.90	08.00	01.90	00.51	00.38	0.13
3	3	3	2	09.48	07.[illegible]5	01.[illegible]3	[illegible]	[illegible]	0.10
3	3	3	3	11.12	09.96	01.16	00.61	00.45	0.16
4	1	1	1	05.65	03.90	01.75	00.38	00.27	0.11
4	1	1	2	04.20	02.77	01.43	00.31	00.24	0.07
4	1	1	3	07.18	04.56	02.62	00.73	00.55	0.18
4	1	2	1	07.33	05.93	01.40	00.41	00.36	0.05
4	1	2	2	05.98	04.35	01.63	00.52	00.41	0.11
4	1	2	3	10.17	07.75	02.42	00.94	00.75	0.19
4	1	3	1	08.10	06.64	01.46	00.45	00.38	0.07
4	1	3	2	07.23	05.20	02.03	01.17	00.70	0.47
4	1	3	3	09.60	07.17	02.43	00.98	00.77	0.21
4	2	1	1	07.74	05.42	02.32	00.39	00.27	0.12
4	2	1	2	04.57	03.38	01.19	00.37	00.28	0.09
4	2	1	3	06.40	04.45	01.95	00.58	00.41	0.17
4	2	2	1	09.74	08.54	01.20	00.52	00.46	0.06
4	2	2	2	08.84	06.74	02.10	00.70	00.50	[illegible]
4	2	2	3	13.90	10.64	03.26	[illegible]	[illegible]	0.22
4	2	3	1	07.25	06.58	00.67	00.36	00.31	0.05
4	2	3	2	12.02	09.72	02.30	00.94	00.79	0.15
4	2	3	3	12.14	10.74	01.40	[illegible]	00.76	[illegible]
4	3	1	1	05.68	04.22	01.46	00.26	00.21	0.05
4	3	1	2	05.81	04.30	01.51	00.44	00.36	0.08
4	3	1	3	10.30	07.32	02.98	00.65	00.47	0.18
4	3	2	1	15.19	11.72	03.47	00.42	00.16	0.26
4	3	2	2	07.92	06.63	01.29	00.57	00.47	0.10
4	3	2	3	11.93	[illegible]	[illegible]	[illegible]	[illegible]	0.13
4	3	3	1	07.05	05.60	01.45	00.35	00.28	0.07
4	3	3	2	09.13	07.13	02.00	00.33	[illegible]	[illegible]
4	3	3	3	12.24	10.65	01.58	01.05	00.88	0.17

APPENDIX TABLE 16 Continued

5	1	1	1	05.22	03.90	01.32	00.39	00.32	0.07
5	1	1	2	04.45	03.33	01.07	00.35	00.28	0.07
5	1	1	3	11.02	07.00	03.92	00.98	00.77	0.22
5	1	2	1	09.38	07.73	01.60	00.61	00.53	0.06
5	1	2	2	05.19	06.62	02.03	00.60	00.53	0.07
5	1	2	3	01.04	07.47	02.93	00.37	00.68	0.19
5	1	3	1	07.50	05.97	00.93	00.45	00.40	0.05
5	1	3	2	09.40	07.10	02.30	00.70	00.58	0.12
5	1	3	3	10.45	07.78	02.07	00.86	00.62	0.24
5	2	1	1	07.60	05.37	02.23	00.43	00.29	0.14
5	2	1	2	05.60	04.60	01.17	00.40	00.33	0.07
5	2	1	3	09.67	07.20	02.47	00.83	00.66	0.17
5	2	2	1	09.02	07.03	01.78	00.50	00.39	0.12
5	2	2	2	08.03	06.33	01.20	00.60	00.47	0.13
5	2	2	3	12.63	10.12	02.52	00.59	00.63	0.16
5	2	3	1	07.27	06.12	01.15	00.38	00.34	0.04
5	2	3	2	09.00	07.08	01.52	00.65	00.55	0.10
5	2	3	3	13.82	11.02	02.80	00.91	00.90	0.10
5	3	1	1	10.70	08.03	02.67	00.55	00.44	0.11
5	3	1	2	07.22	05.53	01.65	00.53	00.43	0.10
5	3	1	3	12.50	08.37	04.13	00.94	00.71	0.23
5	3	2	1	09.[illegible]	07.10	01.48	00.47	00.51	0.0[illegible]
5	3	2	2	07.92	06.60	01.32	00.60	00.50	0.10
5	3	2	3	15.42	11.66	03.56	01.07	00.49	0.13
5	3	3	1	05.27	06.52	01.45	00.45	00.37	0.08
5	3	3	2	09.90	07.86	02.04	00.70	00.60	0.1[illegible]
5	3	3	3	11.04	09.34	01.70	00.67	00.59	0.1[illegible]
6	1	1	1	06.53	05.63	00.90	00.50	00.42	0.07
6	1	1	2	05.72	04.33	01.43	00.43	00.37	0.07
6	1	1	3	07.70	05.36	02.34	00.53	00.36	0.13
6	1	2	1	08.90	07.25	01.65	00.40	00.36	0.07
6	1	2	2	06.82	05.02	01.37	00.60	00.47	0.13
6	1	2	3	07.93	05.68	02.25	00.51	00.37	0.14
6	1	3	1	09.22	07.30	01.92	00.52	00.38	0.14
6	1	3	2	07.25	06.05	01.20	00.60	00.50	0.10
6	1	3	3	11.56	08.66	02.90	00.73	00.49	0.24
6	2	1	1	05.50	02.52	00.92	00.23	00.19	0.04
6	2	1	2	06.00	04.50	01.47	00.47	00.37	0.10
6	2	1	3	1[illegible]	07.43	03.50	00.92	00.71	0.21
6	2	2	1	07.42	06.50	00.92	00.52	00.47	0.0[illegible]
6	2	2	2	07.74	06.26	01.48	00.42	00.32	0.10
6	2	2	3	14.[illegible]	11.[illegible]	03.20	01.08	00.87	0.21
6	2	3	1	07.73	06.50	01.23	00.35	00.31	0.04
6	2	3	2	06.95	05.73	01.22	00.34	00.25	0.09
6	2	3	3	11.16	09.64	01.52	00.79	00.62	0.17
6	3	1	1	05.50	03.70	01.80	00.35	00.27	0.08
6	3	1	2	05.65	05.00	01.56	00.46	00.36	0.10
6	3	1	3	10.42	07.50	02.93	00.74	00.60	0.14
6	3	2	1	05.73	06.00	00.73	00.37	00.31	0.06
6	3	2	2	09.08	07.62	01.46	00.73	00.60	0.13
6	3	2	3	14.17	11.47	02.70	01.00	00.84	0.17
6	3	3	1	06.46	05.32	01.14	00.52	00.45	0.07
6	3	3	2	07.48	05.94	01.54	00.52	00.46	0.0[illegible]
6	3	3	3	11.50	10.62	01.52	00.54	00.73	0.14

APPENDIX TABLE 17 Analysis of Variance for Experiment 6

Source of Variation	DF	M.S.							
		Fresh Mass				Dry Mass			
		Whole plant	Shoot	Root	Root/Shoot Ratio x 10^{-2}	Whole plant x 10^{-1}	Shoot x 10^{-2}	Root x 10^{-2}	Root/Shoot Ratio x 10^{-2}
Blocks	5	1,6	1,3	0,3	0,8	0,4	0,6	0,3	8,3
Conc.	2	58,4**	48,5**	0,8	10,0*	1,7*	7,6**	0,1	11,1
Times	2	101,4**	124,5**	0,7	40,3**	5,1**	30,7**	0,8	11,6
Kinds	2	224,1**	129,1**	19,5**	3,6*	29,4**	178,8**	15,7**	13,2
Times .Conc.	4	7,5	3,7	1,1	1,5	0,2	3,7	0,2	9,5
Times .Kinds	4	11,6*	7,9*	0,4	1,6	0,2	4,1	0,2	9,9
Conc. .Types	4	4,7	3,1	1,5*	2,8	1,4	0,9	0,6	11,1
Times. Conc. .Types	8	4,9	2,5	0,4	0,8	0,4	1,1	0,1	6,7
Error	130	2,9	1,5	0,3	0,6	0,3	4,0	0,3	6,9
CV %		19,0	17,3	28,2	25,7	27,6	20,9	41,0	98,3

APPENDIX TABLE 18 Data for Experiment 10*

1 1 1 1	3134	4.5	696	11	50	33
2 2 1 1	4938	6.0	823	25	8	66
3 1 2 1	4691	6.5	722	19	31	46
4 2 2 1	2212	3.0	737	22	33	44
1 2 1 2	3723	5.3	698	38	31	32
2 1 2 2	4934	6.8	731	33	30	18
3 2 2 2	3953	6.5	608	43	19	44
4 1 1 3	3935	5.5	715	27	36	50
1 1 2 3	2938	4.3	668	29	35	31
2 2 2 3	3202	5.3	610	48	38	45
2 1 1 1	4479	6.5	689	42	23	35
3 2 1 1	3400	5.0	680	25	40	30
4 1 2 1	2885	4.3	669	18	35	41
1 1 1 2	3757	5.5	683	18	41	37
2 2 1 2	2418	3.8	645	40	7	37
3 1 2 2	3758	5.8	654	48	26	25
4 2 2 2	3298	5.8	574	30	35	43
1 2 1 3	3121	5.0	624	30	20	10
2 1 2 3	4343	5.5	790	27	32	27
3 2 2 3	2391	4.0	598	50	25	35
3 1 1 1	3433	5.3	654	38	14	38
4 2 1 1	1387	2.3	594	44	0	43
1 2 2 1	3445	4.8	725	16	63	21
2 1 1 2	4734	6.8	701	37	22	23
3 2 1 2	3211	5.5	584	64	9	26
4 1 2 2	2662	3.8	683	27	20	29
1 1 1 3	3577	5.8	622	22	30	29
2 2 1 3	3521	4.8	741	26	37	33
3 1 2 3	3417	5.3	651	43	19	39
4 2 2 3	1996	3.0	665	44	11	32
4 1 1 1	1915	3.3	589	39	46	15
1 1 2 1	4350	6.5	679	38	27	35
2 2 2 1	5629	7.8	726	29	26	42
3 1 1 2	5036	7.0	719	15	43	30
4 2 1 2	1851	3.5	529	21	14	53
1 2 2 2	3397	4.8	715	16	32	37
2 1 1 3	5495	7.8	709	29	23	38

APPENDIX TABLE 18 Continued

3 2 1 3	2724	4.3	641	53	29	33
4 1 2 3	2808	4.3	661	59	12	39
1 2 1 1	2700	4.3	635	29	24	47
2 1 2 1	4726	7.0	675	36	39	25
3 2 2 1	4205	5.5	765	27	27	45
4 1 1 2	2773	4.5	616	33	11	19
1 1 2 2	3944	6.3	631	40	24	40
2 2 2 2	4564	7.5	509	43	27	41
3 1 1 3	2393	4.0	598	50	25	35
4 2 1 3	3318	5.0	664	30	30	25
1 2 2 3	2347	3.0	782	33	33	18

*Variates in column order are volume of medium (1 = 7ℓ; 2 = 10ℓ; 3 = 13ℓ; 4 = 17ℓ), between-row spacing (1 = 30 cm; 2 = 60 cm), in-row spacing (1 = 20 cm; 2 = 40 cm), blocks, yield (g plant^{-1}), total no fruit, mean fruit mass (g), per cent. class 3, per cent. class 2, per cent. class 1

APPENDIX TABLE 19 Analysis of Variance for Experiment 10

Source of Variation	DF	M.S.								
		Total yield	Total No. fruit	Mean fruit Mass	Per Cent. No. in Class			No. Fruit in Class		
					1	2	3	1	2	3
		x 10^4		x 10^2		x 10^2	x10	x 10^{-1}	x 10^{-1}	x 10^{-1}
Blocks	2	82,7	2,4	71,9	0,6	1,4	32,0	6,3	2,4	7,8
Between	1	50,5	0,8	47,8	0,03	1,5	2,0	0,3	6,1	4,8
In	1	350,2	6,1	11,3	2,6	1,2	4,6	25,6	12,5	1,5
B.I	1	29,0	0,8	0,3	0,03	4,9	0,01	0,3	13,0	1,0
Error (a)	6	106,1		39,7	0,9	1,1	15,6	8,9	5,6	1,9
Volume	3	682,7**	10,7**	90,8*	1,5*	2,6	33,7*	15,4*	11,6	2,5**
V.B	3	7,2	0,4	34,3	0,4	1,1	2,5	3,8	5,7	0,7
V.I	3	5,3	0,2	25,0	0,2	0,2	5,4	1,8	0,3	2,7
V.B.I	3	27,0	1,8	6,2	0,1	1,5	6,2	1,2	1,5	1,7
Error (b)	24	55,4	0,8	28,3	0,4	1,5	9,1	4,2	4,1	0,3
CV %		23,3	19,6	8,3	40,7	43,0	34,2	40,7	46,2	32,3

APPENDIX TABLE 20 Data for Experiment 12*

1	1	1	3523	21	2204	14	743	5	1197	13	2027	24	2751	37
1	1	2	4317	23	3133	26	1072	10	981	10	3109	27	1236	14
1	1	3	3423	24	4256	40	1774	19	2036	21	1789	24	368	6
1	1	4	4125	30	3759	25	2651	32	1618	20	1641	21	563	7
1	1	5	3257	20	3939	35	2316	22	2573	29	1972	26	922	13
1	1	6	4770	38	4341	38	3093	25	1672	21	2555	34	3675	43
1	1	7	4750	34	2950	25	2302	33	1107	10	655	7	1790	27
1	1	8	3631	30	3621	31	3502	41	2341	29	1390	15	3729	47
1	2	1	2594	26	1974	24	825	10	369	9	332	6	356	6
1	2	2	2642	32	2165	23	1993	20	2109	26	586	12	471	8
1	2	3	2224	23	2662	28	2539	22	1372	18	590	7	547	7
1	2	4	3436	28	1715	22	1907	23	1572	17	747	10	734	13
1	2	5	2074	23	1630	17	1614	17	543	9	571	9	323	6
1	2	6	1920	17	4516	42	2368	23	1521	24	1147	13	535	[illegible]
1	2	7	2530	22	3123	27	1424	15	2246	31	635	13	2172	32
1	2	8	2729	23	2004	19	2250	22	1760	26	373	6	*	*
2	1	1	4511	26	927	5	112	2	1303	10	1357	11	3052	37
2	1	2	4523	30	2956	19	115	2	1036	17	1743	15	[illegible]	34
2	1	3	3726	29	3267	30	1726	23	1473	24	2076	33	2223	45
2	1	4	4359	39	3765	25	2798	32	2412	36	3334	44	4313	50
2	1	5	4159	30	4443	26	3359	35	2713	29	3930	36	3467	47
2	1	6	4658	34	2803	20	1979	26	1172	13	2560	31	[illegible]	45
2	1	7	4583	37	2155	19	2226	33	1617	10	3759	44	4523	49
2	1	8	3681	35	4573	38	3715	41	1573	19	3210	51	4155	50
2	2	1	4556	40	3529	32	2529	25	3283	48	3246	44	1090	15
2	2	2	3167	30	2615	27	2749	29	2382	25	1372	30	1589	24
2	2	3	2091	26	2315	25	1361	14	1112	16	738	11	541	11
2	2	4	2154	22	2152	20	1629	20	2503	40	3735	47	[illegible]	11
2	2	5	3035	32	2050	21	1545	22	2022	32	3429	42	[illegible]	11
2	2	6	3149	27	2659	27	2522	25	1361	19	3142	43	[illegible]	[illegible]
2	2	7	2505	22	2215	17	1219	13	1549	25	2425	37	2424	42
2	2	8	2077	28	1044	27	2535	27	1127	20	2335	37	[illegible]	1
3	1	1	4291	23	714	3	467	4	377	4	1547	22	3760	40
3	1	2	2721	22	2644	24	2495	25	735	10	[illegible]	32	[illegible]	40
3	1	3	4167	35	[illegible]	[illegible]	2992	23	[illegible]	17	[illegible]	[illegible]	[illegible]	11
3	1	4	4115	31	5734	47	[illegible]	44	2857	[illegible]	[illegible]	[illegible]	[illegible]	7
3	1	5	4219	30	2554	12	[illegible]	[illegible]	2747	16	[illegible]	[illegible]	[illegible]	[illegible]
3	1	6	5013	42	[illegible]	44	[illegible]	34	[illegible]	27	[illegible]	[illegible]	[illegible]	[illegible]
3	1	7	[illegible]	40	4723	30	5275	[illegible]	[illegible]	35	[illegible]	[illegible]	[illegible]	[illegible]
3	1	8	[illegible]	20	[illegible]	33	[illegible]	[illegible]	[illegible]	[illegible]	2013	[illegible]	[illegible]	[illegible]
3	2	1	[illegible]	40	4470	[illegible]	3407	32	[illegible]	37	[illegible]	[illegible]	[illegible]	[illegible]
3	2	2	3051	29	2730	32	[illegible]	[illegible]	2352	26	[illegible]	37	[illegible]	[illegible]
3	2	3	[illegible]	24	2621	31	[illegible]	[illegible]	[illegible]	27	[illegible]	[illegible]	[illegible]	[illegible]
3	2	4	2970	35	2553	30	3720	46	2797	37	[illegible]	[illegible]	[illegible]	[illegible]
3	2	5	[illegible]	20	2251	29	[illegible]	42	[illegible]	43	2567	[illegible]	[illegible]	[illegible]
3	2	6	[illegible]	43	2090	26	[illegible]	24	[illegible]	44	[illegible]	41	[illegible]	[illegible]
3	2	7	2067	21	3321	31	[illegible]	[illegible]	1971	19	2564	43	1541	[illegible]
3	2	8	[illegible]	41	2071	[illegible]	[illegible]	44	3122	39	2117	27	[illegible]	[illegible]

*Variates in column order are blocks, times of planting (1 = 1978:02:16; 2 = 1978:03:09), media (1 = vermiculite; 2 = perlite; 3 = Umgeni river sand; 4 = peat : vermiculite; 5 = 1 peat : 1 sand; 6 = 1 peat : 2 sand; 7 = peat : perlite; 8 = peat:polystyrene), truss 1 - mass (g), truss 1 - No. of fruit, truss 2 - mass (g), truss 2 - No. of fruit, truss 3 - mass (g), truss 3 - No. of fruit, truss 4 - mass (g), truss 4 - No. of fruit, truss 5 - mass (g), truss 5 - No. of fruit

APPENDIX TABLE 21   Analysis of Variance for Experiment 12

Source of Variation	DF	M.S.								
		Yield on Truss						Total yield	Total No. fruit	Mean fruit mass
		1	2	3	4	5	6			
		x 10^3	x 10^3	x 10^3	x 10^3	x 10^3	x 10^3	x 10^4	x 10	x 10
Blocks	2	35,1	36,7	220,1	178,0	425, 2	258,0	408,3	72,0	21,1
Times	1	576,6	346,5*	19,5	9,1	254,4	1311,9*	925,2*	16,3	404,9**
Error (a)	2	34,9	5,4	9,4	298,8	42,8	50,8	27,2	5,9	0,04
Media	7	30,5	38,5	89,1**	234,2	43,1	41,4	75,4	10,3*	15,5*
M.T	7	25,8	113,7**	94,5**	268,4	6,2	43,4	66,0	11,3*	15,2*
Error (b)	27	12,8	29,0	21,4	230,5	25,5	27,0	34,6	3,9	5,3
CV %		15,9	28,2	30,0	38,3	35,9	41,8	19,4	19,2	7,7

APPENDIX TABLE 22 Data for Experiment 13*

1	1	1	3128.8	32.7	972.7
1	1	1	4153.8	41.5	100.0
1	1	3	3364.5	35.3	95.2
1	1	4	4231.8	43.8	96.5
1	1	5	4464.3	42.5	105.0
1	1	6	4270.2	36.8	115.9
1	2	1	3374.3	36.0	93.7
1	2	2	3680.7	43.6	84.2
1	2	3	3785.8	38.1	99.1
1	2	4	4132.7	42.8	96.4
1	2	5	4260.8	42.5	100.2
1	2	6	3336.3	39.8	83.7
2	1	1	5444.7	52.6	103.3
2	1	2	4800.3	47.5	101.0
2	1	3	4728.8	46.8	100.9
2	1	4	4627.0	47.1	98.1
2	1	5	4562.2	43.1	105.6
2	1	6	4821.7	52.6	91.5
2	2	1	4858.5	44.0	94.5
2	2	2	4048.7	42.3	95.6
2	2	3	3449.8	41.5	83.1
2	2	4	3857.8	44.8	86.0
2	2	5	4784.5	49.5	96.6
2	2	6	3697.0	40.8	90.5
3	1	1	3921.5	40.1	97.6
3	1	2	4538.3	43.6	103.9
3	1	3	3965.8	42.5	93.3
3	1	4	4246.5	43.6	97.2
3	1	5	4780.5	48.5	98.5
3	1	6	4529.8	44.1	102.5
3	2	1	3945.7	42.0	93.9
3	2	2	3841.8	42.5	90.4
3	2	3	3140.3	39.1	80.1
3	2	4	3419.5	41.5	82.4
3	2	5	4102.5	45.0	91.1
3	2	6	3324.0	41.5	80.1
4	1	1	3851.7	43.3	88.8
4	1	2	3675.0	37.1	98.8
4	1	3	3816.8	43.3	88.0
4	1	4	4143.5	45.3	91.4
4	1	5	2899.0	31.1	93.0
4	1	6	3710.8	42.5	87.3
4	2	1	5371.2	44.1	121.6
4	2	2	3280.8	38.5	85.2
4	2	3	3803.2	44.0	86.4
4	2	4	3506.3	40.8	85.8
4	2	5	3778.8	40.8	92.5
4	2	6	3236.3	36.6	88.2

*Variates in column order are blocks, fertilisation (1 = pre-enrichment, 2 = post plant feeding only), media (1 = 1 local peat: 3 sand; 2 = local peat; 3 = bagasse; 4 = sand:bagasse; 5 = mushroom compost:vermiculite; 6 = 1 local peat:1 sand), yield (g $plant^{-1}$), number of fruit per plant, mean fruit mass (g)

APPENDIX TABLE 23 Analysis of Variance for Experiment 13

Source of Variation	DF	M.S. Total Yield x 10^{-4}	Total No. Fruit	Mean Fruit Mass (g)
Blocks	3	1020	98,6	70,2
Fert.	1	1825	13,0	597,1
Error (a)	3	627	22,7	119,6
Media	5	227	6,1	89,1
F.M	5	334	12,3	79,5
Error (b)	30	211	14,0	45,0
CV %		11,5	8,8	7,1

APPENDIX TABLE 24 Data for Experiment 14*

1	2799	25	3118	35	4261	43	3383	39	2374	26	1580	20	0943	15	0777	12	0000
2	4415	44	3947	46	1612	22	2727	34	2590	28	0910	10	1045	16	0177	03	0298
3	2701	32	2395	33	2969	34	1857	19	1456	18	1081	16	0931	16	0940	14	0000
4	4129	39	3177	40	4347	46	3329	33	1529	20	0403	07	1317	17	0845	10	0000
5	2257	28	2904	26	2478	26	2435	31	1113	15	0741	12	0759	11	0811	13	0448
1	4179	39	4439	43	4459	53	4016	47	2975	34	0526	08	0990	16	0711	11	0000
2	3881	34	3171	35	3352	42	4771	53	4068	49	1731	25	1167	19	1332	25	0000
3	4344	39	3598	36	3479	42	5353	53	3452	38	2027	27	0749	13	0865	19	0000
4	5037	50	3634	37	2975	40	1701	51	1594	64	1887	37	2607	51	1397	21	0000
5	4241	42	3404	40	5491	61	3894	43	2081	26	1152	24	1304	22	1510	24	0000
1	3617	35	3846	40	3114	44	4372	62	0745	15	1091	21	1353	30	1094	17	0887
2	4275	45	3374	36	4126	49	3795	41	1987	29	1915	26	1470	21	0439	08	2192
3	4209	44	4104	55	5108	54	2904	28	2403	26	0977	14	0916	13	1717	22	0000
4	2552	28	2967	48	3383	54	2556	30	2057	31	0858	12	0976	16	0436	08	0088
5	3690	39	3605	41	4519	48	5317	61	2557	35	1380	17	1966	28	0695	08	0000
1	3041	28	2067	22	2670	32	3394	41	2703	39	1057	14	0437	08	0582	14	0000
2	4745	36	3916	38	4675	55	3435	39	2849	35	1612	21	0954	15	0881	20	0000
3	4044	34	2937	34	1757	30	3280	52	1376	25	0934	18	0249	06	0501	10	0540
4	2971	33	2248	28	2694	32	1952	23	1539	20	1166	16	0662	09	0459	09	1960
5	3470	34	3543	36	3646	37	2071	29	0908	15	1249	23	1312	27	1029	21	0624
1	3604	43	5039	53	4072	59	4300	60	1483	24	0457	11	0284	09	0121	03	0090
2	4380	43	4336	53	3492	42	4699	50	3195	39	1293	20	0286	07	1544	30	1336
3	4497	45	3635	38	4602	53	3615	38	1632	22	2190	31	1345	22	0921	21	0960
4	3556	40	2974	39	2015	39	2082	49	1124	42	1207	29	0699	17	0983	20	0501
5	4388	35	5311	59	4856	56	2606	26	2700	36	1630	29	1207	23	0983	21	1287
1	4603	43	3005	37	5840	64	4560	52	2984	32	1029	17	1110	17	0343	10	0000
2	4999	51	2201	24	3431	42	4331	43	3568	48	1258	22	1015	18	1220	20	0000
3	3986	44	3501	41	3490	40	6216	57	0683	10	0566	13	1028	14	3828	60	0000
4	4343	45	3310	41	2667	40	2723	50	2612	53	1401	28	0757	18	1466	32	0640
5	5014	50	3705	41	3822	45	5388	57	2597	35	2459	32	0936	18	1096	20	0932
1	5184	49	3358	32	4011	43	3433	44	2046	32	1131	17	0675	14	0776	22	0000
2	3066	28	3397	34	4182	42	3847	39	1963	25	1184	21	0615	13	0958	25	0000
3	2992	31	2936	34	3176	32	1709	18	1907	29	0773	13	0517	13	1131	24	0796
4	3396	30	3637	33	3190	30	2939	27	1370	21	1431	25	1577	28	1037	16	0372
5	3383	37	3482	39	2952	27	1693	21	0943	16	0551	14	0557	16	1700	44	0000
1	3322	42	3616	47	3291	40	5262	68	1437	20	1398	28	0682	19	0805	17	0000
2	2371	30	2262	35	3874	46	3340	40	2729	46	1444	24	1142	22	0284	08	0000
3	4254	45	1775	20	4565	51	3617	42	2489	41	1167	23	1443	29	0293	05	0000
4	5142	53	2972	36	3686	45	3450	37	2079	31	1699	30	0832	16	1533	32	1223
5	4135	44	4090	40	3162	34	2370	32	1425	32	1066	19	0740	14	1276	20	1996
1	3847	35	6016	66	6242	75	6676	79	3363	47	1449	29	1972	40	0682	20	0343
2	3166	46	5043	53	5648	68	4346	51	2300	28	1726	31	1185	24	0955	24	1192
3	3506	37	3297	35	4761	53	3420	40	2674	29	1391	23	1212	22	0739	12	0000
4	4149	35	4816	50	4445	53	2640	39	1033	21	0761	24	0937	19	1069	19	0000
5	4277	39	3040	30	4821	48	3554	46	2235	39	0752	16	1283	26	0665	17	0000
1	4286	48	3675	45	4462	49	3372	42	1325	20	0435	13	0625	19	0491	10	1036
2	2895	32	3492	44	4214	56	4240	57	2396	40	0764	14	0346	12	0383	09	0363
3	3142	32	2910	30	4242	47	2590	36	0673	11	0542	11	0446	13	0305	09	0000
4	2924	31	3330	38	4161	41	2970	37	1917	26	0643	14	0000	00	0000	00	0336
5	3196	36	3124	32	2166	23	1423	21	0612	10	0696	13	0349	06	0514	08	0000
1	2517	30	3503	49	3855	46	3461	44	1708	27	0740	15	0104	03	0282	08	0000
2	2601	32	4642	54	2380	29	4303	56	2587	29	1392	23	0740	14	0641	12	0000
3	4288	47	3042	37	4661	52	3361	43	2171	31	1454	30	0815	13	0696	12	0000
4	3090	41	1689	31	2837	44	1592	46	1416	40	0890	20	0614	23	0686	33	0000
5	3385	33	3052	37	3327	35	2760	36	1836	26	1546	25	0585	14	0685	13	0734
1	3615	44	3015	38	4680	63	3521	54	1176	20	0597	09	0312	07	0140	04	1262
2	2771	33	4317	61	6205	73	3216	34	2067	32	0382	22	1078	17	1399	28	1311
3	4114	46	4248	49	4973	51	4093	50	2060	29	0683	14	0569	13	0965	17	0801
4	3142	33	4070	54	4977	51	4669	52	1928	23	0569	12	0211	05	1016	24	0220
5	3730	46	4438	58	6110	68	3576	46	1695	28	0607	11	1066	18	1449	29	0000

* Variates in column order are blocks, fertilisation (1 = Scottish; 2 = Jensen; 3 = ® Chemicult), media (1 = small bark; 2 = large bark; 3 = sawdust; 4 = sand : peat; 5 = perlite), total fruit mass (g) (4 plants) and No. fruit (4 plants) respectively on trusses 1, 2, 3, 4, 5, 6, 7, 8, 9

APPENDIX TABLE 25 Analysis of Variance for Experiment 14

Source of Variation	DF	M.S. Number of Fruit on Truss 1	2	3	4	5	6	7	8	9
Blocks	3	1,5	5,2	4,1	2,7	5.4	7,5	16,7	11,9	12,9
Fert.	2	16,5*	31,4	88,2*	77,3**	40,6*	21,5**	11.3*	8,0	1,0
Error (a)	6	3,0	9,5	11,5	5,2	5,5	1,5	1,9	12,2	10,9
Media	4	0,4	4,2	9,2	27,4**	14,4*	2,6	1,0	6,6	7,3
F.M	8	4,6	4,9	6,0	8,8	8,8	3,7	5,6	7,8	13,9
Error(b)	36	2.4	4.3	5,0	6,1	4,9	2,0	3,5	4,9	7,6
CV %		15,9	20,6	19,6	22,9	29,9	28,6	43,9	50,7	127,7

Source of Variation	M.S. Yield on Truss (kg) 1 $x10^{4}$	2 $x10^{[illegible]}$	3 $x10^{4}$	4 $x10^{[illegible]}$	5 $x10^{[illegible]}$	6 $x10^{4}$	7 $x10^{4}$	8 $x10^{4}$	9 $x10^{[illegible]}$	Total Yield $x10^{5}$	Total No. Fruit x10	Mean Fruit Mass (g) x10
Blocks	9.6	0,4	8,5	2,3	5,1	4,2	8,8	3,0	1,7	10,5	11,4	14,4
Fert.	7,5	11,8	50,2*	53,9**	10,7	5,1*	4,2**	4,4	0,8	84,9**	186,5**	18,5**
Error (a)	3,3	10,5	8,0	3,6	3,1	0,5	0,3	2,7	3,0	6,0	6,1	1,7
Media	0,4	4,9	6,3	25,1**	11,8**	1,4	0,5	2,9	1,2	11,1*	7,7	15,2
F.M	4,7	3,3	6,7	8,5	3,9	1,7	1,8	2,3	3,9	8,3	10,3	14,5
Error(b)	2,9	3,4	5,0	4,9	2,5	1,0	0,9	1,5	1,8	4,1	6,1	41,4
CV %	18,3	21,1	23,0	25,4	31,4	35,2	42,2	54,8	129,3	12,8	12,0	8,3

APPENDIX TABLE 26 Data for Experiment 15*

1	1	1	4.0	3359	840	06.3	06.3	31.3	56.0	5.44	4.95	5.67	5.35
1	1	2	4.3	2662	625	11.9	52.9	11.8	23.5	4.19	5.04	5.39	5.49
1	1	3	5.3	3055	590	34.8	38.0	59.0	19.0	4.29	5.96	5.58	5.93
1	1	4	3.9	3022	600	06.7	20.0	40.0	33.3	4.09	5.56	5.48	6.43
1	1	5	4.0	2855	714	00.0	05.0	31.3	50.0	0.00	5.40	5.35	5.35
1	2	1	3.[illegible]	2804	74[illegible]	00.0	08.7	46.7	42.7	0.00	5.12	5.46	5.94
1	2	2	4.0	2087	672	03.3	33.3	41.7	10.7	4.42	5.23	5.79	6.50
1	2	3	4.3	2733	636	00.0	35.3	[illegible]	[illegible]	[illegible]	[illegible]	5.3[illegible]	5.6[illegible]
1	2	4	3.3	2435	755	07.7	15.4	30.5	46.2	4.49	5.75	5.38	5.99
1	2	5	2.3	1621	720	00.0	22.2	55.6	22.2	0.00	4.90	5.53	5.62
1	3	1	7.3	4013	701	00.0	13.7	42.9	4[illegible]	0.00	4.57	5.47	5.3[illegible]
1	3	2	9.3	7024	755	03.6	16.7	59.3	4[illegible]	[illegible].43	4.7[illegible]	5.76	5.[illegible]
1	3	3	7.3	4639	676	00.0	10.0	37.9	51.7	0.00	5.1[illegible]	[illegible]	5.4[illegible]
1	3	4	5.3	4034	790	04.[illegible]	[illegible]	2[illegible].6	57.1	[illegible].56	4.44	5.5[illegible]	5.57
1	3	5	[illegible].0	5512	702	00.0	12.5	50.0	37.5	[illegible].00	5.27	5.20	5.9[illegible]
2	1	1	4.5	3016	737	00.0	11.1	3[illegible]	50.0	0.00	4.73	[illegible]	5.07
2	1	2	[illegible].5	4224	758	04.5	[illegible]	27.2	5[illegible]	[illegible].05	4.9[illegible]	5.[illegible]2	5.[illegible]1
2	1	3	4.[illegible]	3455	729	05.3	21.0	36.8	3[illegible]	5.51	5.15	5.34	6.0[illegible]
2	1	4	5.5	3063	702	00.0	[illegible]	[illegible].0	40.[illegible]	[illegible]	4.[illegible]	5.[illegible]7	5.63
2	1	5	3.[illegible]	[illegible]	674	00.0	[illegible]	50.[illegible]	1[illegible]	[illegible]	4.47	5.[illegible]2	6.1[illegible]
2	2	1	[illegible].3	[illegible]	633	00.0	38.[illegible]	30.[illegible]	30.[illegible]	[illegible].00	[illegible]	[illegible].[illegible]9	5.9[illegible]
2	2	2	[illegible].3	1[illegible]	[illegible]	11.1	[illegible]	44.4	2[illegible]	[illegible]	[illegible]	[illegible].71	5.7[illegible]
2	2	3	[illegible].3	21[illegible]	[illegible]1[illegible]	07.1	57.1	[illegible]1.4	14.3	[illegible].[illegible]6	[illegible]	5.31	6.1[illegible]
2	2	4	[illegible].3	1[illegible]	[illegible]	07.7	[illegible]	46.2	07.7	5.39	4.97	5.[illegible]4	5.[illegible]
2	2	5	[illegible].[illegible]	174[illegible]	74[illegible]	00.0	14.[illegible]	71.4	1[illegible]	[illegible].00	[illegible]	5.71	6.4[illegible]
2	3	1	7.[illegible]	[illegible]1[illegible]	[illegible]	00.0	12.9	[illegible]	7[illegible]	[illegible]	4.[illegible]	5.[illegible]	5.24
2	3	2	7.5	[illegible]43[illegible]	7[illegible]	03.2	1[illegible]	[illegible]	5[illegible]	4.03	5.2[illegible]	[illegible].79	5.60
2	3	3	7.5	4032	544	03.3	13.3	33.3	30.0	[illegible]	4.85	5.06	5.90
2	3	4	[illegible].5	4125	73[illegible]	00.0	1[illegible]	[illegible].4	4[illegible]	0.00	5.32	5.20	5.4[illegible]
2	3	5	[illegible]	3557	[illegible]	00.0	30.4	47.[illegible]	21.7	0.00	4.75	5.15	5.2[illegible]
3	1	1	[illegible].0	3521	65[illegible]	07.[illegible]	2[illegible]	2[illegible].2	[illegible]	[illegible]	4.73	4.[illegible]1	5.35
3	1	2	4.0	2525	731	00.0	05.5	25.0	65.5	0.00	4.25	4.93	5.55
3	1	3	4.3	3131	670	00.0	26.3	50.0	[illegible]	0.00	4.54	4.95	6.05
3	1	4	5.0	[illegible]77	675	0[illegible]	26.0	25.7	45.7	4.21	4.85	5.06	5.61
3	1	5	4.0	24[illegible]	623	0[illegible].0	43.8	37.5	18.5	0.00	4.8[illegible]	5.10	6.00
3	2	1	4.0	2445	611	12.5	12.5	31.3	43.8	4.77	4.62	5.42	5.35
3	2	2	4.3	3115	657	00.0	15.5	47.4	35.8	0.00	4.21	5.01	5.[illegible]
3	2	3	3.[illegible]	2274	[illegible]	17.[illegible]	40.0	[illegible]	2[illegible]	[illegible].49	4.97	5.58	6.03
3	2	4	4.0	30[illegible]	771	00.0	15.0	31.3	50.0	0.00	5.25	5.27	5.74
3	2	5	2.0	0942	471	00.0	75.0	25.0	00.0	0.00	4.55	5.09	0.00
3	3	1	7.0	4572	657	00.0	17.9	42.9	39.3	0.00	4.75	4.74	5.77
3	3	2	5.3	3019	575	09.5	33.3	23.8	33.3	5.16	4.35	4.62	5.13
3	3	3	[illegible].3	4[illegible]	601	00.0	24.0	[illegible]0.6	15.2	0.00	5.15	5.22	5.13
3	3	4	5.8	3955	535	07.4	33.3	37.3	25.9	4.92	4.71	5.36	5.63
3	3	5	6.3	3754	596	11.1	44.4	22.2	22.2	4.33	4.65	5.08	5.72
4	1	1	4.3	3045	717	00.0	17.6	23.5	58.8	0.00	5.20	4.94	5.51
4	1	2	4.[illegible]	3392	714	00.0	00.0	36.8	63.2	0.00	0.00	4.73	5.64
4	1	3	5.8	3564	672	00.0	26.1	39.1	34.8	0.00	4.79	5.34	6.05
4	1	4	5.5	3454	633	00.0	36.4	18.2	45.5	0.00	5.17	4.97	5.50
4	1	5	4.0	2075	569	00.0	43.8	43.8	12.5	0.00	5.05	5.22	6.17
4	2	1	2.8	1331	565	00.0	45.5	27.3	27.3	0.00	5.61	5.71	5.35
4	2	2	3.0	2285	763	00.0	25.0	33.3	41.7	0.00	5.17	5.03	6.00
4	2	3	4.0	2722	680	06.3	25.0	37.5	31.3	5.21	4.75	5.56	5.91
4	2	4	2.3	1335	576	09.1	45.4	36.4	09.1	5.33	4.85	5.43	6.00
4	2	5	2.0	1150	575	12.5	62.5	25.0	00.0	4.06	5.2[illegible]	5.19	0.00
4	3	1	4.3	2129	501	23.5	23.5	35.3	17.6	4.06	4.75	4.79	4.74
4	3	2	6.3	3755	601	08.0	16.0	44.0	32.0	4.50	5.17	5.03	5.71
4	3	3	5.8	3150	543	00.0	47.8	39.1	13.0	0.00	4.90	5.08	5.44
4	3	4	5.0	2483	497	05.0	40.0	25.0	30.0	4.50	4.91	4.76	5.35
4	3	5	6.8	3393	532	14.3	44.4	33.3	07.4	5.00	4.94	5.22	6.23

*Variates in column order are blocks, fertilisation (1 = Guernsey; 2 = Jensen; 3 = ® Chemicult), media (1 = mushroom compost; 2 = pine bark; 3 = milo; 4 = sand:local peat; 5 = old sand:peat), no fruit, yield (g plant^{-1}), mean fruit mass (g), per cent. class 1, class 2, class 3, class 4, mean fruit diameter (cm) class 1, class 2, class 3, class 4

APPENDIX TABLE 27 Analysis of Variance for Experiment 15

Source of Variation	DF	M.S.										
		No. Fruit	Yield	Mean Fruit Mass	PER CENT.				FRUIT DIAM.			
					Class 1	Class 2	Class 3	Class 4	Class 1	Class 2	Class 3	Class 4
			x10⁵	x10³		x10	x10	x10		x10⁻¹	x10⁻¹	
Blocks	3	1,3	19,9	33,5	15,9	55,8	17,2	28,0	1,7	8,3	2,7	1,5
Fert.	2	58,2**	220,6**	24,4	39,8	59,8	7,4	116,7	5,6	5,7	6,7*	1,2
Error(a)	6	1,3	15,9	10,6	54,7	19,9	8,0	46,4	9,8	5,6	1,3	0,9
Media	4	2,4	15,0	7,4	7,9	64,1	15,3	135,0	13,2	7,3	0,8	1,6
F.M	8	1,1	3,9	0,5	17,4	2,3	16,1	5,6	4,7	5,9	0,5	2,8
Error(b)	36	0,7	4,1	4,1	26,3	22,1	12,2	15,7	5,7	4,8	0,8	0,8
CV %		17,0	19,8	9,6	130,3	56,9	30,8	36,9	104,1	14,1	5,3	16,4

POTENTIAL POTTING MIXTURES FOR TUNNEL GROWN TOMATOES

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ABSTRACT

The effects of growing tunnel tomatoes in eight different growing media were recorded for two times of planting in late summer at Pieter-aritzburg.

Plants experiencing cooler conditions during their growth period had a slower growth rate and yielded less.

Mixtures containing peat moss generally yielded higher than others, and had a lower pH. Those containing vermiculite and perlite, both ood insulators, experienced smaller temperature fluctuations. Although salinity levels were high, no relationship between the salinity levels in a ixture and yield could be found.

The size and extent of the root system in the pot depended on the water holding capacity of the medium, with the most branched root stem being in the sand alone.

INTRODUCTION

One of the earliest hydroponically orientated tunnel systems ld in South Africa incorporated the use of vermiculite as the potting ixture. The inherently high pH of the local product, and its loss of ructure with use resulted in nutrient imbalance problems in certain rcumstances, and costly replenishment after each crop respectively.

A trial was established at the University of Natal in Pieterma-tzburg, to test the suitability of other commercially available potting iixtures for tomato production. The results discussed here aim to resent the advantages and disadvantages of each to the grower, oting at the same time that cost and reuseability are of prime im-ortance, besides the fact that optimum growth and yield must be ob-ined.

PROCEDURE

The trial was carried out in a 'small' 15 x 6m tunnel in which ere situated 3 double rows of black plastic pots at the recommended pacing for tomatoes.

The different potting mixtures were fed daily with a commer-ially available nutrient solution such that each pot received a total of ,5 g of nutrient mixture per litre of water per day.

The solution was applied to each pot through microtubes, and ie daily application was made by giving half the amount at 8 a.m. nd half at 2 p.m. The amount applied was such that excess solution ways drained from the bottom of the pots.

The tomato plants of the variety 'HOTSET' were grown, trel-sed, pruned, pollinated and sprayed according to normal tunnel stan-ards.

The number of fruit and fruit mass were recorded for each uss as the fruit matured, and the figures shown represent the *mar-table* yield.

For one month during mid-winter the temperatures of the dif-rent mixtures in pots in the centre row of the tunnel were recorded.

At monthly intervals samples were taken to test whether salt uild-up (salinity) was occurring, and the mixtures were tested for sa-ity at the start and end of the trial.

The main treatments were:

Two times of planting

16.2.78 – so that the plants grew and set some fruit during warmer temperature conditions.

9.3.78 – so that the plants experienced cold winter tempera-tures early on in their growth, but were still yielding during warmer spring temperatures.

Both of these planting dates were such that fruit was being harvested during the higher priced period of the year on the Durban and Pieter-maritzburg markets.

2. **Eight potting mixtures**

1.	Vermiculite	
2.	Perlite	
3.	Umgeni River Sand	
4.	Peat moss : Vermiculite	1 : 1
5.	Peat moss : Sand	1 : 2
6.	Peat moss : Sand	1 : 3
7.	Peat moss : Perlite	1 : 1
8.	Peat moss : Polystyrene	1 : 1

The peat moss was from a South African source.

RESULTS AND DISCUSSION

1. **Plant growth**

At the first time of planting the fastest growth occurred in the peat : vermiculite treatment (Figure 1). All other treatments had the same growth rate as the vermiculite treatment shown. At the second time of planting there was no difference between treatments, but Figure 1 shows that the growth was slower than in the first planting, as these plants experienced cold winter temperatures earlier in their development.

2. **Yield**

a) *Total yield.* Figure 2 shows that the average yield (mean of the two planting dates was lowest for vermiculite and highest for peat : vermiculite and peat : sand (1 : 3). In fact all mixtures with peat resulted in higher yields than any single medium.

It must be noted that only five trusses were included in the yield figures due to the size of the tunnel.

In all cases, except vermiculite, the first planting yielded higher than the second planting. This trend was caused by a reduced fruit mass in the second planting (Figure 4), probably due to poorer pollination during the cooler winter period.

b) *Components of yield.* The mean fruit mass decreased sharply with increasing truss number (Figure 3), and the fruit harvested near the end of the trial were about half the size of those which were first picked for both times of planting.

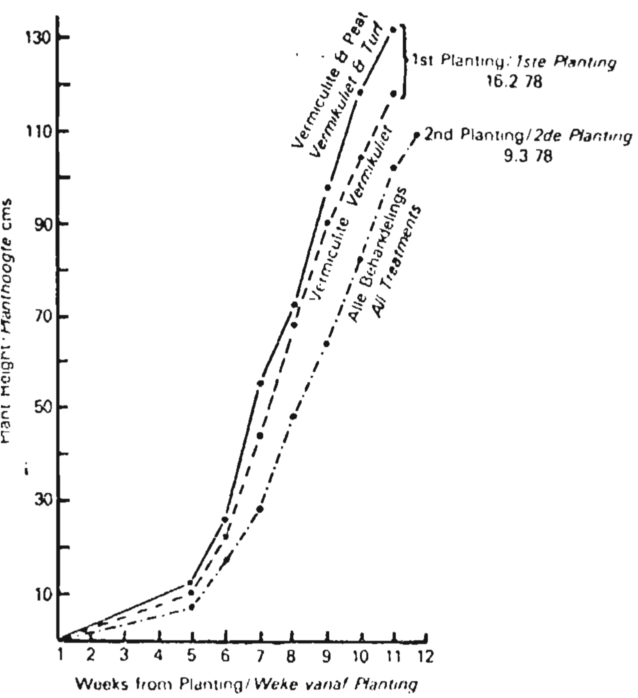


FIG. 1: **Plant growth at two different times of planting**
FIG. 1: Plant ontwikkeling (twee verskillende plantings datums)

In the first planting, vermiculite tended to result in the largest fruit (Figure 3) even though it yielded the lowest. This was because there were fewer fruit per truss. All other treatments tended to produce fruit of a similar size.

In order to determine whether the decline in mean fruit mass up the plant was related to the number of fruit per truss these two variables were plotted together in Figure 4 using the means for all treatments.

The number of fruit per truss remained relatively constant up the plant but the mass declined with increasing truss number.

Figure 5 shows that over 80 per cent of the fruit was harvested within 23 weeks from planting, and that the remaining 20 per cent, which was all small fruit, was harvested over the last week.

Depending on market prices and demand, growers would have to decide whether it would be worth delaying harvesting for 8 weeks, at the expense of establishing a new crop in the tunnel, or whether all the remaining fruit should be stripped and ripened artificially.

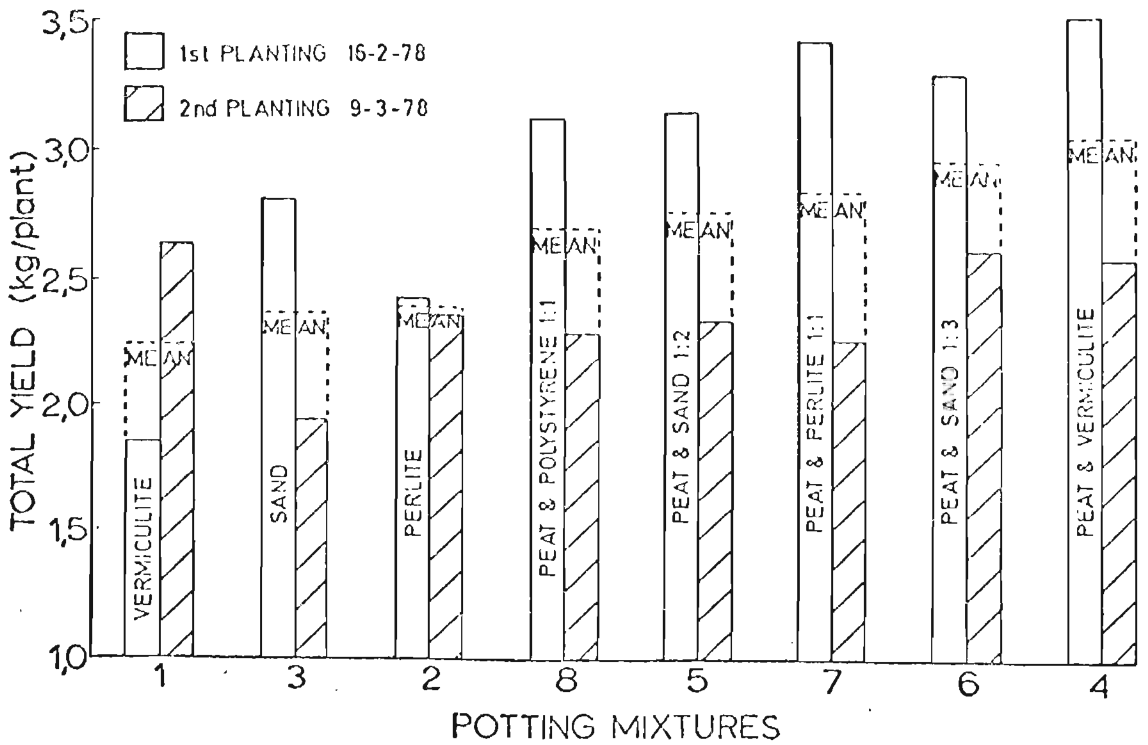
In summary it can be seen that the highest yields were for the peat : vermiculite or peat : sand mixtures.

In order to explain the differences in yield, other characteristics of the potting mixtures need to be examined.

3. pH

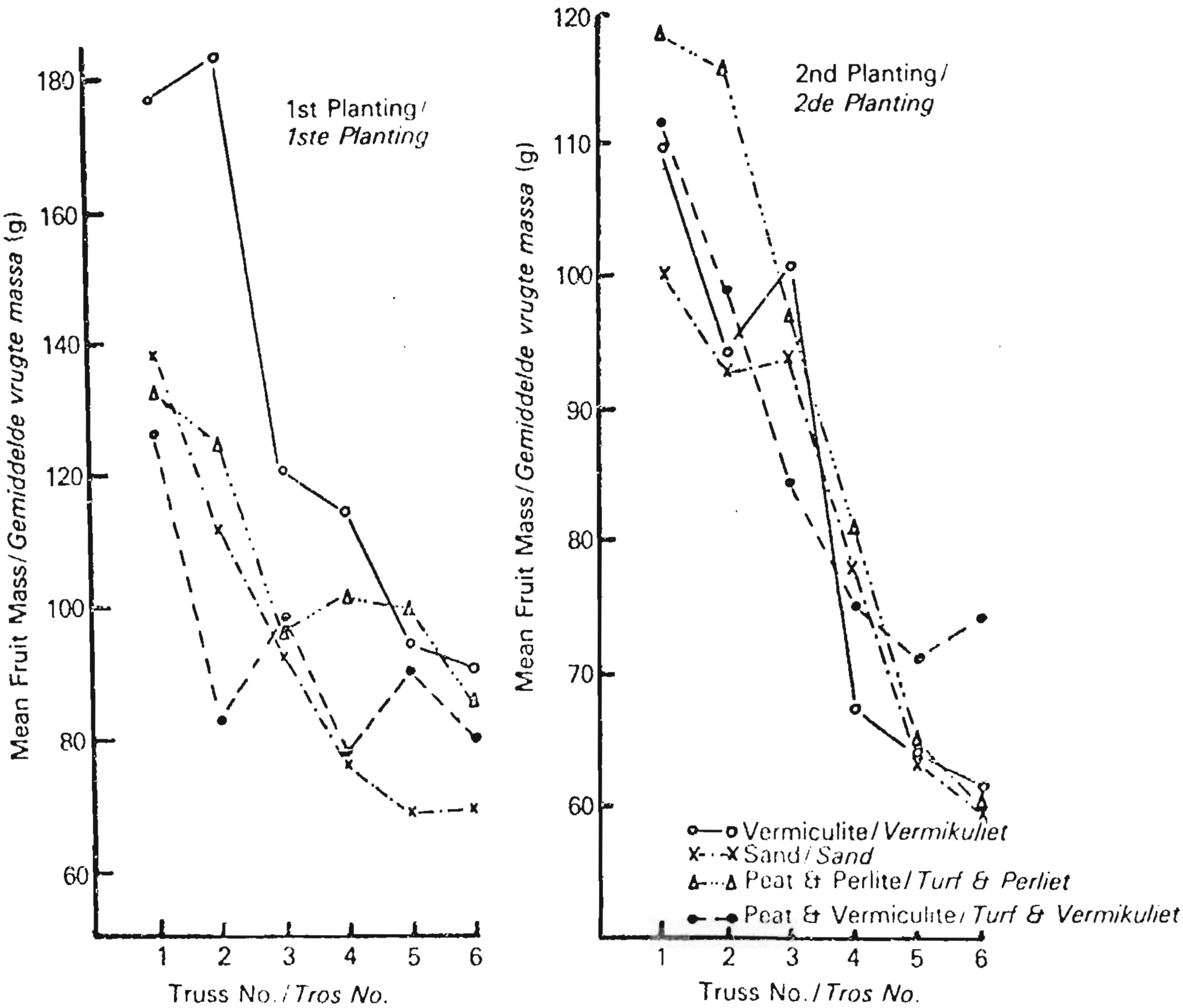
Monthly pH measurements were made of the water and the different mixtures (Figure 6). The water tended to be alkaline (± pH 8) except at the end when a pH of 6 was recorded.

The nutrient mixture had an acidifying effect on the water and the pH of the mixture was gradually stabilised at approximately 6 at each sampling.



. 2: **Total yield of marketable fruit on two different planting dates for eight different potting mixtures**

FIG. 2: Totale opbrengs van bemarkbare vrugte op twee verskillende plantingsdatums vir agt verskillende potmengsels



G. 3: The effect of truss no. on mean fruit mass per truss

FIG. 3: Uitwerking van tros no. op gemiddelde tros-vrugte massa

The pH of the vermiculite was initially 8, but with constant tering it assumed the pH of the nutrient solution. Similarly perlite d a pH 7 to start with, but soon changed to the pH of the nutrient lution. The Umgeni river sand maintained a pH of 6 throughout the al.

The acidity of the peat was dominant in all the mixtures, and ost peat mixtures had a pH of between 4 and 5.

It was notable that the two highest yielding mixtures main- ned a pH in the region of 5.

Temperature

The pot temperatures of the different mixtures are shown for a -hour period in two different climatic situations:

A sunny clear day and the following night (Figure 7)

For the period shown, outside air temperatures were closer to C at 6 a.m. in the morning, and reached a maximum of 20°C at 2 n. in the afternoon. The temperature climbed sharply between 8 n. and 10 a.m. and dropped off sharply between 4 p.m. and 8 p.m.

The air temperatures inside the tunnel rose sharply with the in- ase in outside air temperature, but climbed to a higher maximum at °C. The tunnel cooled faster than the outside air between 3 p.m. d 6 p.m., but thereafter the rate of cooling slowed down so that the nel was 3°C warmer during the coldest time (6 a.m.).

Pots with vermiculite tended to remain the warmest at night, ich is indicative of the insulative character of vermiculite. Thus the at : vermiculite mixture did not heat up to the highest temperature during the day, but was the warmest at night. The peat : sand (1 : 3) mixture became hottest during the day (15°C), but cooled to a greater extent at night.

For some unaccountable reason the peat : polystyrene mixture became very cool at night.

b) *A cloudy night and the following day*

Under cloudy conditions less radiational cooling takes place. Thus the air and pot temperatures remained relatively warmer at night under these conditions (Figure 8).

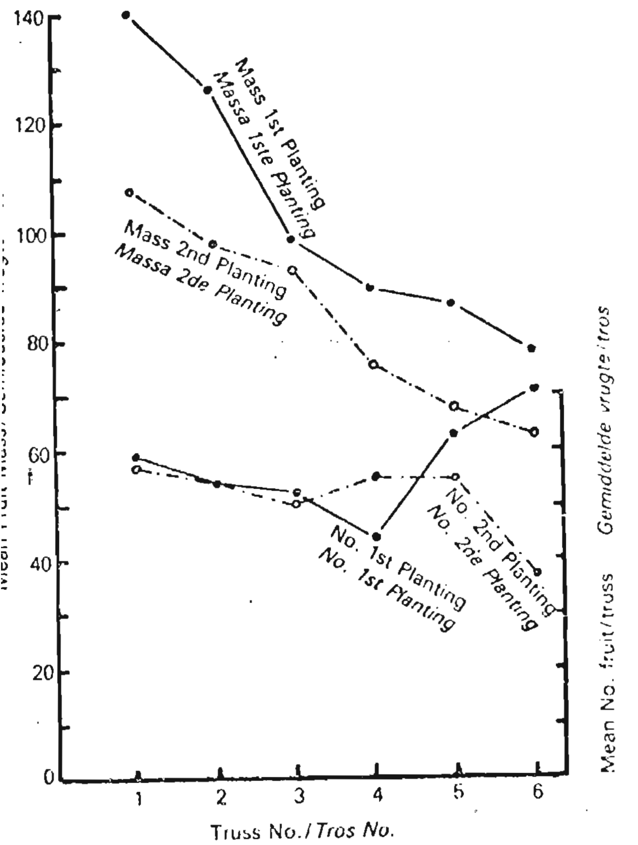
It was, however, still noticeable that the peat : vermiculite mixture remained the warmest during the night period and the peat : polystyrene the coldest. All other treatments had temperatures between these two extremes.

In terms of temperature the two highest yielding treatments tended to have the highest pot temperatures (peat : sand during the day and peat : vermiculite at night).

5. **Salinity build up**

Salinity (measured as the total amounts of Ca, Mg and Na in the mixtures) was measured at the beginning and end of the trial (Figure 9) and the treatments rated according to increasing mean levels.

The lowest salinity levels were found in the peat : vermiculite mixture, which gave the highest fruit yield, the highest salinity levels were found in the peat : sand (1 : 3) which yielded well, and the vermiculite which yielded poorly. Overall no definite relationship existed between the salinity and yield.



IG. 4: **Relationship between no. of fruit and the mean fruit mass per truss**

IG. 4: ***Verwantskap tussen no. vrugte en gemiddelde vrugte massa op 'n tros***

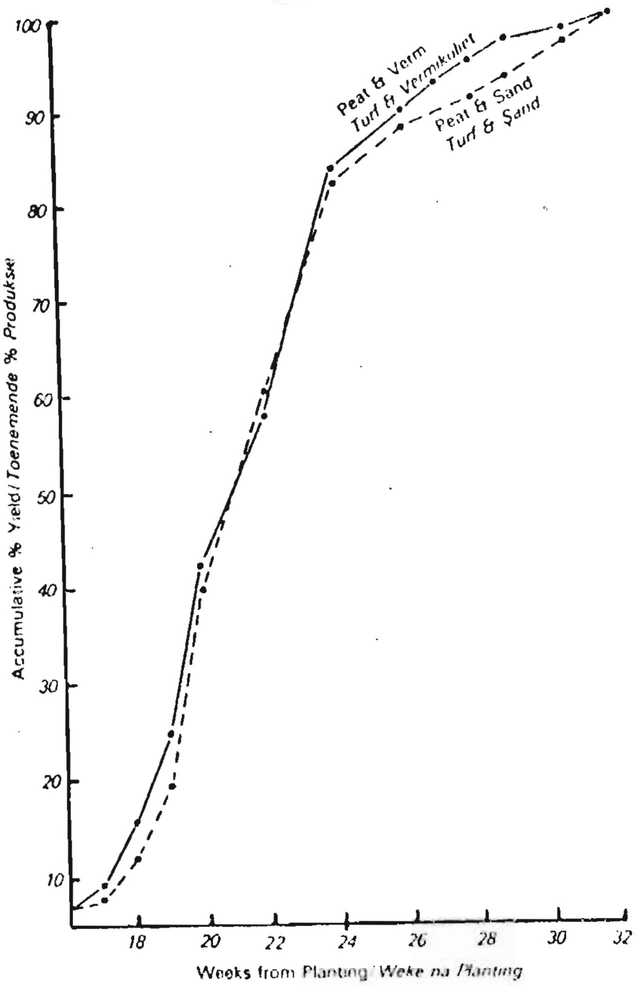


FIG. 5: **The accumulated total amount of fruit picked during the harvest period at the first planting**

FIG. 5: ***Toenemende totaal vrugte gepluk (1ste planting)***

It was noticeable, however, that there had been a build up in alinity from the start to the end of the trial, to levels which other orkers (Mass & Hoffman, 1977) have reported resulted in yield re uctions, as shown in Figure 9. Further research is being undertaken) study this aspect more critically, as it could become a problem here a growth medium is used for consecutive crops.

A few suggestions as to how to avoid salinity build-up may be ppropriate at this stage:

It is apparently better to over-water with each nutrient application so that some solution drains through the pots.

Holes should be made in the bottom of pots (and not 2,5 cm from the base) to prevent high concentrations of salts building up in the water usually found in the bases of pots.

The pots should be flushed with pure water once a week.

At the end of a crop 10 litres of water should be run through each pot.

Potting mixtures should be tested for salinity at the end of each crop.

Observations on the root systems of plants grown in the different mixtures

At the end of the trial, pots from each treatment were opened and the root systems examined by washing off all the media.

In general, the size of the root system was related to the water ling capacity of the potting mixture. Thus peat and vermiculite ded to result in smaller root systems confined to the central part of pot.

The largest and most branched root system was in the sand alone. The root systems in the sand and peat mixtures depended on the amount of sand in the mixture, but were not as large as those in the sand alone.

In most potting mixtures the roots were distributed evenly throughout the pot. In perlite, however, a large percentage were situated at the top of the pot.

It would appear, therefore, that the size and extent of branching of the root system depends on how difficult it is for the roots to obtain water. In the sand medium, which was well drained and held little water, an extensive root system developed. Root proliferations would depend on the daily watering frequency of the potting mixture in question.

CONCLUSIONS

In considering the characteristics of the different potting mixtures, yield is the main factor to be considered affecting the growers' income. Whilst all mixtures resulted in relatively similar yields, there was a tendency for peat : vermiculite and peat : sand mixture to result in the highest yields. These latter two mixtures also have the property of reuseability, which reduces on the cost of reestablishing each season where applicable.

Table 1 shows that the sand and local peat mixtures are far less expensive than any of the others at present. Growers may be justified in having a high initial cost if the medium can be used for several seasons, and the yield is definitely higher. However, on the evidence available the sand : local peat mixture appears to be the most economical.

Apart from yield and cost, it appears that the other main contributing factors to the suitability of a mixture are the water holding

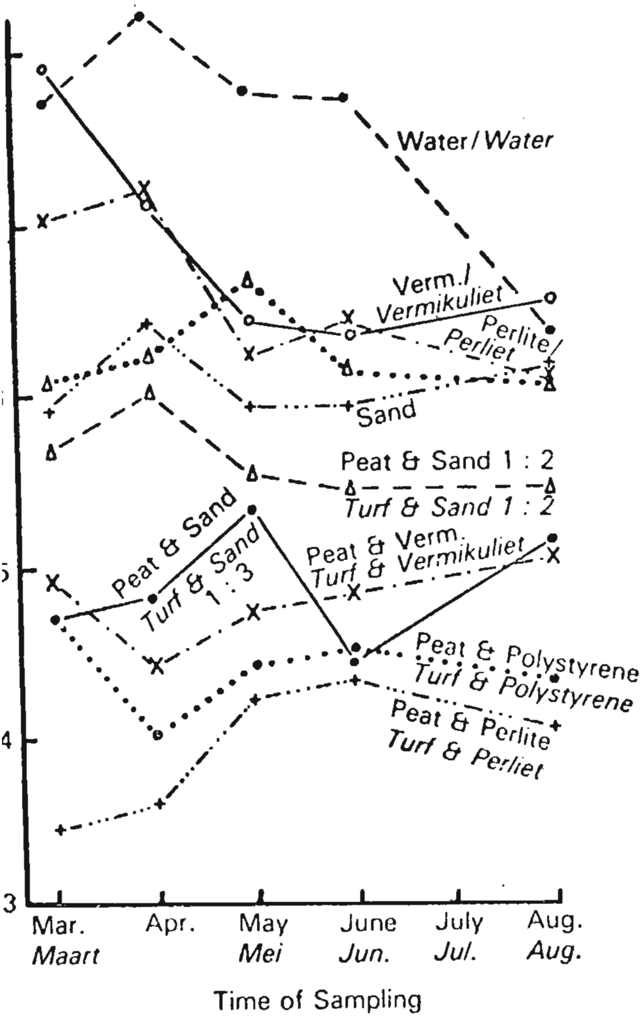


FIG. 6: The change in pH of the different potting mixtures with time

FIG. 6: Wisseling van verskillende potmengsels pH met tyd

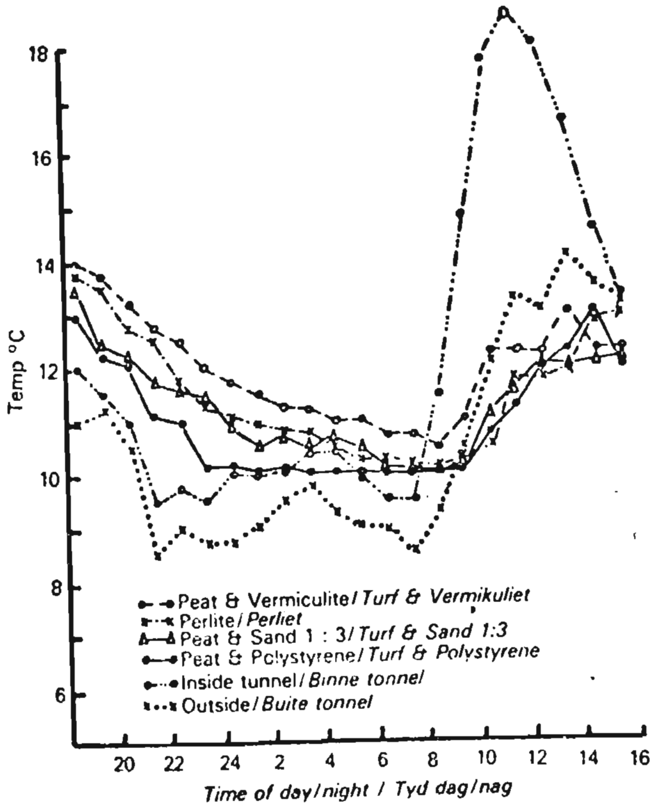


FIG. 8: Potting mixture and air temps. during a cloudy night and the following day

FIG. 8: Potmengsel en lugtemperatuur gedurende bewolkte nag en die volgende dag

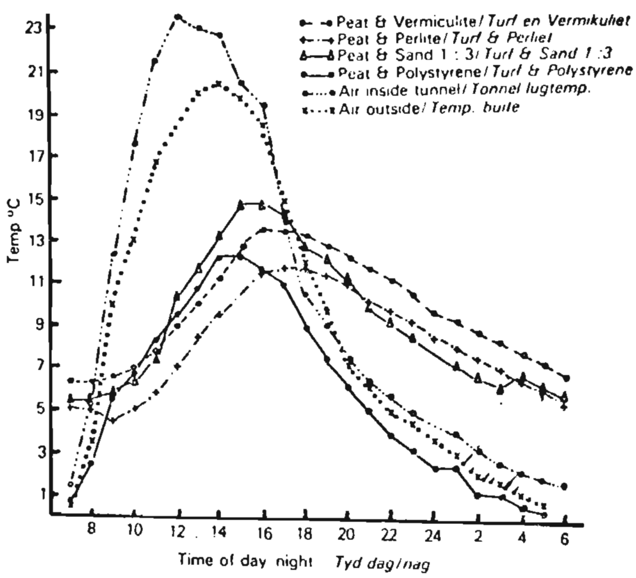


FIG. 7: Potting mixture and air temps. during a sunny day and the following night

FIG. 7: Potmengsel en lugtemperatuur gedurende onbewolkte dag en die volgende nag

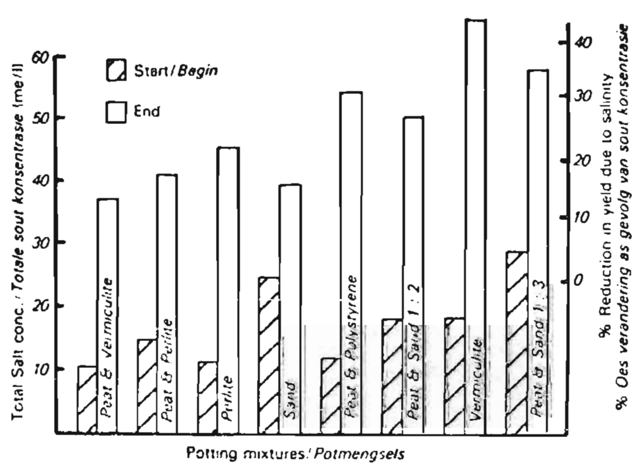


FIG. 9: Salinity levels in the different potting mixtures at the start and end of the trial

FIG. 9: Soutkonsentrasies in verskillende potmengsels by begin en voltooiing van proef

apacity and aeration. In this respect an important characteristic would be whether the plants would require watering once per day, or nore often as most growers practice.

Also the pH is important and in this trial mixtures with a pH of 5 esulted in the best yields, which is consistent with other workers' fin ings (Walliham, Sharpless & Pointy, 1977).

The temperature of the mixture can also play a part, especially uring cold winter periods.

ABLE 1: Cost of the main ingredients and different combinations of potting mixtures

Material	Cost (R/100 litres)	Cost per 10 litre pot (R)
. Irish Peat	14,71	1,47
. Local Peat	1,90	0,19
. Vermiculite	3,00	0,30
. Perlite	12,00	1,20
. Sand	0,76	0,08
. Polystyrene	6,00	0,60
MIXTURES		
2 + 3 (1 : 1)		0,25
5 + 2 (2 : 1)		0,12
5 + 2 (3 : 1)		0,11
2 + 4 (1 : 1)		0,70
2 + 6 (1 : 1)		0,40
1 + 3 (1 : 1)		0,88

Finally, a factor which will become important with constant re use of a mixture is the salinity build up and precautions should be taken to ensure that this does not occur.

OPSOMMING

POTENSIELE POTMENGSELS VIR TONNEL TAMATIES

Die invloed van agt potmengsels, en twee plantings datums gedurende die laat somer in Pietermaritzburg, was getoets.

Stadiger ontwikkeling en laer produksie, van plante wat gedurende die koeler periode van die jaar ontwikkel het, was gevind.

Mengsels waarin turf een van die bestanddele was, het die grootste oes en laagste pH meting bewys. Die mengsels waarin vermikuliet en perliet bestanddele was, het laer temperatuur wisseling bewys. Alhoewel sout konsentrasies hoog was, was daar geen verwantskap met produksie gevind nie.

Die grootheid van die wortel sisteem was aan die mensel se waterhouvermoe verband. Die grootste wortel sisteem was in die alleenlik sand medium gevind.

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THE RADIATION ENVIRONMENT OF TUNNEL GROWN TOMATOES: ROW SPACING AND POT VOLUME EFFECTS

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ABSTRACT

The use of plastic tunnels makes it possible to modify the crop microclimate for marginal areas. The radiation environment of an east-west tunnel was investigated for a winter tomato crop.

Solar irradiance of foliage is an important factor affecting the photosynthetic process in a plant canopy. For close and intermediate spacing where competition occurs, the diurnal curves of irradiance in the upper layers of the canopy are characteristically M-shaped because a greater amount of short wave radiation is absorbed an hour or so before and after local noon than at solar noon.

The close spaced plants absorbed more than 35 % of the incident daily radiant density in the 900 to 1 200 mm layer. For wide spaced plants this amount was 20 to 40 % for the lowest layer. In the former case, the yield per plant was lower but the yield per unit area was much greater than the latter (wide spacing).

Pot volume was shown to affect the radiant energy utilization for the intermediate and far spacing treatments.

INTRODUCTION

The energy crisis has prompted consideration of ways of achieving maximal agricultural production per unit of energy instead of land area (Bockhurst, 1976). The plastic tunnel serves to protect crops in marginal areas (for example, in frost prone areas) so that large solar energy inputs generally available can be more efficiently utilized (Hanan, Holley & Goldsberry, 1978). In fact, for most parts of South Africa, favourably large winter insolation values together with unfavourably low night time air temperatures are the main climatic reasons for the rapidly expanding greenhouse industry. Other reasons such as wind and rain protection are contributory.

Spectral transmission properties of glass and plastic shells in the design of greenhouses are vital to the radiation environment of greenhouse-grown crops (Damagnez, 1976). Basiaux, Deltour & Nisen (1973) justified the semi-cylindrical shape of the plastic tunnel type of greenhouse. They concluded that this shape, when orientated east-west captures and transmits the maximum amount of radiant energy during the autumn equinox to the spring equinox.

North (1979), North, De Jager & Allan (1978) and Savage (1980) investigated the environment inside a plastic tunnel in relation to outside conditions but did not include radiation profile measurements.

Rodriguez & Lambeth (1975) investigated the effect of different row spacings (which create different radiation environments) on the yield of greenhouse tomatoes. They found that the widest spacing treatments gave the greatest yield per plant for natural and supplemented lighting. Examination of their data suggests however that the yield per unit area is not always greatest for the widest row space.

The question which now arises is whether the measurement of the radiation environment will provide useful guidelines for determining the optimum number of plants per unit area for maximum yield per unit area. Effects of spacing on yield of tunnel-grown tomatoes are discussed by Smith & Richards (1980).

The aim of this study is to investigate the radiation environment of a plastic tunnel with a view to explaining observed effects of row space on crop yield on the basis of the radiation profiles within the plastic tunnel.

TERMINOLOGY

Terminology here is adapted from Savage (1978; 1979a, b).

Irradiance, foliage irradiance or radiant flux density (W m^{-2}) is the total (short wave and long wave) radiant energy received per unit area per unit time.

Short wave radiation is a term used for radiation with wavelengths between 300 and 3 000 nm (Rosenberg, 1974). Long wave radiation is a term used for radiation with wavelengths between 3 000 and 60 000 nm.

Total radiant density (J m^{-2}) is the radiant energy received per unit area. Over a given day, the total radiant density is defined as $\int_D I\,dt$ where I is the irradiance, t is the time and $\int_D$ indicates an integration over the daylength D.

Photosynthetically active radiation is that radiation with wavelengths between about 380 and 720 nm which produces a photosynthetic response.

PROCEDURE

The radiation profile measurements were performed over a five week period. Details of the tunnel (orientated east-west) are given by Smith, Whitfield, Savage & Cass (1979) and the experimental design by Smith & Richards (1980). Radiation measurements were obtained using a Weather Measure** line pyranometer commonly referred to as a tube solarimeter. The copper-constantan thermopile of the pyranometer is 200 mm long. The entire detector assembly is housed in a glass tube and hence is ideal for the measurement of radiation of short wavelengths as glass is opaque to long wavelength radiation (Dubois, 1978; Kubin 1971). The instrument was factory calibrated against a source traceable to an American National Standard. A microvoltmeter was used to measure the voltage output from the pyranometer. On the day of measurement, radiation readings were obtained at each hour from 08h00 to 16h00, inclusive.

A radiation profile for each treatment was obtained by placing a pyranometer in an east-west direction between the crop double row. There were three double rows, the profiles being measured in the middle row. Heights of measurement above the pot surfaces were 300 mm, 600 mm, 900 mm, etc., up to crop height. The outside tunnel radiation was measured at the beginning and end of each set of hourly readings. On a given day, nearly 400 radiation measurements were obtained, but this varied depending on the height of the crop. Care was taken to ensure that the pyranometer was levelled before each measurement. Six different treatments were chosen (treatments A to F), and the details of these are shown in Table 1.

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**The mention of proprietary products is for the convenience of the reader and does not constitute endorsement, or otherwise, by the authors or the University of Natal.

TABLE 1: The details of the six treatments
TABEL 1: Die besonderhede van die ses behandelings

Treatment *Behandeling*	Inter-row spacing *Tussen-ry spasiëring* (mm)	Inter-plant spacing *Tussen-plant spasiëring* (mm)	Pot volume *Pot volume* (ℓ)
A	300	400	10
B	300	400	16
C	600	400	16
D	600	400	10
E	300	200	16
F	300	200	10

RESULTS AND DISCUSSION

Figure 1 shows typical three dimensional graphs of irradiance as a function of local time and height above pot level for treatment B

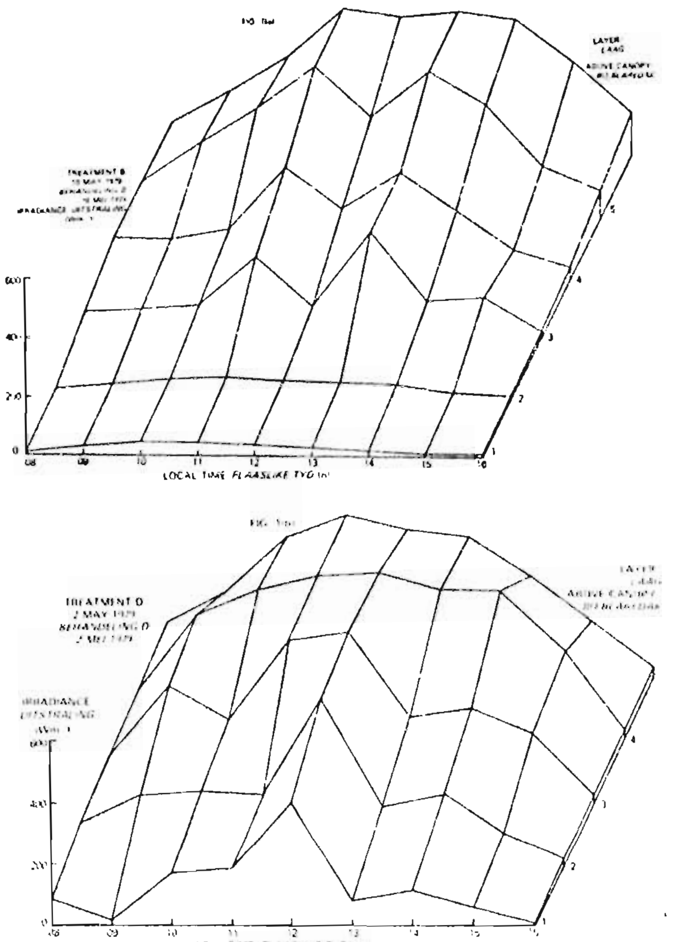

FIG. 1: Irradiance as a function of local time for the various layers for treatment B and D, for 16 and 2 May respectively
FIG. 1: Uitstraling as 'n funksie van plaaslike tyd vir die verskeie lae van behandelings B vir 16 en D vir 2 Mei

(16 May) and treatment D (2 May). In the latter case, the crop had grown to a height of about 1,2 m and the former to a height of 1,5 m.

Of interest is that for the upper layers of the closely spaced rows (Fig. 1a) where competition occurs, maximum irradiance does not occur at solar noon, but rather an hour or so before and after solar noon. In this case then, the diurnal radiation profiles for the upper layers are characteristically M-shaped. Generally then, for the closely spaced rows, a three dimensional graph as shown in Fig. 1a has a Y-shape, where the base of the Y is due to radiant energy intercepted by the lower leaves and the arms of the Y are due to the M-shape in the diurnal radiation profile of the upper leaves. In the case of the widely spaced rows where little competition occurs, maximum irradiance at any level is generally at solar noon (Fig. 1b).

The daily radiant density (kJ m^{-2}) was calculated by integrating the irradiance curves from 08h00 to 16h00, for each treatment. The crop canopy was divided into layers (layer 1 is 0 to 300 mm; layer 2 is 300 to 600 mm, etc.) and the daily radiant density calculated. Figure 2 shows the daily radiant density adsorbed by each layer for 2, 9 16 and 23 May 1979 for treatments A to F inclusive. As shown, in some

FIG. 2

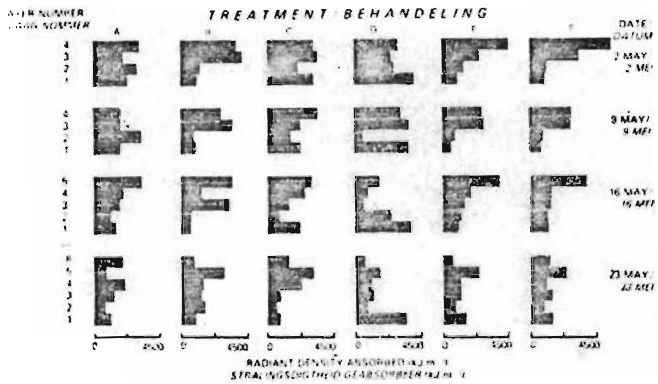

FIG. 2: The radiant density absorbed by the different layers for various treatments as a function of time
FIG. 2: Die stralingsdigtheid geabsorbeer deur die verskillende lae vir verskeie behandelinge as 'n funksie van tyd

cases the upper layers absorbed most of the radiant energy (treatments B, E and F), but for other treatments (e.g. D) the lowest layers absorbed significant amounts. Hence for treatments B, E and F, the plants would have a large leaf area index for the upper leaves but a small index for the lower leaves. The reverse would occur for treatment D. In terms of yield then, this would result in "top-" and "bottom-heavy" plants respectively. Richards (1979) noted that treatments E and F had the highest number of spindly plants. Treatments A and C had the most uniform (absorbed) radiant density profile.

With regard to the radiant density absorbed by layer 6 (for all treatments) on 23 May, the crop had not grown to the height of 1 800 mm, so that there was not much absorption, as Fig. 2 shows. The comparisons of the histograms of Fig. 2 can be misleading since the area of each histogram may not be the same. Hence, from these data, the percentage of the daily radiant density (incident at the top of the canopy) absorbed by each layer was calculated, for each treatment, as shown in Table 2. For treatments E and F, the most closely spaced plants, 50 % of the daily radiant density was absorbed by the uppermost layer (4) in the first week (2 May). Less than 10 % was absorbed by layer 1. For the 23 May the percentage absorbed by layer 1 was 20 % and layer 5 absorbed less than 35 %. It would seem that for the closely spaced plants, the percentage absorbed by the upper layers are large and the lower small initially, but in time, the opposite occurs. Photosynthesis would obviously be affected by this situation.

The average percentage absorbed by layer 1 of treatment D was 37 %. As far as photosynthesis is concerned, this is really wasted energy as most of this will eventually be absorbed by the pot media.

With regard to pot volume, there appears to be no effect on the close spaced plants; aerial competition effects are more growth inhibiting then the pot volume effects in the case of these exceptionally close spacings. Use of the 16 ℓ pots (treatments B and C) resulted in layer 1 absorbing less radiant energy and layer 4 (or 5) absorbing more compared to the 10 ℓ pots (treatments A and D) for the treatment pairs (B,A) and (C,D). The reason for this is that possibly the larger pot volumes did not inhibit growth whereas the smaller pots did. In the latter case, the plants were presumably smaller, allowing greater penetration of radiant energy and hence a greater amount absorbed by layer 1.

The yield and the yield per unit area for the various treatments are depicted in Fig. 3. Treatments E and F then, in spite of absorbing about 50 % of the total incident radiant energy in the upper layers had the greatest yield per unit area. This was also in spite of the fact that

TABLE 2: The percentage daily radiant density absorbed by the different layers for the various treatments for the dates indicated
TABEL 2: *Die persentasie daaglikse stralingsdigtheid geabsorbeer deur die verskillende lae vir die verskeie behandelings vir die datums aangedui*

Layer/*Laag*	A 2/5	A 9/5	A 16/5	A 23/5	B 2/5	B 9/5	B 16/5	B 23/5	C 2/5	C 9/5	C 16/5	C 23/5
1	23	21	15	14	10	13	7	10	27	24	22	9
2	28	36	12	10	12	11	7	17	18	16	8	7
3	20	22	19	16	41	43	35	15	29	24	14	9
4	29	21	21	26	37	33	14	16	26	36	26	23
5	—	—	33	10	—	—	37	32	—	—	29	36
6	—	—	—	24	—	—	—	10	—	—	—	16

Layer/*Laag*	D 2/5	D 9/5	D 16/5	D 23/5	E 2/5	E 9/5	E 16/5	E 23/5	F 2/5	F 9/5	F 16/5	F 23/5
1	33	33	40	38	10	10	11	19	9	11	13	17
2	22	6	26	9	15	12	14	10	10	12	13	10
3	21	33	6	14	27	40	15	16	30	38	16	17
4	24	28	10	13	48	38	20	15	51	39	16	13
5	—	—	18	19	—	—	40	31	—	—	42	28
6	—	—	—	7	—	—	—	9	—	—	—	15

there were more spindly plants for these treatments. However, such a close spacing could be impractical due to difficulties with pest and disease control and cultural practices. Management aspects aside, treatments E and F are making the most efficient use of the radiant energy and are certainly recommended.

FIG. 3(a)

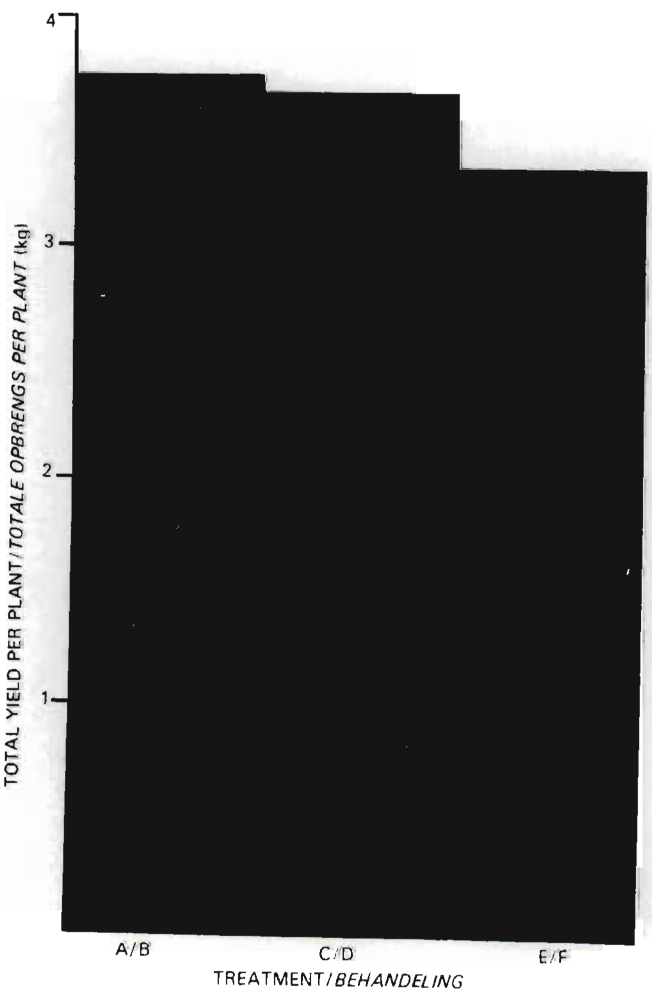

FIG. 3: **(a) Total yield per plant for the various treatments (after Richards, 1979, p.15). (b) Total yield per unit area for the various treatments**

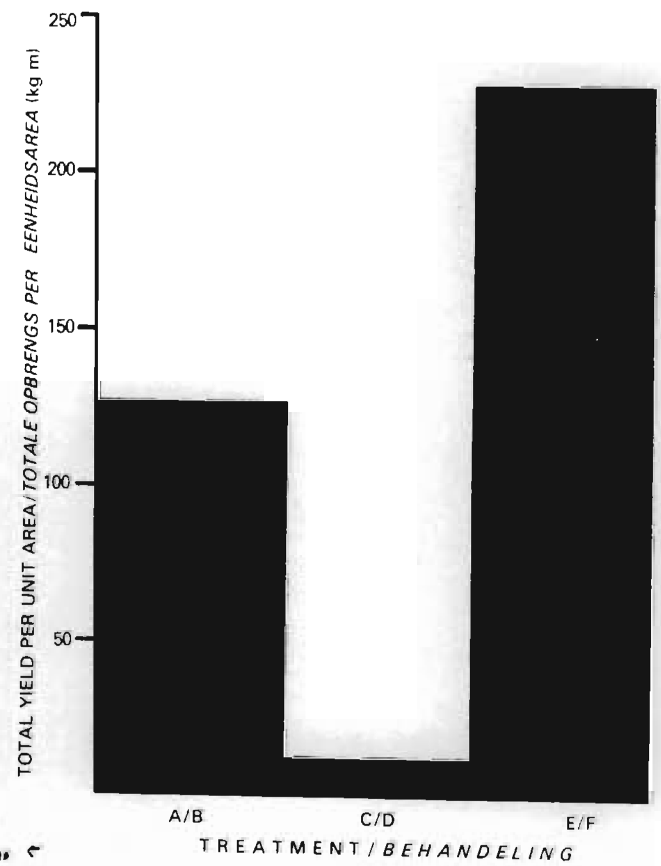

FIG. 3: ***(a) Totale opbrengs per plant vir die verskeie behandelings (na Richards, 1979, bl. 15). (b) Totale opbrengs per eenheidsarea vir die verskeie behandelings***

OPSOMMING

DIE STRALINGSOMGEWING VAN TONNEL-VERBOUDE TAMATIES: RY SPASIËRING EN POT VOLUME EFFEKTE

Vir die nou gespasieerde plante vroeg in die groeiseisoen, was meer as 50 % van die invallende stralingsdigtheid deur die 900 tot 1 200 mm laag geabsorbeer. Minder as 10 % was deur die 0 tot 300 mm laag geabsorbeer. 'n Aantal van die wyer gespasieerde behandelings (D) het omtrent 37 % van die stralingsdigtheid in die 0 tot 300 mm laag geabsorbeer (Fig. 2 en Tabel 2).

Die digte plantpopulasie (behandelinge E en F) het laer opbrengs per plant in vergelyking met die wyer plantpopulasie (behandelinge C en D) en die aangedui in Fig. 3a is. Maar in terme van totale opbrengs per eenheidsarea was behandeling E en F baie beter as C en D (Fig. 3b). Die digste plantpopulasie is meer doeltreffend in die gebruik van die invallende sonstralingsenergieë.

Behalwe vir die digste plantpopulasie (behandelinge E en F) het die groter pot volume (16ℓ) tot gevolg gehad dat meer van die stralingsenergieë deur die hoër blare geabsorbeer is, in vergelyking met die 10 ℓ pot volume. Gevolglik was die 16 ℓ pot meer doeltreffend in die gebruik van die invallende sonstralingsenergieë.

ACKNOWLEDGEMENTS

The authors wish to thank the following students who ably assisted with the radiation measurements: RN de Vos, GT Horton, AP Mendes (Ms), TB Nott and SA Oosthuysen.

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THE EFFECT OF SPACING, AND VOLUME OF MEDIA ON GROWTH AND YIELD OF HYDROPONICALLY GROWN TUNNEL TOMATOES

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ABSTRACT

The continued disease problems in soil grown tomatoes in tunnels has necessitated further research into container growing techniques. Earlier trials at Pietermaritzburg established the superiority of sand:peat mixes in plastic containers, but up to now the optimum volume of mixture was not determined. A trial was set up with tomatoes (cv Angela) to compare from 7 to 17 ℓ of medium per plant, with a view to finding the optimum volume, especially for a module type container as used in Guernsey. At the same time the trial was arranged to determine the optimum, between and in row spacings, for plants in different volumes of mixture.

The smallest volume of mix resulted in lower yields and smaller fruit size, and required more management in terms of watering frequency. There was little advantage in using the maximum volume of medium tested.

The different spacings resulted in different light interception patterns, and consequently yields, with the closest in row spacing resulting in the greatest reduction in yields per plant.

The reduction in fruit size up the plant as normally experienced by growers was less marked in wider spacings and larger volumes of mix per plant.

INTRODUCTION

Hydroponics has become an important production technique for tunnel tomatoes in South Africa, and is especially favoured in Natal. Previous work at the University of Natal, Pietermaritzburg showed that a pot media of the three parts sand to one part local peat gave rise to high yields and was economical (Smith, Whitfield, Savage & Cass, 1979). At Stellenbosch University straw bales and rockwool were shown to have good potential for cucumbers and tomatoes respectively (Marce, 1979). In a bed system (Harris, 1970) has preferred granite chips.

With respect to containers most local growers have preferred a polythene pot system. Many overseas growers have turned to a module, and this is especially the case in Guernsey (Moorat, 1979), where the preferred medium is peat.

Under S.A. conditions no work has been carried out to determine the optimum volume of media required, a factor which can affect yields and the cost of production. Moorat advises Guernsey growers to use a 42 ℓ module for 3 plants.

Another important production factor with tomatoes is spacing. Maree & Laubscher (1978) found no significant difference in yield per plant if the in row spacing was 45 cm or 36 cm with a 1 m between row spacing. Rodriguez and Lambeth (1975), in North America recorded the highest yield per plant with a spacing of 51 x 41 cm, with a reduced yield at closer in row spacings. However the highest yield per unit area was with the 30 x 40 cm spacing.

This trial was therefore established to determine the optimum spacing for tomatoes under Natal conditions, and at the same time to determine the optimum volume of media required per plant, with a view to going over to a module system of growing in the future.

PROCEDURE

The trial was carried out in a 'small'' 15 m x 6 m plastic tunnel, orientated East-West, and situated close to the Faculty of Agriculture, Pietermaritzburg. The floor of the tunnel was ridged so as to provide raised pathways between the double rows of plants. The floor was covered with a dual coloured plastic (black to the floor and white up) for light reflection and weed control.

Tomato seed (cv Angela) were sown in a local peat medium in seedling trays on 25.2.79 and transplanted into the pots in the tunnel on 13.3.79.

The pots contained a 3 sand : 1 local peat media which was previously sterilized with formalin, and were irrigated by spaghetti tubes attached to pipes from a 400 ℓ asbestos cement tank.

The plants were grown, trellised, pruned and sprayed according to normal tunnel standards. Initially each pot received 1 g of 'Chemicult' dissolved in a litre of water per day. At first flowering the amount of chemicult was increased to 2 g/ℓ/day and after the 3rd truss had flowered to 3 g/ℓ/day until the end of the trial.

The trial was laid out as a 2 x 2 factorial with split plots and three replications. There were 2 between row spacings (60 cm and 30 cm), and 2 in row spacings (40 cm and 20 cm) as the whole plot factors, with four volumes of media (17 ℓ, 13 ℓ, 10 ℓ and 7 ℓ) as the sub-plot factor. There were four plants per subplot.

Records included plant height, number of nodes to the first truss, height of the first truss, and the mass and number of fruit per truss. Any fruit with a mass of less than 30 g was not weighed and rejected. The number of flowers/truss was recorded in Rep. 2.

Savage & Smith (1980) measured the radiation intensity at different levels in the canopy.

RESULTS

a) Growth rate

Fig. 1 shows that the wider in row spacing of 40 cm resulted in a slower growth rate than the close in row spacing. The between row spacing had little effect. Although there was no significant difference in growth rates between plants in the different pot volumes it was evident that the plants in the small pots were spindly, with long internodes, thin stems and small leaf area.

b) Position of the first truss

The number of nodes to the first truss varied from 8 to 10 with no significant differences between treatments.

The height to the first truss was significantly greater in the close in row spacing (20 cm) than in the wide in row spacing (Fig. 2). Between row spacing had no effect.

Pot volume also significantly affected the height to the first truss, the height generally increasing as the pot volume decreased. This was especially the case at closer in row spacings (Fig. 2).

c) Yield

The 40 cm in row spacing produced a significantly greater mass of fruit per plant than the 20 cm in row spacing (Fig. 3). Varying the between row spacing had little effect on the yield (Fig. 3).

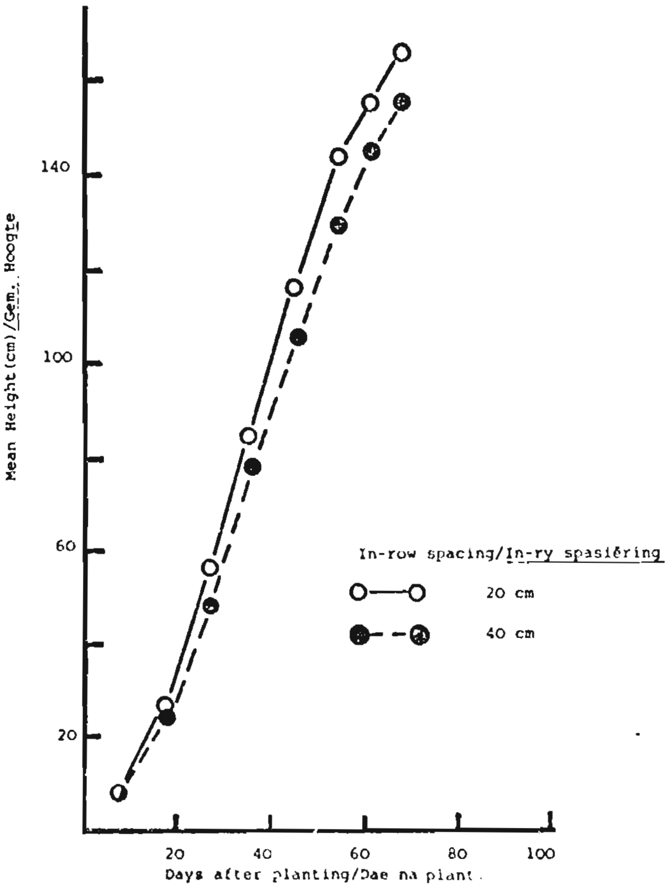

FIG. 1: Plant growth rates at different in row spacings

FIG. 1: Plantontwikkeling by verskillende in-ry spasiërings

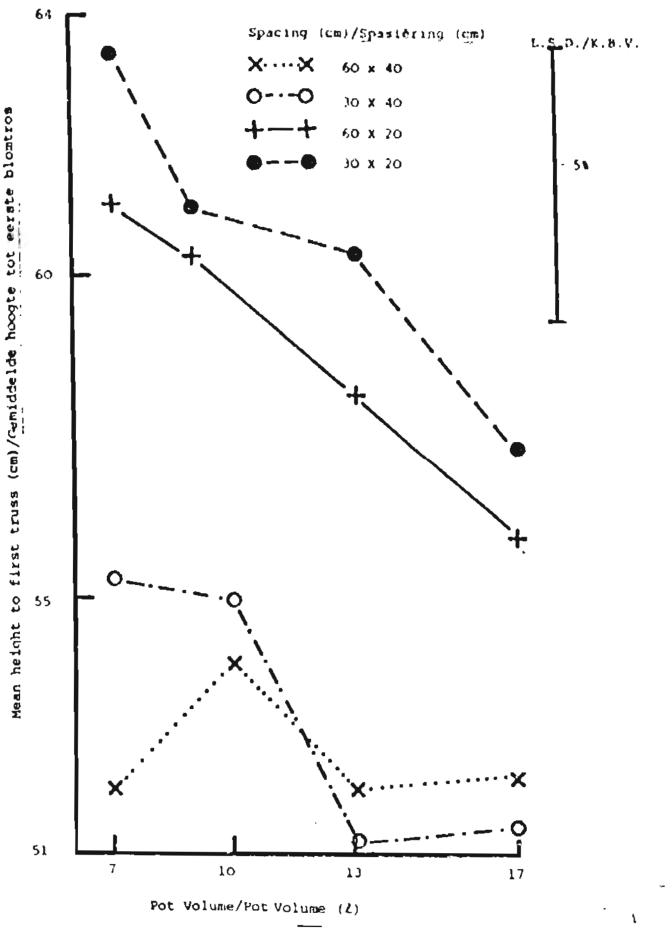

FIG. 2: Mean height to first truss for different spacings and pot volumes

FIG. 2: Gemiddelde hoogte tot eerste blomtros by verskillende spasiërings en pot volumes

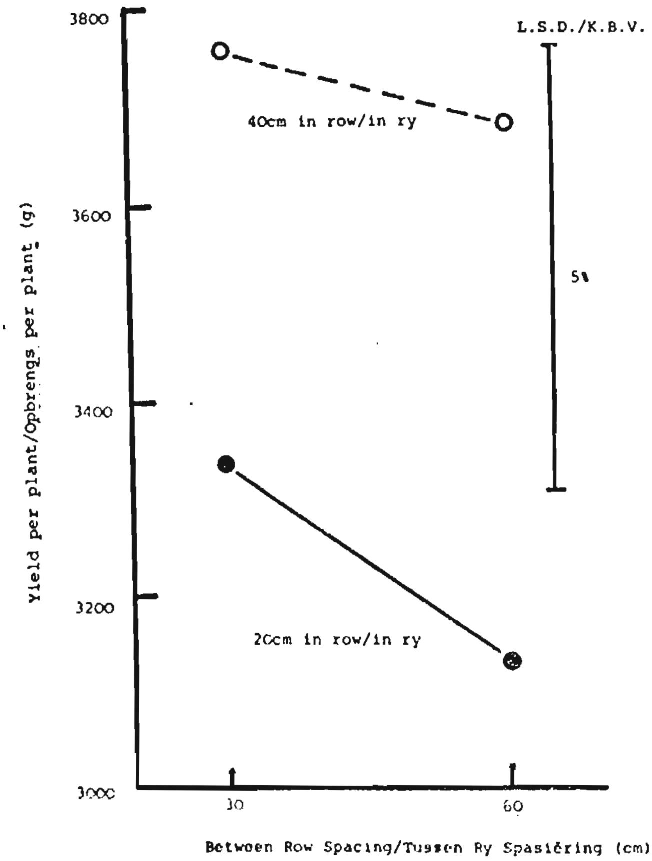

FIG. 3: Between and in row spacing effects on total yield per plant

FIG. 3: Invloed van tussen- en in-ry spasiëring op totale opbrengs per plant

Pot volumes from 10 ℓ upwards gave significantly higher yields than the 7 ℓ pot volume (Fig. 4). However, the optimum volume appeared to be 10 ℓ with a falling off in yield at 13 ℓ and 17 ℓ (Fig. 4).

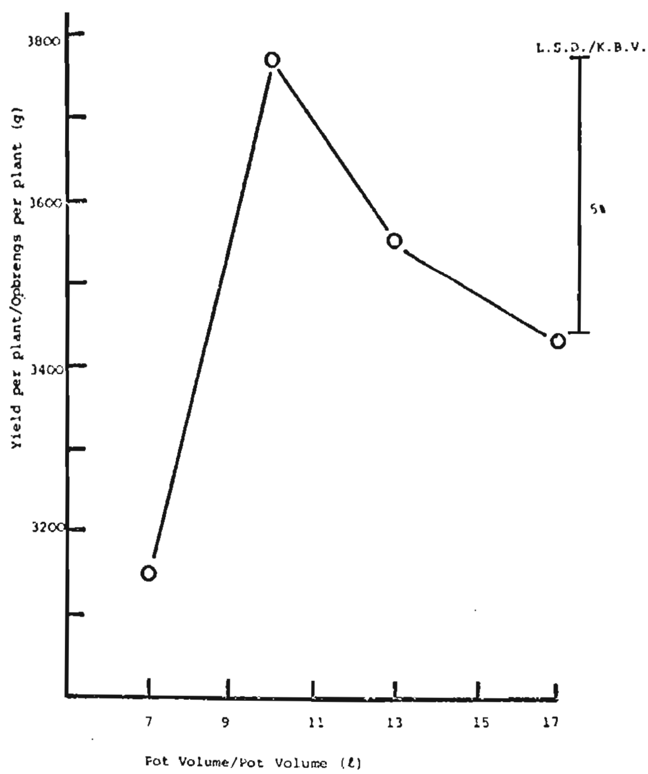

FIG. 4: Effect of pot volume on total yield per plant

FIG. 4: Uitwerking van pot volume op totale opbrengs per plant

The interaction between the different spacings and pot volumes (Fig. 5) showed that the highest yield in all spacings was with the 10 ℓ pots. It was significant that at close in row spacings the largest pots performed badly, and therefore, at those spacings there was a disadvantage in using a large volume of medium. At most in row spacings larger volumes of media yielded equally as well as the 10 ℓ pots.

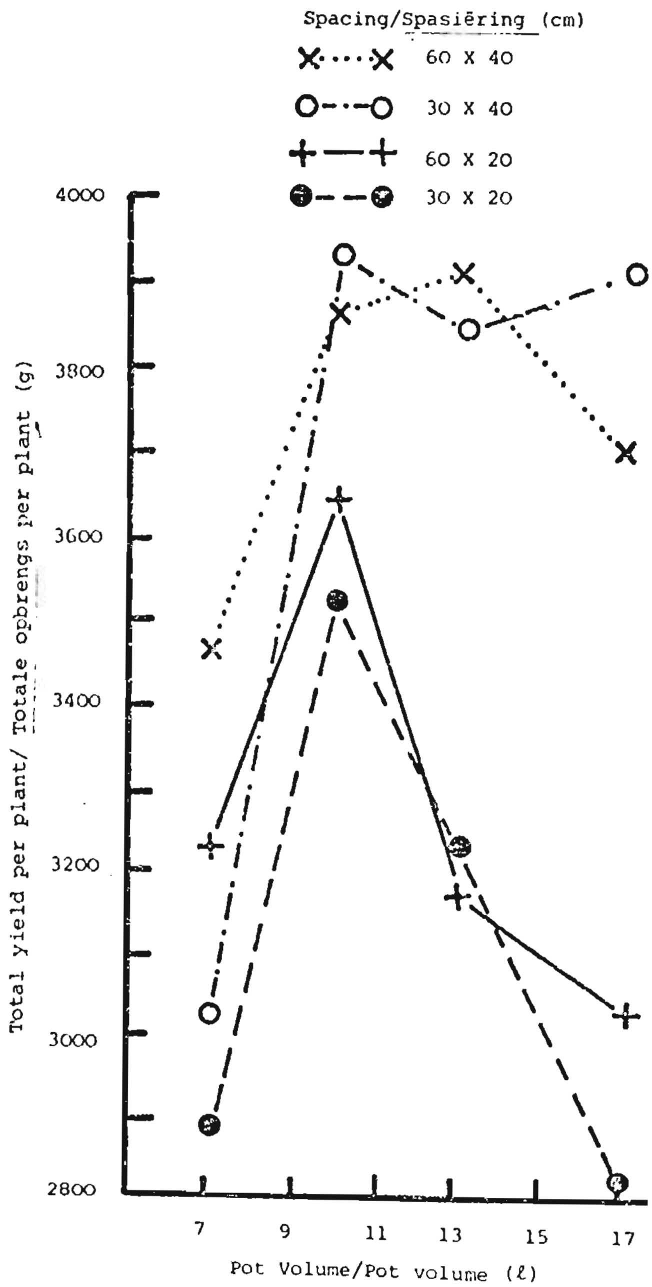

FIG. 5: Effect of spacing and pot volume on yield per plant

FIG. 5: Uitwerking van spasiëring en pot volume op opbrengs per plant

d) **Total number of fruit per plant**

Plants in the 30 cm x 40 cm spacing produced significantly more fruit than the other spacing combinations (Fig. 6a), with the wider in row spacing resulting in an average of 5 fruit per plant more than the close in row spacing. Between row spacing did not affect the number of fruit produced per plant.

With respect to volume, the smallest volume tested resulted in fewer fruit per plant than the other volumes (Fig. 6b).

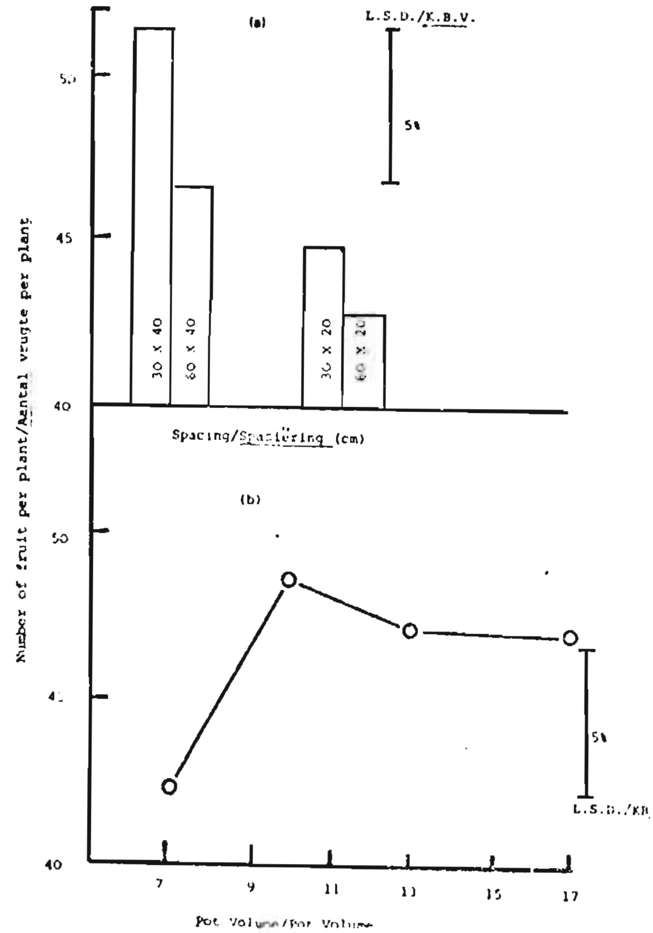

FIG. 6: Effect of a) spacing and b) pot volume on total number of fruit per plant

FIG. 6: Uitwerking van a) spasiëring en b) pot volume op aantal vrugte per plant

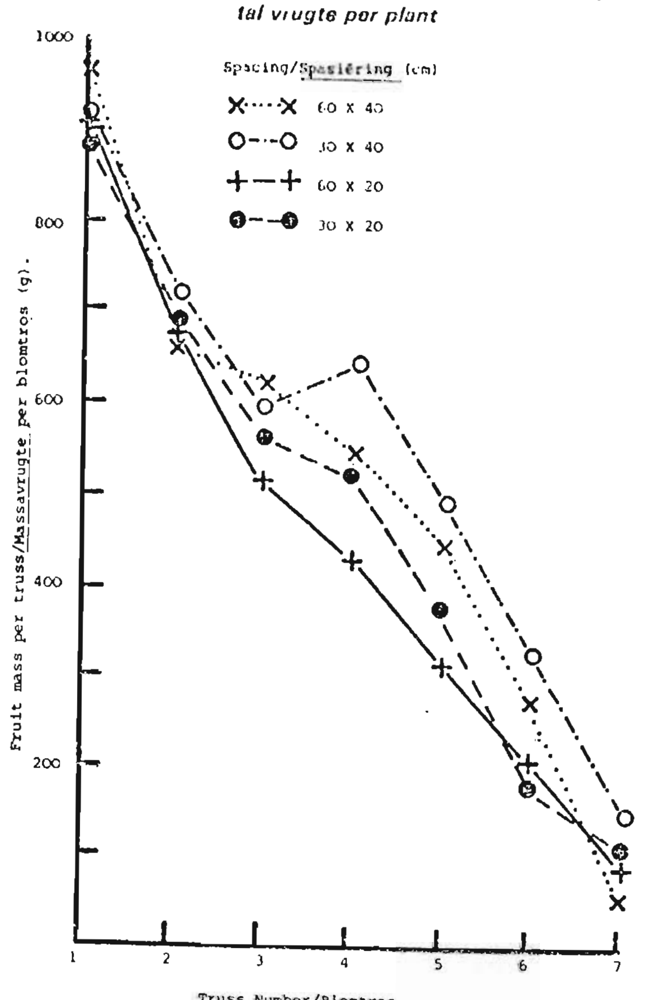

FIG. 7: Effect of spacing on yield per truss

FIG. 7: Uitwerking van spasiëring op opbrengs per blomtros

e) **Mean fruit mass**

There was no difference in the overall mean fruit mass per plant, with the average fruit size in the trial being 76 g.

f) **Yield components of the individual trusses**

As usual there was a decline in the *yield per truss* up the plant (Fig. 7) and this occurred in all treatments.

With respect to volume the lowest yield per truss was always in the 7 ℓ pots with little difference between the other volumes (not shown).

The spacing effect, however, was notable, and is important. Fig. 7 shows that the yields were better at higher trusses where the in row spacing was wider.

As with the yield per truss, there was also a decline in the number of fruit per truss up the plant in all treatments (Fig. 8).

Again, it was significant, that at the wider in row spacing the plants produced a greater number of fruit per truss on the higher trusses.

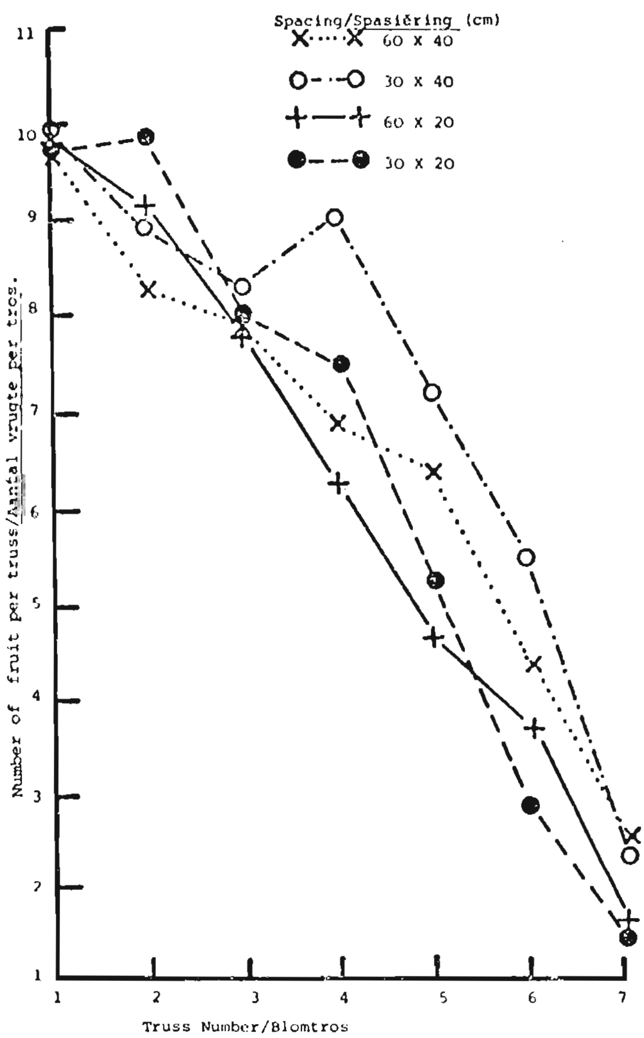

FIG. 8: Effect of spacing on the number of fruit per truss
FIG. 8: Uitwerking van spasiëring op aantal vrugte per blomtros

The mean fruit mass of each consecutive truss decreased until the sixth truss, with a slight increase at the seventh truss (Fig. 9). This increase in fruit mass was attributed to better pollination during the warmer weather in spring when fruit set took place.

The average size of the fruit on each truss was greater in the 40 cm in row spacing, especially on the 3rd and 4th trusses. At higher trusses the close spacing treatments, which had the least number of fruit tended to produce slightly larger sized fruit.

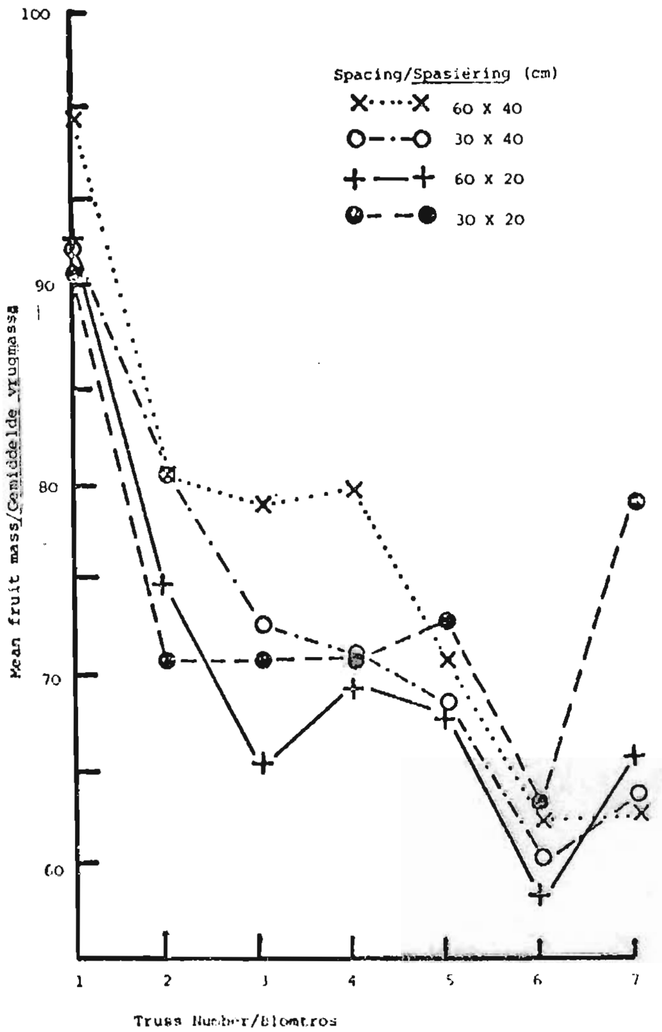

FIG. 9: Effect of spacing on mean fruit mass per truss
FIG. 9: Uitwerking van spasiëring op gemiddelde vrugmassa per blomtros

g) **Number of flowers and percent fruit set per truss**

These counts were only made in the one replicate and therefore could not be analysed. The number of flowers per truss varied considerably and any trends were hard to define. In some treatments the 4th truss tended to produce the most flowers. The percentage of flowers which set and produced harvestable fruit (Fig. 10) decreased with increasing truss number, and was generally higher at the wider in-row spacing.

Generally then it could be said that although the wider spacing did not result in more flowers per truss, each truss had a higher yield due to a higher percent fruit set and the fact that each fruit grew to a larger size. This difference was especially evident at the higher trusses.

h) **Radiant density**

Savage & Smith (1980) measured the radiant density at different canopy heights within the different spacing arrangements in the trial. Fig. 11 shows that the top 30 cm layer of the plants had 70 per cent available energy in the wide spacings, compared to 50 per cent in the close spacings. In the middle layer of leaves there was 45 per cent energy available in the wide spacings, but only 20 per cent in the close spacings. At the lowest level (30 — 60 cm from ground) nearly 30 per cent remained in the wide spacings, compared to only 10 per cent in the close spacings.

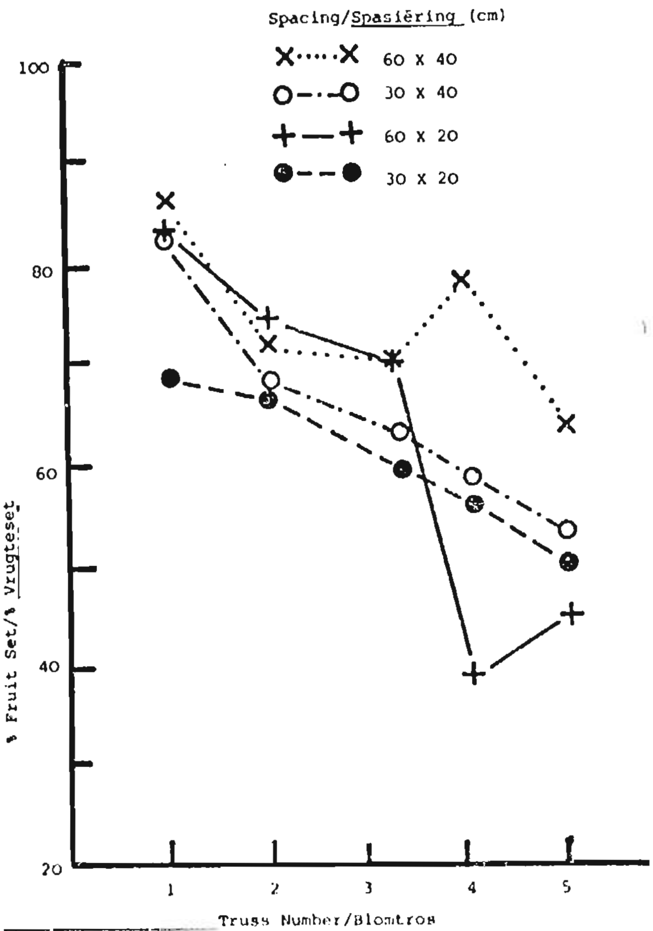

FIG. 10: Effect of spacing on % fruit set per truss

FIG. 10: Uitwerking van spasiëring op % vrugteset per blomtros

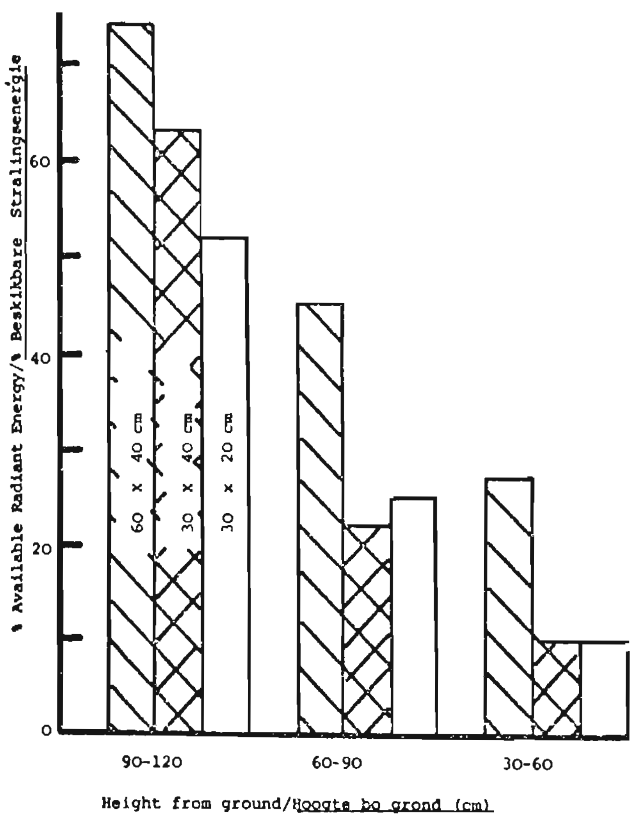

FIG. 11: % radiant energy available at different heights in the centre of double rows of tomatoes at different spacings (after Savage & Smith, 1980)

FIG. 11: % beskikbare stralingsenergie by verskillende hoogtes in die middel van dubbele rye tamaties met verskillende spasiërings (Savage & Smith, 1980)

DISCUSSION

The wider in row spacing of 40 cm resulted in a slower growth rate and reduced stem node length. At close spacings the faster growth rate and increased internode length resulted from competition for light with the plants having a spindly growth habit, this being most marked in 7 ℓ pot volumes. The reduced amount of radiant energy in the close spacings is closely related to those of Harper, Pallas, Bruce & Jones (1979) working in Georgia, U.S.A., who found that in 2 m tall plants about 15 to 25 per cent of available solar radiation was transmitted to the floor surface at spacings of 45 cm x 45 cm (2,5 plants/m²). They subsequently increased their plant populations to 3,3 plants/m² with a far better radiation interception pattern.

In our measurements 27 per cent radiant energy reached the lower canopy levels at a 60 x 40 cm spacing and 10 per cemt at a 30 x 40 cm spacing.

The plant growth characteristics in this trial are also similar to those of Kedar & Retig (1968) who found that decreased light intensity increased the internode length in tomatoes.

Rodriguez & Lambeth (1975) recorded the highest per plant yield at a spacing of 51 x 41 cm, with a yield reduction as the in row spacing was reduced. In the present trial the *highest per plant* yield was at the 30 x 40 cm spacing, although this was not significantly greater than any of the other combinations.

What was significant, however, was the higher yield of plants at wider in row spacing, suggesting that the in row spacing is the most critical factor. At wider in row spacings there was a more even distribution of radiant energy throughout the canopy (Fig. 11), whereas in the close in row spacing too much energy was absorbed by the upper layers.

With respect to pot volumes the highest per plant yield was recorded in the 10 ℓ pot volumes, with apparently (but not significant) lower yields at greater pot volumes, especially at close spacings. This finding differs from Moorat's (1979) recommendation of 13 ℓ to Guernsey growers.

It would seem that under our environmental conditions the more restricted root volume in the 10 ℓ of medium gave rise to a better balanced plant in terms of vegetative growth and fruiting. A possible reason for the lower yield in larger volumes of medium was the plant became too vegetative to the detriment of yield.

Increased yields were due to increased numbers of fruit, especially at the higher trusses, rather than to an increase in fruit mass. This was especially notable at the wider in row spacing, and is an important consideration in helping to overcome the reduced yields at higher trusses which most growers experience.

TABLE 1: Total number of plants and total yield in a 30 m x 8 m tunnel with a 2 m door space

Spacing Between-row (cm) In-row (cm)	Total number of plants	Plants per m² of tunnel	Total Yield to 6 trusses (kg)
30 x 40	520	2,2	1953,0
60 x 40	520	2,2	1914,4
30 x 20	1 040	4,3	3468,6
60 x 20	1 040	4,3	3254,4

In spacing work it is not the optimum yield per plant that is important, rather the total yield per tunnel area, in conjunction with the required quality of the product. Table 1 shows the yields for the different spacing arrangements. Obviously at the closer spacings there would be twice as many plants per tunnel so the yields were far higher. Note that the yield is not double as the per plant yields were lower at the close spacings.

It would seem therefore that at an in between plant population would be the best. This could be achieved by either

a) Using a 30 – 35 cm in row spacing on a 4 double row system to give 746 – 640 plants per tunnel, or 3,1 – 2,7 plants/m² respectively, or

b) By using the 30 cm x 40 cm spacing but including an extra single row of plants on each side of the tunnel to give a population of 640 plants/tunnel (2,7/m²). Alternately a 5 double row system at the above spacing could be used – this would reduce the cost of the irrigation system.

It is important to note that this discussion only applies to plants with a restricted root system in a pot or other container. Soil grown plants may be more vegetative and would require a wider spacing.

CONCLUSIONS

It is evident that for maximum yield per plant a wider in row spacing was preferable, the between row spacing having little effect within the arrangements tested. On a per tunnel basis the maximum yield resulted from close in row spacing due to the greater plant population. This spacing would however, provide problems in terms of management practices, and pest and disease control.

In the author's opinion the optimum spacing on a per plant basis would be approximately 35 cm x 35 cm, while on a per tunnel basis a 30 cm x 40 cm spacing with 5 double rows, or 4 double rows and single rows on the outside, to give 640 plants per 30 m tunnel would be a good system.

The least pot volume that could sustain good growth and yields was 10 ℓ, there being no advantage in increasing the amount of medium. The optimum volume for a 3 plant module would therefore be 30 ℓ.

OPSOMMING

DIE INVLOED VAN SPASIËRING EN DIE VOLUME GROEIMEDIA OP GROEI EN OPBRENGS VAN WATERKULTUUR GEKWEEKTE TONNEL TAMATIES

*Die voortdurende voorkoms van siektes in grondgekweekte tamaties het genoodsaak dat verdere navorsing van tegnieke om tamaties in plastiek-houers te kweek, gedoen moes word. In vroeëre proewe uitgevoer by Pietermaritzburg is vasgestel dat 'n sand:veen groeimedium uiters geskik is, maar die optimum hoeveelheid per plant is nog nie vasgestel nie. 'n Proef is met tamaties (cv Angela) uitgevoer waarin verskillende volumes groeimedium, van 7 tot 17 ℓ/*plant met mekaar vergelyk is met die doel om die optimum volume van 'n module, soortgelyk aan die wat in Guernsey gebruik word, vas te stel. Terselfdertyd is ook ondersoek wat die geskikste tussen- en in-ry spasiëring van plante in die verskillende volumes groeimedium is.

Die kleinste volume groeimedium het die laagste opbrengs en kleinste vrugte gelewer, die plante het ook meer aandag benodig omdat hulle meer dikwels besproei moes word. Daar was weinig voordeel in die gebruik van die grootste houers.

Die verskillende spasiërings het verskillende ligonderskeppingspatrone getoon, gevolglik het die nouste in-ry spasiëring die grootste afname in opbrengs getoon.

Die voorkoms van kleiner vrugte hoër op teen die plant, wat gewoonlik deur kwekers ondervind was nie so opvallend by wyer spasiëring en groter houers nie.

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Agrochemophysica 12, 53–57 (1980)

POT TEMPERATURE AS A FACTOR IN PLASTIC TUNNEL CROP PRODUCTION

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Abstract

Keywords: Micrometeorology, artificial climate; plastic tunnels; microclimate; pot temperature; temperature.

Pot temperature was monitored for a winter tomato crop in an east-west oriented plastic tunnel. Pot media affected pot temperature with a peat and sand (1:3 by volume) mixture generally having the highest polystyrene and peat (1:1) having the lowest day time pot temperatures. During the night time, peat and vermiculinte (1:1) had one of the highest pot temperatures, while sand and the polystyrene and peat (1:1) mixture had the lowest.

The east-west orientation of the tunnel resulted in large pot temperature differences between rows. From the northernmost row to the next, the daily mean pot temperature decreased by 4,4 °C for peat and sand (1:3) and 3,5 °C for peat and vermiculite (1:1).

There was no clear relationship between crop yield and pot temperature possibly because of the interacting effects of the different potting media. However, this study provides strong evidence that pot temperature is an important factor affecting crop yield.

Uittreksel

DIE INVLOED VAN POTTEMPERATUUR OP OESOPBRENGS IN 'N PLASTIESE TONNEL

Pottemperatuur is gemeet vir wintertamaties in 'n oos-wes-georiënteerde plastiese tonnel. Daar is bevind dat pottemperatuur deur die potmedium beïnvloed is: die veen en sandmengsel (1:3 by volume) het die hoogste en polystyreen een veen (1:1) het die laagste dagtemperatuur gehad. Gedurende die nag, het veen en vermikuliet (1:1) die hoogste pottemperatuur gehad terwyl sand en die polistireen en veen (1:1) mengsel die laagste gehad het.

Die oos-wes-oriëntasie van die tonnel het 'n belangrike invloed op pottemperatuur tussen rye gehad. Van die noordelikste ry na die volgende het die daaglikse gemiddelde pottemperatuur verminder met 4,4 °C vir veen en sand (1:3) en 3,5 °C vir veen en vermikuliet (1:1).

Daar was geen duidelike verband tussen opbrengs en pottemperatuur nie, miskien as gevolg van die wisselwerking van die verskillende potmengsels. Hierdie studie lewer egter bewys dat pottemperatuur 'n belangrike invloed op opbrengs het.

Résumé

TEMPÉRATURE DES POTS EN TANT QUE FACTEUR POUR LA PRODUCTION DE CULTURES SOUS TUNNEL EN PLASTIQUE

La température des pots a été contrôlée pour une culture de tomates d'hiver faite sous un tunnel de plastique orienté d'est en ouest. Le mélange contenu dans les pots affecta la température du pot, le mélange de tourbe et de sable (1:3 par volume) ayant généralement la température la plus elevée et le melange de polystyrene avec tourbe (1:1) ayant la température la plus faible pendant le jour. Pendant la période nocturne, la tourbe avec de la vermiculite (1:1) indiquèrent une des températures les plus élevées tandis que le sable et le mélange de polystyrene avec tourbe (1:1) montrèrent les températures les moins élevées.

L'orientation d'est en ouest du tunnel résulta en de grandes différences de température entre les lignes. De la ligne la plus au nord jusqu'à la suivante, la température diurne moyenne du pot diminua de 4,4 °C pour la tourbe et le sable (1:3) et de 3,5 °C pour la tourbe avec vermiculite (1:1).

Aucune claire relation n'exista entre le rendement de la culture et la température des pots, probablement à cause des effects en inter-action des différents mélanges contenus dans les pots. Cependant cette étude procure une forte évidence sur le fait que la température du pot est un important facteur qui affecte le rendement de la culture.

Introduction

Climate modification by man is one method used to compensate for his growing demands on the environment. An example of climate modification is the use of plastic tunnels. As Savage (1980b) states, plastic tunnels trap solar energy. Provided water and soil nutrients are not limiting, crop yield is governed by the seasonal input of solar energy and the efficiency with which that energy is utilized (Cooper, 1969). Savage & Smith (1980) discuss factors affecting the utilization of radiant energy in plastic tunnels.

Soil and air temperatures also play an important rôle in the growth and development of field crops (Abdelhafeez, Harssema, Heri & Verkerk, 1971; Canham, 1970; Downs & Hellmers, 1975; Menhenett & Wareing, 1975; Watts, 1972a, b). Savage (1980b) discusses some aspects of air temperature in plastic tunnels.

Downs & Hellmers (1975) state that root temperature exerts control over plant growth by affecting the uptake of water and minerals and by affecting initiation and growth of roots. These authors point out that root temperatures can yield much valuable information in relating plant behaviour to soil types (or in the case of plastic tunnels, to pot media). It is assumed here that pot temperature, at a specified depth within the crop root zone, is a measure of root temperature.

The objective of this study was to describe the diurnal variation in pot temperature in relation to pot media type, position in the tunnel and time of day and to try to establish whether pot temperature is indeed a factor directly affecting crop yield. Tomatoes, a crop sensitive to frost, was used in this experiment.

Procedure

The experimental details of the tunnel and its crop are discussed by Savage (1980b) and by Smith, Whitfield, Savage & Cass (1979). Resistance thermometers were used to measure the temperature of the different pot media. The construction of the inexpensive resistance thermometers used is discussed by Savage (1980a). The pot temperatures were measured at a depth of 100 mm below the surface in eleven pots with eight different kinds of pot media. The pots were of the normal black plastic. Table 1 shows the type of pot media with the respective numbers and Fig. 1 shows a plan view of the tunnel. Pot temperature was measured in 2 of the 3 double rows during the months June and July, generally the coldest time

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Received 10 October 1979

TABLE 1 The mean of the daily maximum and minimum and the mean pot temperatures, together with the yield data for the period 78.6.15 to 78.7.14. The pot number is indicated to the left of the pot media type

TABEL 1 *Die gemiddeld van die daaglikse maksimum en minimum en die gemiddelde pottemperature asook die oesopbrengsdatum vir die tydperk* 78.6.15 *tot* 78.7.14. *Die potnommer is links van die potmedium aangedui*

Pot media *Potmedium*	Mean of daily maximum *Gemiddeld van die daaglikse maksimum* (°C)	Mean of daily minimum *Gemiddeld van die daaglikse minimum* (°C)	Mean *Gemiddeld* (°C)	Crop yield *Oesopbrengs* (kg/plant)
1. Peat and sand (1:2)/ *Veen en sand* (1:2)	13,4	6,4	9,9	2,27
2. Sand/*Sand*	14,1	6,1	10,1	2,02
3. Peat and vermiculite (1:1)/ *Veen en vermikuliet* (1:1)	13,6	7,5	10,6	2,54
4. Polystyrene and peat (1:1)/*Polistireen en veen* (1:1)	13,3	6,1	9,7	1,65
5. Peat and sand (1:3)/ *Veen en sand* (1:3)	14,7	6,2	10,5	3,16
6. Perlite/*Perliet*	13,6	6,4	10,0	2,98
7. Vermiculite/*Vermikuliet*	13,2	7,0	10,1	2,43
8. Peat and perlite (1:1)/ *Veen en perliet* (1:1)	12,3	6,4	9,4	2,73
9. Perlite/*Perliet*	18,6	7,6	13,1	3,29
10. Peat and sand (1:3)/ *Veen en sand* (1:3)	23,5	6,2	14,9	3,86
11. Peat and vermiculite (1:1)/ *Veen en vermikuliet* (1:1)	20,9	7,3	14,1	5,59

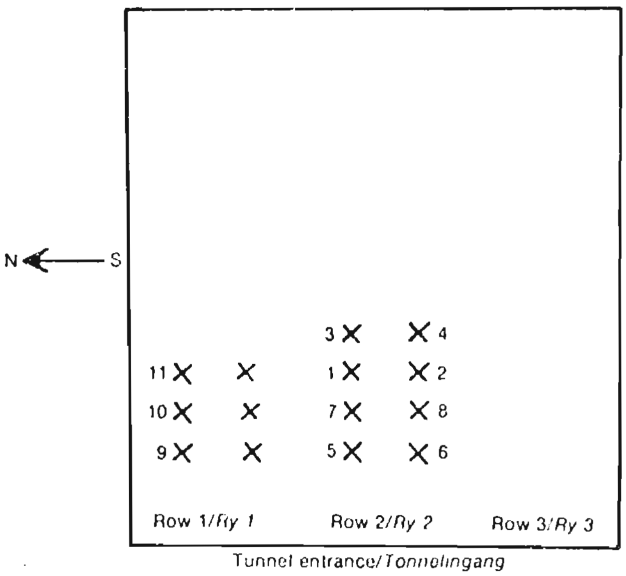


FIG. 1 Plan view of the tunnel where the numbers shown refer to the treatments in Table 1

FIG. 1 *Sketsplan van die tonnel waar die nommers verwys na die behandelings in Tabel* 1

of the year. All treatments received the same amount of water and nutrients, as discussed by Smith *et al.* (1979).

The tunnel was orientated in an east-west direction (Fig. 1). This meant that a greater percentage of the crop would be able to absorb more radiant energy in the winter months than if the tunnel were orientated north-south.

Results and Discussion

The diurnal variation of pot temperature for selected pots (in the same row) for a cold night, a hot day and a cloudy day is shown in Fig. 2. Generally, the maximum pot temperature occurs between 15h00 and 17h00 but on average at about 16h00. The minimum pot temperature occurred at 08h00. Sunrise time was about 07h00. For the sake of comparison, the diurnal air temperature variation is also shown, taken from Savage (1980b). During the day, the air temperature was much greater than the pot temperature but this was reversed at night.

Table 1 shows the minimum and maximum pot temperatures for the various pots for the period 78.6.15 to 78.7.14. In all cases, the 1:3 (by volume) peat and sand mixture had the highest pot temperatures during the day. The next highest day temperatures were recorded for peat and vermiculite (1:1). Sand also had high day time pot temperatures and the 1:1 peat and perlite mixture had the lowest mean pot temperatures of all the media.

At night, peat and sand (1:3) experienced relatively low temperatures but the peat and vermiculite (1:1) mixture had high temperatures. In fact, both the vermiculite and peat and vermiculite (1:1) media appear to retain more heat energy than most of the other media during the night time. Polystyrene and peat (1:1) and sand experienced the lowest night time pot temperatures.

From the data of Table 1, it would appear that the peat and sand (1:3) medium generally has the highest day pot temperatures, the greatest diurnal pot temperature range and the greatest mean pot temperatures. Also, from these data it would seem that peat and sand (1:3) is the most suitable medium from the point of view of providing temperatures beneficial to crop growth. With these criteria in mind, the peat and vermiculite (1:1) medium is also suitable although it should be emphasized that these choices are on the basis of the available data.

Treatments 11 and 3 (1:1 peat and vermiculite in both cases) and 10 and 5 (1:3 peat and sand) are on the northern side of rows 1 and 2 respectively (Fig. 1). In each case the pots are in nearly the same position in the respective row so that temperatures may be compared. Fig. 3 shows these comparisons for a warm day (78.6.26). For peat and sand (1:3), the maximum pot temperature was 24,0 °C in row 1 and 15,7 °C for row 2, a difference of 8,3 °C and for peat and vermiculite this difference was 7,5 °C. Table 1 shows this pot temperature difference between the corresponding treatments, over a period of a month.

Crop yield has been shown to be affected by soil temperature (Peacock, 1975; Power, Grunes, Reichman & Willis, 1970). Table 1 shows the crop yields for different treatments. A comparison of the yields for the same media type (treatments 9 and 6, 10 and 5, 11 and 3 respectively) shows a possible pot temperature effect. In each case the yield per plant is greater for the pots with the higher pot temperatures (treatments 9, 10 and 11). In the case of peat and vermicu-

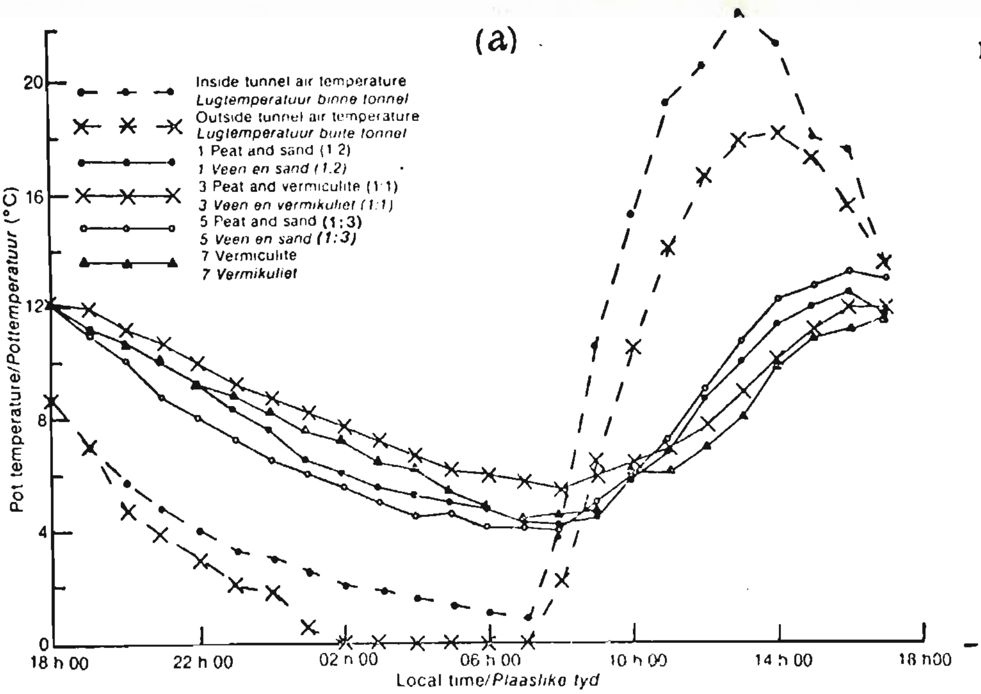


FIG. 2 (a) Diurnal variation of pot temperature for selected pots from 18h00 on 1978.6.22 (a cold night) to 18h00 on 1978.6.23

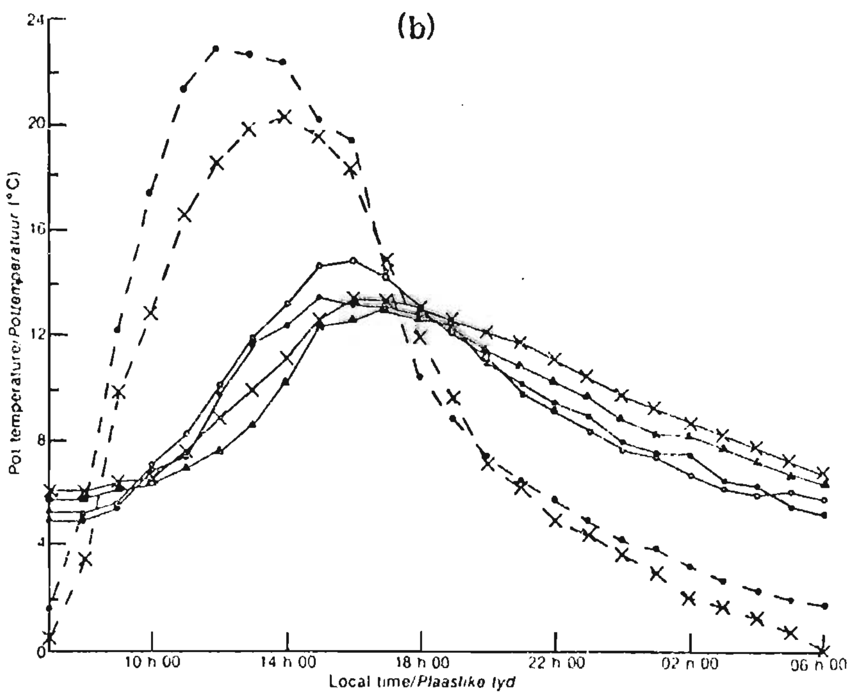
FIG. 2 (a) *Daaglikse wisseling van pottemperatuur vir gekeurde potte vanaf 18h00 op 1978.6.22 ('n koue nag) tot 18h00 op 1978.6.23*

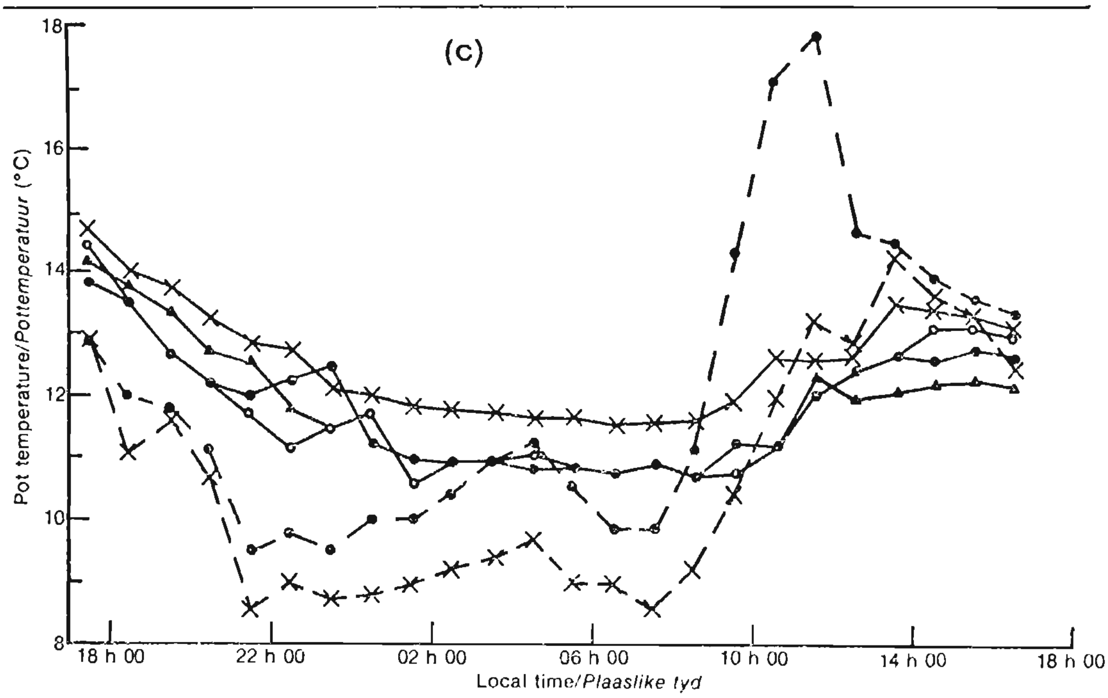
FIG. 2 (b) Diurnal variation of pot temperature for selected pots from 07h00 on 1978.6.26 (a warm day) to 06h00 on 1978.6.27

FIG. 2 (b) *Daaglikse wisseling van pottemperatuur vir gekeurde potte vanaf 07h00 op 1978.6.26 ('n warm dag) tot 06h00 op 1978.6.27*

FIG. 2 (c) Diurnal variation of pot temperature for selected pots from 17h30 on 1978.7.1 to 16h30 on 1978.7.2 (cloudy day)

FIG. 2 (c) *Daaglikse wisseling van pottemperatuur vir gekeurde potte vanaf 17h30 op 1978.7.1 tot 16h30 op 1978.7.2 ('n bewolkte dag)*





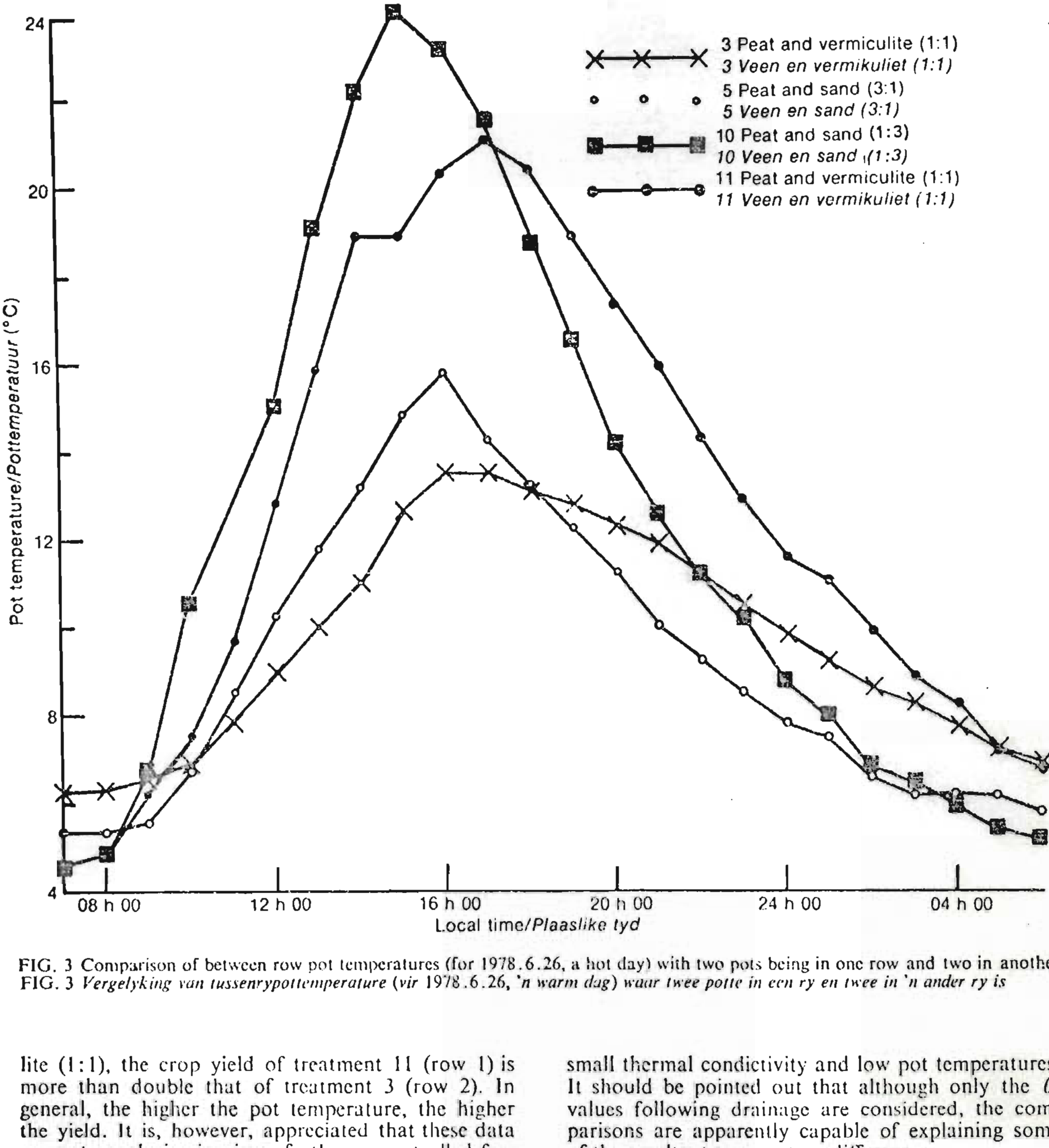


FIG. 3 Comparison of between row pot temperatures (for 1978.6.26, a hot day) with two pots being in one row and two in another
FIG. 3 *Vergelyking van tussenrypottemperature (vir 1978.6.26, 'n warm dag) waar twee potte in een ry en twee in 'n ander ry is*

lite (1:1), the crop yield of treatment 11 (row 1) is more than double that of treatment 3 (row 2). In general, the higher the pot temperature, the higher the yield. It is, however, appreciated that these data are not conclusive in view of other uncontrolled factors that could have affected these yields.

The pot temperatures shown in Table 1 may be explained by comparing the air filled porosity θ_a values given in volume per cent. The thermal conductivity of the media will depend mainly upon θ_a and it may be anticipated that the greater the thermal conductivity the greater the daily range of pot temperatures. For simplicity, θ_a for the various media following drainage will be compared. θ_a is greater than 30% for perlite whereas for peat and sand (1:3), $\theta_a < 10\%$ (Mastalerz, p. 350, 1977). Hence perlite will have a smaller thermal conductivity than peat and sand (1:3). Sand, and peat and sand (1:3) both have $\theta_a < 10\%$ and also have very high pot temperatures. Presumably the polystyrene and peat (1:1) mixture has an extremely large θ_a and hence very low pot temperatures, which would possibly account for the low yields of this medium (Table 1). For vermiculite, $\theta_a > 25\%$ and hence this medium has a small thermal condictivity and low pot temperatures. It should be pointed out that although only the θ_a values following drainage are considered, the comparisons are apparently capable of explaining some of the resultant temperature differences.

Conclusion

Pot media were found to affect pot temperature markedly. The other factor affecting pot temperature was position in the tunnel with pots closest to the northern side having the highest temperatures. Pot temperature appeared to affect crop yield but the effects of the different pot media could not be clearly separated. The air filled porosity and therefore thermal conductivity of the potting medium may be of help in anticipating the relative temperature variation in pots with different media.

Acknowledgements

The writers are sincerely grateful to Mr P. N. Dovey and Miss W. Morgan for their assistance, Mr P. F. Whitfield for growing the crop and to Mr M. A. Khan for reading data from the temperature charts.

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EFFECT OF SHADING ON THE ENVIRONMENT, ;ROWTH AND YIELD OF GREENHOUSE CUCUMBERS

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ABSTRACT

An analysis of the environment inside a plastic tunnel, and the growth and yield of greenhouse cucumbers, with or without 30 % adecloth, was made over a 15 week period in autumn in Pietermaritzburg.

The total daily radiant density in the unshaded environment was double that for the shaded (typically 1 MJ m⁻² compared to 2 MJ m⁻²). Little 'ference in air and leaf temperatures was recorded because a single tunnel was used, although these were more uniform in the shaded environ-ent due to the insulating effect of the shadecloth.

Shaded plants adapted to their environment by producing a greater leaf area, but smaller root system, associated with which was an in-eased resistance to leaf water movement. Shaded plants produced less total dry matter and proportionately put more dry matter into leaves and ems, and less into roots and fruits.

Although relative growth rates were similar in both environments, the net assimilation rates were higher for unshaded plants.

INTRODUCTION

South African greenhouse growers still have to rely on impor-d European cucumber varieties, bred and selected under European onditions, with controlled temperature and relatively low radiation :gimes. Such varieties are expected to perform well under the ariable, and often extremely high summer air temperatures in South frica, using greenhouse structures which offer only limited forms of imate control.

Recommended temperatures for greenhouse cucumbers in urope are 21 °C day 19 °C night for the first 45 days, followed by 19 C day/17 °C night, with typical total daily radiation densities of near 6 MJ m⁻² (Anon, 1980). In America, Wittwer & Honma (1979) have :commended a growing temperature of 28 °C, and state that inimum temperatures should not be below 21 °C or else heating lould be applied.

Milthorpe (1959) found that cucumber foliage had an optimum 24 °C for both assimilatory activity, and the expansion of assimila-ng surface. Challa (1976), in extensive growth studies with green-ouse cucumbers, considered 25 °C the optimum growth tempera-ire, and showed that the CO_2 uptake of 5 leaf plants was still in-easing at an irradiance of 200 W m⁻², the maximum level tested.

Inside plastic tunnels in South Africa, by comparison, Maree 979) has recorded day temperatures of 40 °C in mid summer at Stel-nbosch, North. Allan & de Jager (1978) 30 °C/15 °C at Pietermaritz-irg, and Savage (1980b) 24 °C/1 °C in mid winter at Pietermaritz-irg, with a total daily radiant density of 14 MJ m⁻².

Obviously, under summer conditions, some form of climate introl should benefit greenhouse cucumbers in plastic tunnels. aree (1979) has suggested shadecloth, or a whitewash paint larvotint 'muralo') which will reduce the maximum daytime air mperature inside the tunnel by about 5 to 10 °C, compared to an un-aded tunnel.

At the same time shading reduces the amount of radiant ener-entering the tunnel, and Maree (1979) recorded about 30 % less diation in a shaded tunnel. Although radiation (flux density) levels iy be high in South Africa (up to 1000 W m⁻² at local noon in mid mmer) the physiological response of the cucumber plant to differ-t levels of radiation under South African conditions has not been :asured.

A trial was thus established to measure the growth and yield, growth analysis techniques, of greenhouse cucumbers in a plastic inel at Pietermaritzburg.

PROCEDURE

neral

The trial was carried out in a single 30 m by 8 m Gundle 'roll up sides' plastic tunnel, orientated North/South near the Faculty of Agriculture, University of Natal, Pietermaritzburg.

Seeds of *Cucurbita pepo* C. *cv* Pepinex were germinated in Speedling[1] trays before being planted into black plastic pots in the tunnel, each containing 13 ℓ of a 1 to 1 mixture (volume basis) of local Umgeni River sand (a coarse grit) and Irish peat moss.

The pots were arranged in four double rows within the centre of the tunnel, at a spacing of 500 mm by 500 mm. Each pot was irri-gated by a microtube inserted into a main delivery pipe from an asbestos tank which contained the nutrient solution. The plants were irrigated twice a day with 1 ℓ of a solution containing 2 g Chemicult per litre.

The plants were trained to a single stem for the duration of the trial, and first fruiting was only allowed to take place at a height of 600 mm from the pot surface.

Experimental design and treatments

The main treatment effect was the effect of shade vs no shade. Shade was supplied by erecting 30 % Alnet shadecloth inside the plastic roof of one half of the tunnel so that half the number of plants in the trial were completely covered, and surrounded by, shadecloth, with the other half the plants being unshaded but adjacent to the shaded plants in the same tunnel.

In all, therefore, there were four treatments, two shade treat-ments, and two pruning regimes, with four replicates consisting of the four double rows of pots. Within each treatment in each replicate there were 11 plants, one of which was chosen at random on each sampling date.

Growth analysis was carried out by sampling one plant from each treatment in each replicate weekly starting two weeks after the plants had been transplanted into the pots in the tunnel. The sowing date was 14.3.80, the transplanting date 28.3.80 and the first sampling date 11.4.80.

Fruit was harvested at normal commercial maturity.

Growth analysis methods

At each sampling the medium was thoroughly washed from the roots, keeping the roots as intact as possible. Each plant was then weighed and divided up into roots, leaves, stems and fruits, each of which was weighed. Each part was dried and its dry mass determined. Leaf area was determined using a leaf area meter.

The following growth analysis formulae were used (Hunt, 1978):-

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[1]The mention of proprietary products is for the convenience of the reader and does not imply endorsement or otherwise by the authors or the University of Natal.

LAR (leaf area ratio) $= \frac{\text{Leaf area}}{\text{Leaf mass}}$ $(m^2\ g^{-1})$; (1)

CGR (crop growth rate) $= \frac{W_2 - W_1}{t_2 - t_1}$ (g plant day^{-1}); (2)

RGR (relative growth rate) $= \frac{\log_e W_2 - \log_e W_1}{t_2 - t_1}$ (g day^{-1}); (3)

NAR (net assimilation rate) $= \frac{W_2 - W_1}{t_2 - t_1} \times \frac{\log_e LA_2 - \log_e LA_1}{LA_2 - LA_1}$

$(g\ m^{-2}\ day^{-1})$; (4)

ıere W_2 is the mass (g) at current week t_2,

W_1 the mass of previous week t_1,

ıd LA the leaf area (m^2) where LA_1 and LA_2 being that at times t_1 and t_2 respectively.

imate measurement

Incoming short wave solar radiation was measured (on cloud- ss days only) using a Weather Measure tube solarimeter, with ıotosynthetically active radiation (PAR) measured using a Li-Cor ıantum sensor. Measurements were performed at hourly intervals. oth of these instruments were factory calibrated, and were placed in e centre of the double row for measuring purposes.

Leaf resistance to water vapour movement was measured us- g a Lambda diffusion porometer. The porometer was calibrated at temperatures between 14 and 36 °C using calibration plates sup- ied by the manufacturers. From the slone and intercept values of ese curves, a temperature coefficient converting all time values me taken to move from 20 to 60 % relative humidity) to those at 25 C was obtained. The humidity sensing element was shielded from diation using an aluminium foil covering. *In situ*, the sensing ele- ent was housed in a dessicator. At every hour, the abaxial leaf resis- nce of four leaves per plant was measured in each treatment.

Air temperature and relative humidity was measured every ıur using an Assmann psychrometer placed at a standard height (1,4) inside or outside the tunnel. Pot temperature, at a depth of 50 mm, ıs measured using three wire resistance thermometers (Savage, 80a, b).

Leaf temperatures were recorded with a thermocouple clip ermometer which was attached to the lower surface of four leaves r plant at any one recording time.

RESULTS

Environment

lative humidity and air temperature

Differences in air temperature (on cloudless days only) be- een the shaded and unshaded treatments were small. Under shade ıth the maximum and minimum were 27,2 and 16,9 °C respectively npared to 28,4 and 15,9 °C under plastic only.

The atmospheric water vapour pressures were generally ater under shade. The small differences in air temperature and rela- humidity can be attributed to the free flow of air through both the ghbouring environments in the well ventilated 'roll up sides' tunnel.

diation and PAR

The radiant densities (Savage, 1979a) for both environments indicated in Fig. 1, in relation to the height above ground, for two erent stages in the crops growth. The shade treatment typically ıced the total daily radiant density by about 1 MJ m^{-2} throughout crop canopy.

The reduction in radiative load due to the plastic, and the plas- and shadecloth, compared to the outside is shown in Fig. 2. At

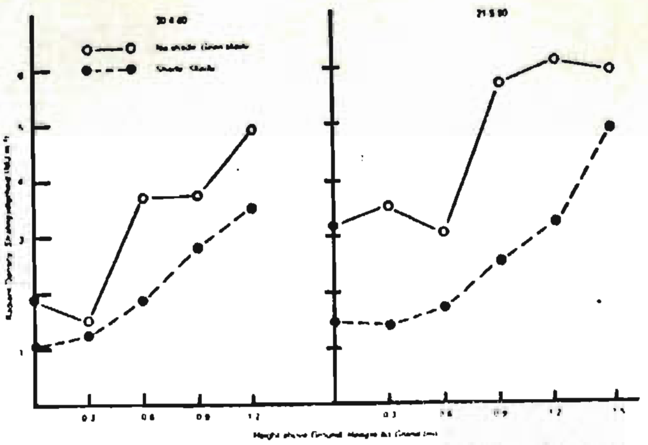


FIG. 1: Radiant density at different heights in the centre of a double row of greenhouse cucumbers grown in a plastic tunnel with or without shade, on two separate sunny days

FIG. 1: Stralingsdigtheid by verskeie hoogtes in die middel van 'n dubbele ry kweekhuis komkommers binne 'n plastiese tonnel, met of sonder skadu, oor twee afsonderlike sonnige dae

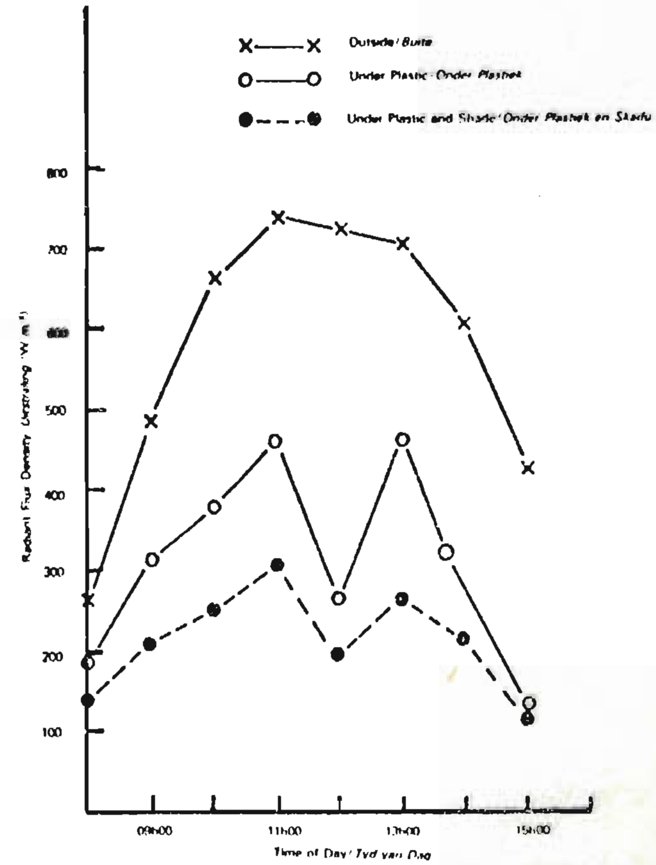


FIG. 2: Radiant flux density outside and inside a plastic tunnel with and without 30% shadecloth on 30.4.80, a sunny day

FIG. 2: Uitstraling binne en buite 'n plastiese tonnel met en sonder 30% skadubedekking te 30.4.80, 'n sonnige dag

11h00 the plastic reduced the radiative load (flux densities) from above 700 W m^{-2} to about 400 W m^{-2}, with the shadecloth causing a further reduction to 300 W m^{-2}. The typical M shaped profiles under plastic were also observed by Savage & Smith (1980). Above crop level, the total daily photosynthetic photon density was typically 8,19 mol m^{-2} and 11,7 mol m^{-2} (Savage, 1979b) for the shaded and unshaded environments respectively.

Pot temperature

For four cloudless days the 08h00 to 17h00 pot temperatures average 23,0 °C for the unshaded area and 21,8 °C for the shaded area, with pot temperatures in both environments typically fluctuating between a 13 °C minimum and a 30 °C maximum.

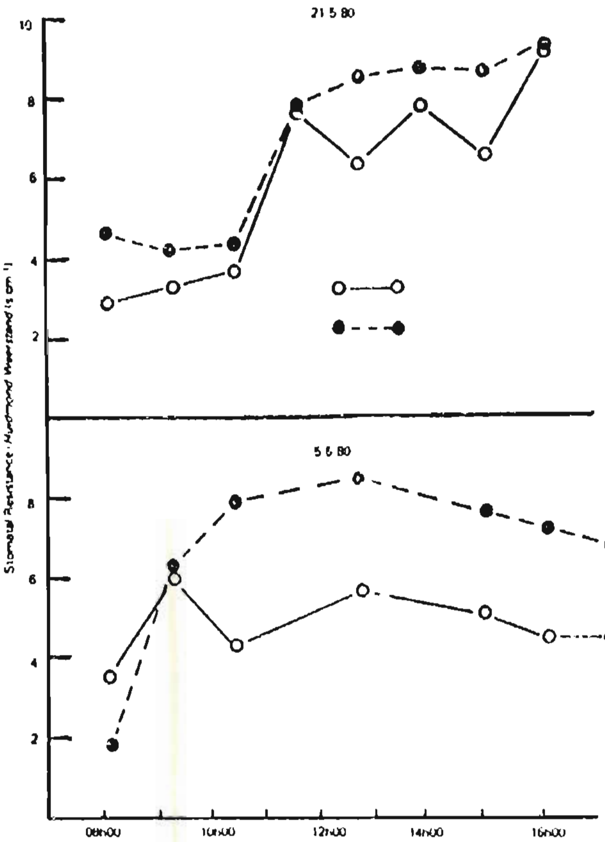
eaf Temperature

There was no difference in average leaf temperatures with or ithout shade, but the daily fluctuation in leaf temperature was great- without shade, probably due to the shade cloth preventing some ack radiation in the evening and at night, thus maintaining a more ven temperature in the leaves of the shaded plants.

Plant characteristics

eaf resistance

In general, the leaf resistance to water vapour movement was reater for the shaded plant than the unshaded. This results from the educed radiative load, as discussed by Slayter (1967). As a conse- uence of this, there were morphological changes in the shaded lants compared to the unshaded, as discussed later. Typically, mid- ay resistances averaged 10 s cm^{-1} and 7 s cm^{-1} for shaded and un- haded plants respectively (Fig. 3).



IG. 3: **Stomatal resistance of greenhouse cucumber leaves n plants grown in a plastic tunnel with or without 30% shade- cloth**

*IG. 3: **Huidmond weerstand van kweekhuis komkommerbla- e van plante gekweek in 'n plastiese tonnel met of sonder 30% skadubedekking***

eight and number of leaves

Immediately after transplanting the shaded plants grew taller an the unshaded plants, and remained that way throughout the trial ig. 4). Shaded plants also had a greater number of leaves on any ven date, and for the first six weeks of the trial they had a greater in- rnode length (Fig. 4). Thus for the earlier part of the trial the shaded ants showed typically etiolated symptoms, although these were not arkedly obvious.

af area and LAR

From week four onwards shaded plants also had a larger leaf a (Fig. 5), an apparent response to the lower radiation intensity der the shade cloth. In terms of LAR (Fig. 5) shaded plants always had values indicating that a greater leaf surface area was required to produce 1 g of dry matter under the shaded conditions.

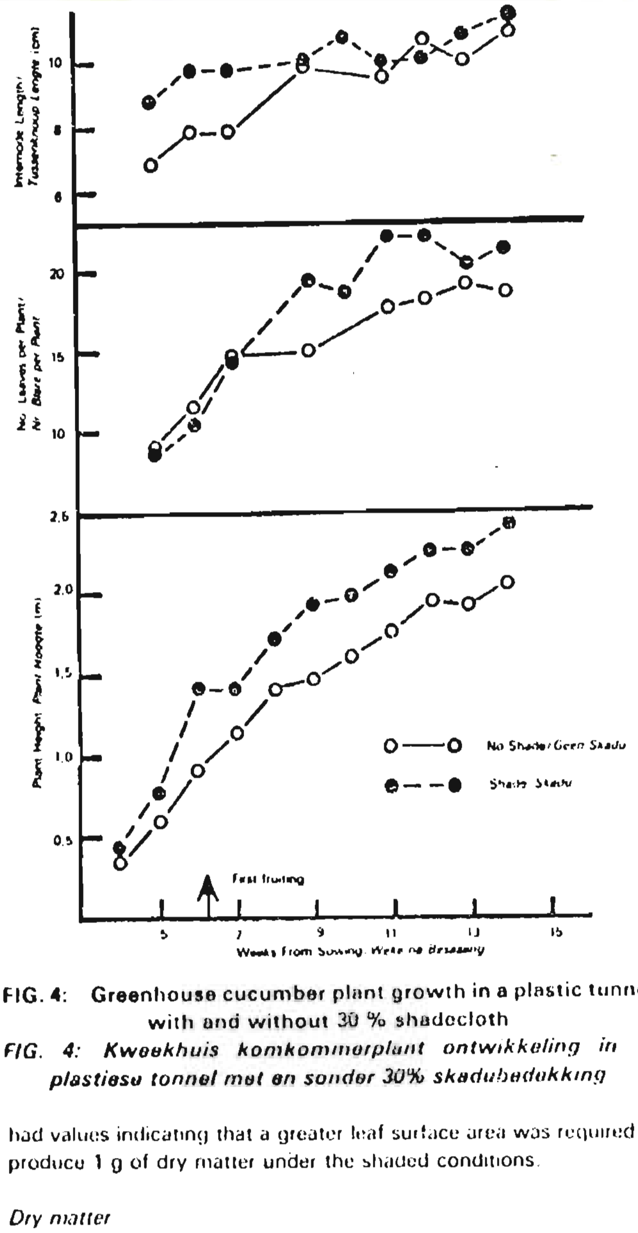


FIG. 4: Greenhouse cucumber plant growth in a plastic tunnel with and without 30 % shadecloth

FIG. 4: Kweekhuis komkommerplant ontwikkeling in 'n plastiese tonnel met en sonder 30% skadubedekking

Dry matter

Total dry matter accumulation and its components (roots, stems, leaves and fruit) are shown in Fig. 6.

The total dry matter yield was greater for control plants than those with shade. However it was interesting to note that control plants had a visibly greater root system from early on (week 3 of sampling), and in terms of dry matter produced greater fruit yields. Alternately shaded plants tended to put more dry matter into leaves and stems, and less into roots and fruit.

These facts are further emphasized if we examine the proportion of total dry matter in each part of the plant (Fig. 7). It can be seen that shaded plants always had a greater proportion of their dry matter distributed in the leaves, and this diminishes as the fruit yield accumulates (Fig. 7). The proportion of dry matter put into stems remains relatively constant as the plant ages, but that put into the roots diminishes.

Growth analysis

Crop growth rate (CGR)

CGR values fluctuated widely from week to week, but were mostly in the range of 1 to 4 g $plant^{-1}$ day^{-1}. On average, for the whole period of the trial the unshaded plants had a CGR of about 2 g day^{-1} compared to that of 1,5 g day^{-1} for the shaded plants.

Relative growth rate (RGR)

RGR values were high in the first four weeks of growth before

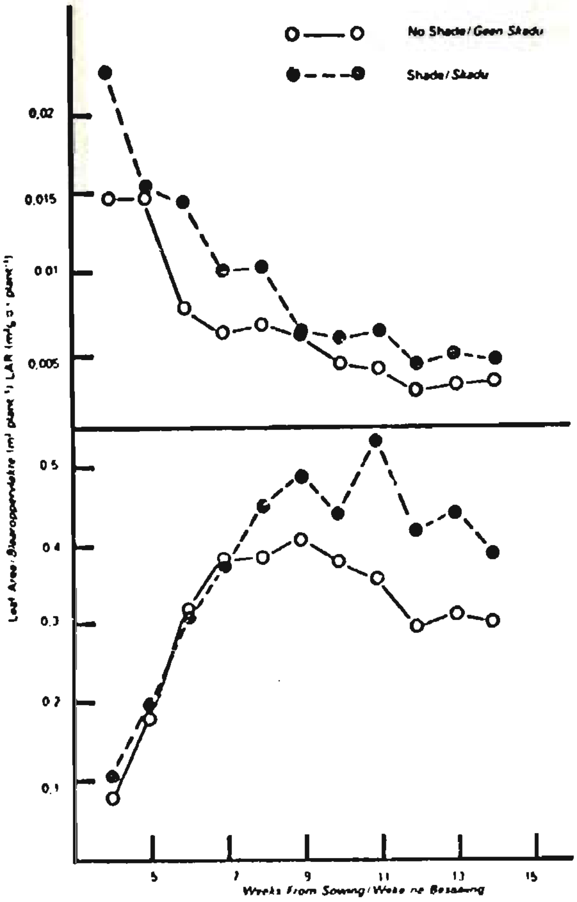


FIG. 5: **Leaf area and leaf area ratio (LAR) of greenhouse cucumber plants grown in a plastic tunnel with and without 30% shadecloth**

FIG. 5: ***Blaararea en blaararea verhouding van kweekhuis komkommerplante gekweek in 'n plastiese tonnel met en sonder 30% skadubedekking***

any fruit set took place (Fig. 8), but dropped to a uniformly low level once the first fruits were harvested (week 5) until the end of the trial. No difference between shaded and unshaded plants existed, except the early stages when plants not under shade had a slightly higher RGR.

Net assimilation rate (NAR)

Fig. 8 shows that unshaded plants had a higher NAR on most sampling dates during the trial i.e. they produced more dry matter per unit of leaf area in a given time. As with RGR, the NAR values were greater in the initial period of the trial, until the first fruits were harvested, thereafter they stabilised at about 5 g m^{-2} day^{-1} and 7,5 g m^{-2} day^{-1} for shaded and unshaded plants respectively.

DISCUSSION AND CONCLUSIONS

The effect of shade on the environment within the plastic tunnel measured here was consistent with the findings of other workers (Maree, 1979; Hammes *et al.*, 1980). One exception however was the small air and leaf temperature differences. This can be explained by the fact that the shadecloth was inside the plastic, and that the two areas were adjacent to each other in the same tunnel, with free air movement from the roll up sides. Thus the incoming radiation was only depleted once it had passed through the polyethylene covering of the tunnel. The shade cloth absorbed most of the short wave radiation and re-radiated it as long wave radiation to the surrounding air.

This problem could be overcome by placing the shadecloth outside the tunnel, thus reducing the energy input into the system, and thereby reducing the temperature.

As in previous studies (North *et al.*, 1978; Smith, Whitfield, Savage & Cass, 1979) a reduction in the radiant flux density was recorded such that the unshaded and shaded environments typically received 400 W m^{-2} and 300 W m^{-2} at midday respectively. These levels may have been low enough to affect photosynthesis rates, considering that Challa (1976) found greenhouse cucumbers to be unsaturated at 200 W m^{-2}, and Sale (1977) recorded maximum net CO_2 uptake rates at about 600 to 800 W m^{-2} in field cucumbers.

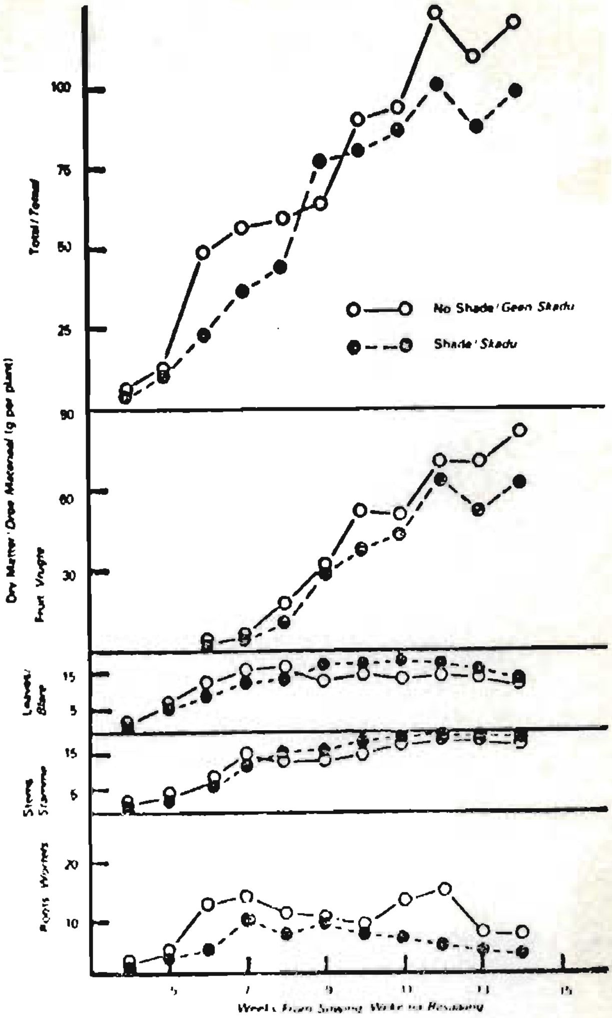


FIG. 6: Dry matter accumulation in different parts of greenhouse cucumbers grown in a plastic tunnel with and without 30% shadecloth

FIG. 6: ***Ophoping van droë materiaal op verskeie dele van kweekhuis komkommers gekweek in 'n plastiese tonnel met en sonder 30% skadubedekking***

Overall then, the main difference between the two environments was the lower radiation load.

The plants growing in the two environments had definite characteristics. Shaded plants grew taller, had more leaves and slightly greater internode length. They produced a greater leaf area, had a higher leaf area ratio, and a smaller root system.

In terms of yield, shaded plants produced less total dry matter. Associated with this a higher leaf resistance to water vapour movement was measured in shaded plant leaves. It appears that this was in response to the larger transpiring surface produced, with a smaller root system with which to absorb water, with the plant limiting the amount of water it might lose under these conditions. It would be important to examine the stomatal distribution on the plants in the two environments to back up this finding.

Besides producing less dry matter overall, shaded plants also proportionately distributed their dry matter differently. Thus in shaded plants a greater proportion of the total dry matter was found in the leaves and stems, whereas in unshaded plants a greater proportion was found in roots and fruit.

The decreasing amounts put into the roots is explained by the fact that the plants were growing in containers, which restricted the

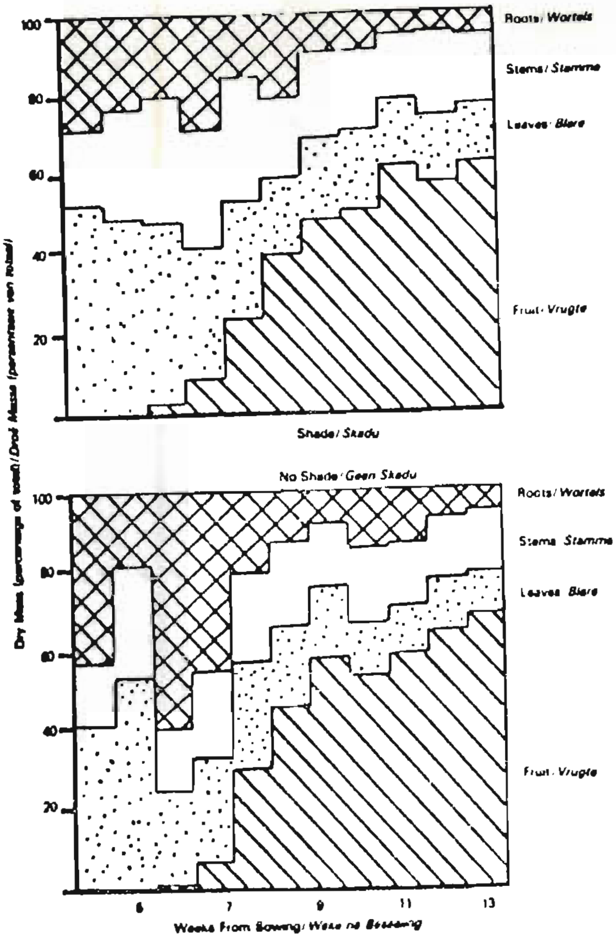


FIG. 7: Percentage distribution of total dry mass in greenhouse cucumber plants grown in a plastic tunnel with and without shade

FIG. 7: Persentasie verspreiding van totale droë massa van kweekhuis komkommerplante gekweek in 'n plastiese tonnel met en sonder bedekking

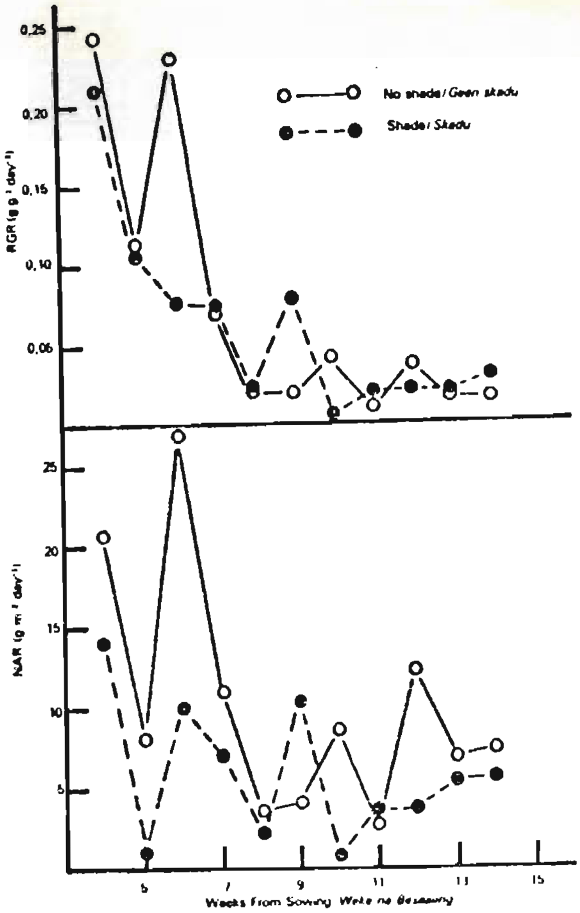


FIG. 8: Relative growth rates (RGR) and Net assimilation rates (NAR) of cucumber (cv Popinex) plants grown with or without shade in a plastic tunnel

FIG. 8: Relatiewe groeitempos en netto verwerkingstempos van komkommer (kv Popinex) plante gekweek met of sonder bedekking in 'n plastiese tonnel

root system to a relatively constant maximum size. The above ground portion of the plant, however, continuously increased in size.

Examining the photosynthetic efficiency of the plant it was seen that RGR values were fairly similar, but that NAR values were higher in unshaded plants. It could be concluded that the shaded plants were functioning less efficiently, presumably due to the lower radiation intensities, and that these plants had compensated for the reduced radiation by increasing their leaf area at the expense of root growth and yield.

The decreasing trend in RGC and NAR with age has also been reported for other plants (Thorne, 1960), and the values recorded here are similar to those of Milthorpe (1959). A direct comparison with work of Challa (1976) is difficult as his records were only up to the 5 leaf stage, and not for fruiting plants.

Large fluctuations in CGR, RGR and NAR made some of the data difficult to interpret, due mainly to sampling procedure, and the fact that fruit maturity differed between plants in successive samples. Further, this experiment was conducted in autumn, at a time when shading, as shown by these results, may not be beneficial in Natal midlands region. Further research is required in mid summer in this region, when radiation intensities are higher, and using separate tunnels, to see whether shade cloth will effectively lower tunnel temperatures without affecting yield.

ACKNOWLEDGEMENTS

The following are thanked for financial and material assistance: National Plant Food Company, Gundle Plastics and the Natal University Research Fund. The assistance of the 1980 Agrometeorology students is gratefully acknowledged, particularly with regard to data collection.

OPSOMMING

DIE UITWERKING VAN BEDEKKING OP DIE OMGEWING, ONTWIKKELING EN OPBRENGS VAN KWEEKHUIS KOMKOMMERS

'n Ontleding van die omgewing binne 'n plastiese tonnel asook die ontwikkeling en opbrengs van kweekhuis komkommers, met of sonder 30% skadunet, is in die herfs oor 'n tydperk van 15 weke in Pietermaritzburg onderneem.

Die totale daaglikse stralingsdigtheid in die onbedekte omgewing was dubbel die van die bedekte omgewing (kenmerkend 1 MJ m⁻² teenoor 2 MJ m⁻²). Min verskil in lug- en blaartemperature is gemeet, alhoewel die temperatuur van die bedekte omgewing meer eenvormig was as gevolg van die insulerende uitwerking van die skadunette.

Bedekte plante het in hul omgewing aangepas deur 'n groter blaar oppervlakte te vorm met 'n kleiner wortelstelsel, gepaard met 'n groter teenstand vir die beweging van blaarwater. Bedekte plante het minder totale droë materiaal opgelewer en het na verhouding meer droë materiaal na die blare en stamme gevoer en minder na die wortels en vrugte.

Alhoewel relatiewe groeitempos in albei omgewings ooreenkomstig was, was die netto verwerkingstempo hoer in die onbedekte plante.

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