

Copyright is owned by the Author of the thesis. Permission is given for a copy to be downloaded by an individual for the purpose of research and private study only. The thesis may not be reproduced elsewhere without the permission of the Author.

TRANSPLANTING STUDIES WITH PROCESSING TOMATO  
(Lycopersicon esculentum Mill.) AND GREEN SPROUTING  
BROCCOLI (Brassica oleracea L. var. italica Plenck)

A thesis presented in partial  
fulfilment of the requirements for the degree  
of Doctor of Philosophy  
in Horticulture at  
Massey University

Stuart Ian Davis  
1992

## ABSTRACT

Field experiments were conducted to evaluate the performance of module-raised and bare-root seedling transplants of determinate tomato and green sprouting broccoli. In the tomato experiment, seedlings raised in 36 cm<sup>3</sup> modules in a greenhouse and bare-root transplants raised in a seed-bed under cold frames were transplanted into a field at Hastings in October 1983. In the broccoli study, seedlings were raised in 36 cm<sup>3</sup> modules and in seed-beds in a field and in a greenhouse and then transplanted into a field at Massey University in November 1984.

Tomato plants established as module-raised transplants had higher shoot and root dry weights 35 days after transplanting, and flowered 2 weeks earlier than plants established as bare-root transplants. A series of nine destructive harvests, at approximately weekly intervals, revealed similar patterns of red fruit yield with time for plants established from the two types of transplant. The loss of the early growth advantage of the plants established from module-raised transplants was not explained by conversion to a thermal time scale. Further research is required to determine if the sharp peak of red fruit yield with time recorded in this experiment is typical for tomato crops grown in New Zealand.

The growth of broccoli plants over the first 32 days from transplanting was recorded from unreplicated plots. From the results of a series of dry weight harvests, it was estimated that, 18 days after transplanting, broccoli plants established as module-raised transplants produced in the field and in the greenhouse were 7 and 5 days, respectively, more advanced in terms of shoot dry weight than plants established from the corresponding bare-root treatments. Plants established from module-raised transplants initiated terminal inflorescences earlier than plants established from the corresponding bare-root transplants. These results were attributed to reduced root disturbance at transplanting for the module-raised transplants.

The effects of transplant type on the maturity and yield of broccoli were evaluated using a series of selective harvests in a replicated experiment. In the case of the field-raised transplants, the more rapid establishment and earlier initiation of the terminal head of plants established from module-raised transplants was reflected in earlier maturity at harvest. There was no difference in the time to maturity of module-raised and bare-root transplants raised in the greenhouse.

The patterns of post-transplanting growth and maturity of plants raised in modules in the greenhouse and transplanted with or without growing medium around the roots were very similar. This indicated that reduced root disturbance was a more important factor in the rapid establishment of module-raised transplants than the presence of a reserve of water in the growing medium of the module.

These results with tomato and broccoli illustrate that earlier and more uniform establishment of module-raised transplants may not always be reflected in earlier and more uniform crop maturity, due to the effects of environmental factors and inter-plant competition later in the growth of the crop. It is suggested that differences in crop maturity and yield between plants established from module-raised and bare-root transplants would have been more marked under more stressful field establishment conditions.

## ACKNOWLEDGMENTS

I am indebted to my principal supervisor, Dr. Keith Fisher, for his support and guidance throughout the course of these studies, his patient editing of my hieroglyphics, and his counsel in all aspects of professional horticulture.

My sincere thanks to Dr. D.J. Woolley and Dr. M.A. Nichols for their advice.

Thanks are also due to other staff and post-graduate students of the Department of Horticulture and Plant Health, who freely offered advice in their particular areas of expertise and to Messrs. A.P. Julian, D.B. Buys and D.R. Anderson for technical assistance.

I am grateful to the N.Z. Ministry of Agriculture and Fisheries for financial assistance for materials, equipment and personal support and, in particular, thank the following M.A.F. staff:

Dr. W.M. Kain - for liaison;

Dr. R.M. Pringle - for much valuable discussion and advice, and;

Mr. J.L. Burgmans - for maintenance of the field experiment at Hastings.

Mr. J.A. Geelen (J. Wattie Canneries Ltd, Hastings) arranged the supply of tomato seed and bare-root transplants for the tomato experiment.

I thank Debbie Turner for her careful typing and editing.

Special thanks to my friends Bruce and Marion MacKay and Keith Funnell for their support.

I am especially grateful to my parents, Ian and Hazel, for their unflagging support and encouragement throughout over two decades of formal education.

This volume is dedicated to my wife, Jackie, without whose encouragement, patience and understanding it would not have been completed.

## TABLE OF CONTENTS

	<u>Page</u>
Abstract	ii
Acknowledgments	iv
Table of Contents	v
List of Figures	x
List of Tables	xi
List of Plates	xii
List of Appendices	xiv
Introduction	xv
<b>1. REVIEW OF LITERATURE</b>	<b>1</b>
<b>1.1 Aspects of the production of tomatoes for processing in New Zealand</b>	<b>1</b>
1.1.1 Introduction	1
1.1.2 Historical background to processing tomato crop culture in New Zealand	1
1.1.3 The role of transplanting as a means of establishing the crop	2
<b>1.2 Aspects of production of green sprouting broccoli</b>	<b>7</b>
1.2.1 Introduction	7
1.2.2 Rationale for the current use of transplants to establish the crop	7
1.2.3 Cultural treatments influencing yield and uniformity of maturity	9
1.2.3.1 Method of establishment	9
1.2.3.2 Stage of growth at transplanting	10
1.2.3.3 Direct manipulation of initiation of reproductive growth	12
1.2.3.4 Lateral head production and plant breeding	15
1.2.4 Harvesting regimes and the importance of harvest uniformity	16
1.2.4.1 Introduction	16
1.2.4.2 Selective harvesting	16
1.2.4.3 Once-over harvesting	17

1.2.5	Plant spacing of broccoli: research results and current practices	19
1.2.5.1	Yield-density relationship	19
1.2.5.2	Plant density and mean head size	20
1.2.5.3	Plant density and crop maturity	20
1.2.5.4	Plant density of process crops grown in the Manawatu	21
<b>2.</b>	<b>FIELD EVALUATION OF TWO TYPES OF TOMATO TRANSPLANT</b>	<b>23</b>
<b>2.1</b>	<b>Introduction</b>	<b>23</b>
<b>2.2</b>	<b>Materials and Methods</b>	<b>24</b>
2.2.1	Introduction	24
2.2.2	Selection of cultivar and source of seed	24
2.2.3	Methods of raising transplants	24
2.2.3.1	Bare-root transplants	24
2.2.3.2	Module-raised transplants	25
2.2.4	Transplanting method and maintenance of experiment in the field	26
2.2.4.1	Preparation of experimental area prior to transplanting	26
2.2.4.2	Transplanting method	29
2.2.4.3	Maintenance of experiment after transplanting	29
2.2.5	Experimental design, data collection and analysis	29
2.2.5.1	Experimental design	29
2.2.5.2	Collection of data	30
2.2.5.2.1	Harvest at transplanting	30
2.2.5.2.2	Harvest following establishment	31
2.2.5.2.3	Fruit fresh weight harvests	31
2.2.5.2.4	Fruit numbers	32
2.2.5.3	Analysis of data	33
2.2.5.3.1	Harvest at transplanting	33
2.2.5.3.2	Harvest following establishment	33
2.2.5.3.3	Fruit fresh weight harvests	33
2.2.5.3.4	Fruit numbers	34

<b>2.3</b>	<b>Results</b>	<b>35</b>
2.3.1	Harvest at transplanting	35
2.3.2	Harvest following establishment	35
2.3.3	Fruit fresh weight harvests	36
2.3.4	Fruit numbers and maturity indices	39
<b>2.4</b>	<b>Discussion</b>	<b>43</b>
2.4.1	Raising of transplants	43
2.4.2	Field establishment and early growth	44
2.4.3	Post-establishment growth and yield	44
2.4.3.1	Introduction	44
2.4.3.2	Time of maturity	44
2.4.3.3	Uniformity and yield	47
2.4.4	Practical implications of the observed patterns of maturity and yield	48
2.4.4.1	Pattern of yield with time	48
2.4.4.2	Implications for yield assessments in tomato field research	50
2.4.4.3	Implications for commercial crop production and direction of field research	54
<b>3.</b>	<b>FIELD EVALUATION OF TYPES OF GREEN SPROUTING BROCCOLI TRANSPLANT</b>	<b>60</b>
<b>3.1</b>	<b>Introduction</b>	<b>60</b>
<b>3.2</b>	<b>Materials and methods</b>	<b>61</b>
3.2.1	Selection of cultivar and treatment of seed	61
3.2.2	The treatments	61
3.2.3	Methods of raising transplants	62
3.2.3.1	Field-raised transplants	62
3.2.3.1.1	Sowing of field seed-bed	62
3.2.3.1.2	Sowing of field seedling trays	63
3.2.3.1.3	Management of field-raised seedlings	64
3.2.3.2	Greenhouse-raised transplants	64
3.2.3.2.1	Sowing of greenhouse seed-bed	64
3.2.3.2.2	Sowing of greenhouse seedling trays	65

3.2.3.2.3	Management of greenhouse-raised seedlings	65
3.2.4	Transplanting of seedlings and maintenance of experiments in the field	65
3.2.4.1	Introduction	65
3.2.4.2	Preparation of experimental area prior to transplanting	66
3.2.4.3	Preparation of seedlings for transplanting	66
3.2.4.3.1	Transplanting date	66
3.2.4.3.2	Field-raised bare-root transplants	66
3.2.4.3.3	Field-raised module transplants	67
3.2.4.3.4	Greenhouse-raised bare-root transplants	67
3.2.4.3.5	Greenhouse-raised module transplants	67
3.2.4.2.6	Selection of seedlings for transplanting	67
3.2.4.4	Method of transplanting	68
3.2.4.5	Maintenance of experiments following transplanting	68
3.2.5	Experimental design, data collection and data analysis	69
3.2.5.1	Experimental design	69
3.2.5.2	Data collection	69
3.2.5.2.1	Collection of observation experiment data	69
3.2.5.2.2	Collection of main experiment data	83
3.2.5.3	Data analysis	85
3.2.5.3.1	Observation experiment	85
3.2.5.3.2	Main experiment	85
<b>3.3</b>	<b>Results and discussion</b>	<b>87</b>
3.3.1	Seedling emergence, seedling densities and size of transplants	87
3.3.1.1	Seedling emergence and densities	87
3.3.1.2	Transplant size	88
3.3.2	Environmental conditions during early establishment	90
3.3.3	Observation experiment - results and discussion	90
3.3.3.1	Leaf, stem and shoot growth	90
3.3.3.2	Relationships between plant parts	92
3.3.3.3	Uniformity of crop establishment	106
3.3.3.4	Head development and leaf numbers	107
3.3.3.4.1	Efficacy of methods of examining stem apices	107
3.3.3.4.2	Leaf number and head initiation	108
3.3.4	Main experiment - results and discussion	114

3.3.4.1	Results of main experiment	114
3.3.4.1.1	Missing data: causes and handling	114
3.3.4.1.2	Effects of methods of transplant production on yield, maturity and head quality	116
3.3.4.1.3	Effects of row location on maturity and head size	121
3.3.4.2	Discussion of main experiment results	125
3.3.4.2.1	Plant losses	125
3.3.4.2.2	Time to maturity	126
3.3.4.2.3	Spread of maturity	130
3.3.4.2.4	Yield	131
3.3.4.2.5	Row location	135
4.	<b>SUMMARY, CONCLUSIONS AND GENERAL DISCUSSION</b>	<b>137</b>
	<b>LITERATURE CITED</b>	<b>146</b>
	<b>APPENDICES</b>	<b>165</b>

## LIST OF FIGURES

<u>Figure</u>		<u>Page</u>
2.1	Fruit fresh weight yields ( $t\ ha^{-1}$ ), in four fruit grades, from bare-root and module-raised transplants of tomato at Hastings.	40
3.1	Change in natural logarithms of shoot dry weight with time from transplanting of broccoli plants.	94
3.2	Change in natural logarithms of leaf dry weight with time from transplanting of broccoli plants.	96
3.3	Change in natural logarithms of stem dry weight with time from transplanting of broccoli plants.	98
3.4	Relationship between mean natural logarithm of leaf dry weight and mean natural logarithm of stem dry weight of broccoli plants.	100
3.5	Relationship between mean natural logarithm of shoot dry weight and mean natural logarithm of root dry weight of broccoli plants.	102
3.6	Root, stem and leaf dry weight as proportions of total dry weight of broccoli plants at Harvests 1 and 2 of observation experiment.	104
3.7	Cumulative number of heads harvested from inner, outer and all rows of a single plot of broccoli.	118

## LIST OF TABLES

<u>Table</u>	<u>Page</u>
2.1 Dates on which fruit yield data were collected.	32
2.2 State of plants at transplanting. Means of three 10-plant samples (converted to the per-plant scale).	35
2.3 State of growth of plants 35 days after transplanting. Means of eight 8-plant plots expressed on a g plant <sup>-1</sup> scale.	36
2.4 Means of fruit numbers and 'maturity indices' for two transplant types at each of three harvest dates. Means of four 8-plant plots.	42
3.1 Dates of harvest for observation experiment (days from transplanting)	70
3.2 Ratio of lsd's for specific comparisons of treatment means to 'approximate lsd' presented in Table 3.9.	86
3.3 Broccoli seedling emergence and plant populations during raising of transplants.	88
3.4 State of plants at transplanting. Means of ten plants of each treatment harvested 1 day after date of transplanting.	89
3.5 Coefficients of variation (%) of shoot dry weight.	107
3.6 Mean leaf numbers at the time of transplanting (Harvest 1).	109
3.7 Mean leaf numbers and terminal inflorescence (head) development following transplanting (ten-plant samples, Harvests 2 to 4).	110
3.8 Five-day means of daily maximum and minimum air temperatures and grass minimum temperatures during raising of transplants in the field.	112
3.9 Effects of method of transplant production on yield and maturity of broccoli.	117
3.10 Maturity data for plot illustrated in Figure 3.7.	120
3.11 Means and significant levels of F-tests from 'split-plot' analyses.	125

## LIST OF PLATES

<u>Plate</u>	<u>Page</u>	
2.1	Bare-root tomato transplants in seed-bed on the day of transplanting	27
2.2	Module-raised tomato transplants in trays on greenhouse bench, 28 days after sowing	28
2.3	Representative plants, established from bare-root and module- raised transplants, 35 days after transplanting	37
2.4	End view of five of the experimental beds, 90 days after transplanting, at Hastings	38
3.1	Enclosure in which field module and field seed-bed broccoli transplants were raised	72
3.2	Broccoli seedlings of field seed-bed treatment on 23 October (21 days after sowing)	73
3.3	Broccoli seedlings of field module treatment on 23 October (21 days after sowing)	74
3.4	Broccoli seedlings of greenhouse seed-bed treatment emerging in seed-bed box on 23 October (4 days after sowing)	75
3.5	Stage of development of the two 'commercial' treatments - greenhouse module (left) - at Harvest 1 of observation experiment (1 day after transplanting date)	76
3.6	Stages of development of broccoli plants of all five treatments at Harvest 1 of observation experiment (1 day after transplanting date)	77
3.7	End view of experimental area, following irrigation, on day of transplanting	78
3.8	End view of experimental area, 4 weeks after transplanting	79
3.9	Broccoli plant of field-raised module treatment lifted from soil to show root growth 16 days after transplanting	80
3.10	Broccoli plant of field seed-bed treatment lifted from soil to show root growth 16 days after transplanting	81

- 3.11 Longitudinal section (80x) of vegetative stem apex of broccoli plant of greenhouse seed-bed treatment at Harvest 1 of observation experiment 122
- 3.12 Plant of greenhouse module treatment showing severe symptoms of 2,4,5-T damage (31 days after transplanting) 123
- 3.13 Terminal heads of broccoli after harvesting and trimming to 150 mm in length 124

## LIST OF APPENDICES

<u>Appendix</u>		<u>Page</u>
1	Nutrient solution applied to module-raised seedlings	165
2	Pest and disease control programme for tomato experiment	167
3	Heat unit calculations for tomato experiment at Hastings	169
4	Lime and fertiliser applications for broccoli experiments	170
5	Pest and disease control programme for broccoli experiments	172

## INTRODUCTION

It is widely recognised that reliable and uniform establishment of a plant stand at a desired plant population is one of the most important factors in the successful production of field-grown vegetable crops, affecting uniformity of size and maturity of harvested produce and, hence, marketable yield and the economics of harvesting. Direct seeding in the field consistently produces uniform stands on a commercial scale for some major vegetable crops. These crops tend to be large-seeded species with relatively high seed vigour and inexpensive seed sown at relatively high plant populations (e.g. sweet corn, peas and beans). Direct seeding in the field is likely to remain as the preferred method of establishment for such crops, except in special circumstances (e.g. transplanting of sweet corn in marginal climates or for early production generating high returns).

Other vegetable crops (predominantly small-seeded species with high seed costs) are often established from seedling transplants (e.g. celery, lettuce, tomato and vegetable brassicas). Apart from more reliably establishing desired plant populations in the field, transplanting often conveys a number of other advantages over direct seeding, including: reduced in-field crop duration; reduced wastage of seed; greater control over the crop microenvironment during germination, emergence and early crop growth; more efficient use of fertiliser and agrichemicals during the early stages of crop growth, and; allowing for less rigorous soil preparation in the field.

Seedling transplants can be classified into two broad categories: 'bare-root' transplants and 'module-raised' transplants. Bare-root or 'peg' transplants are raised in seed-beds or seed-trays, separated by pulling from the growing medium and transplanted with a minimum of growing medium adhering to the roots. Module-raised transplants (also commonly referred to as 'containerised', 'block' or 'cell-raised' transplants) are raised in discrete modules of growing medium (e.g. peat blocks, plastic containers and paper tubes) and are transplanted with minimal

disturbance of the root system.

The transfer of a seedling transplant from its raising environment and its replanting in the field almost invariably results in a 'check' in growth and development of the plant as it adjusts to its new environment (McKee, 1981a,b). This transplanting check can result in transplanted crops being less uniform than direct seeded crops given good, uniform seed-bed conditions in the field (Salter & Fradgley, 1969b). The predominant advantage of module-raised transplants over bare-root transplants is perceived to be a reduction in the level and variability of the transplanting 'check' to growth due to improved plant water relations brought about by reduced root disturbance (McKee, 1977) and the presence of a reserve of water in the transplanted module (Kratky, Cox & McKee, 1980). Other advantages may apply in some circumstances: for example, the ability to include crop protection chemicals (Suett, 1988; Thompson & Suett, 1986) or to establish mycorrhizae (Waterer & Coltman, 1988, 1989) in the transplant-raising medium before transfer to the field.

Since the late 1970's, there has been a world-wide trend towards increased use of module-raised transplants for the establishment of transplanted vegetable crops (Banes, 1984; Hiron & Symonds, 1985; Neefjes-Fletcher, 1984; Nahrung, 1984; Wilcox-Lee & Moyer, 1986). This has been brought about by technological advances in plant raising and transplanting systems which have reduced the costs of establishing module-raised transplants relative to bare-root transplants (Salter, 1982). In order to weigh up the costs and benefits of the use of module-raised versus bare-root transplants in any cropping system, research is required to evaluate the post-transplanting performance of the two types of transplants and its effects on crop establishment, uniformity of maturity and yield.

Two experiments were conducted to examine the field performance of bare-root and module-raised transplants of determinate processing tomatoes and green sprouting broccoli, two field vegetable crops which are commonly established from seedling transplants in New Zealand. The tomato experiment was conducted at Hastings, in one of New Zealand's major tomato-producing districts, and compared the performance of commercially produced bare-root transplants with module-

raised transplants produced in a greenhouse. The two types of transplants were evaluated in terms of early growth in the field, fruit yield and timing of maturity.

In the broccoli experiment, module-raised transplants were produced in a greenhouse and bare-root transplants were raised in a field seed-bed. Other treatments included in this experiment were: bare-root transplants raised in a seed-bed in the greenhouse, module-raised transplants produced in the field, and module-raised transplants produced in the greenhouse and transplanted after careful removal of the growing medium from around the roots. The effects of transplant type on early growth in the field, the timing of the transition from vegetative to reproductive growth, and the yield and uniformity of maturity of terminal heads were studied.

## CHAPTER 1

### REVIEW OF LITERATURE

#### 1.1 Aspects of the production of tomatoes for processing in New Zealand

##### 1.1.1 Introduction

Tomatoes are an important processing vegetable crop in New Zealand, the major areas of production being the Hastings and Gisborne districts with little production from other regions. The most recent official production figures available are of c. 36 000 tonnes produced from 670 hectares for the 1981-82 season (M.A.F., 1985). The 1984-85 crop was estimated at 34 000 tonnes (Burgmans & Lill, 1985) and production has increased, following the construction of a new processing facility at Gisborne in 1985, to over 80 000 tonnes per annum in the early 1990's. The bulk of the crop is processed by evaporation to form tomato paste which is utilised as a raw material in a range of processed food products. Other major uses include: canned 'whole-peel' tomatoes and tomato halves, tomato sauce and tomato juice. The following is a review of crop establishment and other aspects of crop production relevant to the culture of determinate field tomatoes for once-over mechanical harvesting in New Zealand.

##### 1.1.2 Historical background to processing tomato crop culture in New Zealand

Prior to the 1970's tomato crops produced for processing in New Zealand were established from bare-root transplants raised in sterilised soil-based growing media in wooden flats in greenhouses or under cold frames. Plants were hardened off under frames and transplanted into the field from mid-October to mid-November and the fruit was harvested by hand (repeated passes over several weeks) from February to early April (Brown, 1958; June, 1951; Brandon, 1970; Anon., 1977). A limited quantity of transplants of this type are still produced for growers

by nurserymen. These plants are transplanted with bare roots or with a minimum of substrate adhering to the roots.

Methods of production of the crop in New Zealand underwent considerable change in the early 1970's following demonstrations, under New Zealand conditions, of the potential for high yields from once-over mechanically harvested tomato crops facilitated by pre-harvest application of chlorethephon (2-chloroethyl phosphonic acid) to improve the maturity characteristics of the crop (Bussell, 1971). The first mechanical tomato harvester was brought into New Zealand for the 1972-73 season and production systems for the crop developed rapidly after the visit to New Zealand of Dr. W.L. Sims (University of California, Davis) during the 1974-75 growing season.

Cultivars developed in California for uniform maturity, improved ability of ripe fruit to remain attached to the plant without rotting (vine storage) and resistance to damage during mechanised harvesting and bulk handling replaced older, predominantly Australian cultivars (Anon., 1977). Other Californian practices for the culture of the crop (Sims & Rubatzky, 1974) were rapidly adopted in the absence of local experience (Sims, 1975; Anon., 1977). Since the 1970's, Californian cultivars have continued to dominate the New Zealand industry - the four main cultivars in current use are all of Californian origin (Burgmans, 1984; Burgmans & Bussell, 1983) - and the proportion of the total crop area which is harvested mechanically has increased to be almost 100% in the 1980's.

### **1.1.3 The role of transplanting as a means of establishing the crop**

Concurrent with the changes to production systems described in the previous section there was a swing towards direct seeding of the crop on raised beds at 1.5 m centres followed by manual thinning as is the practice under the longer growing season of California (Sims & Rubatzky, 1974; Sims et al., 1979). Tomato crops established in this way have produced high yields in the Hastings and Gisborne districts from mid-February until mid-late March and occasionally into early April (Burgmans & Bussell, 1983).

The above harvesting season is comparatively short and there is considerable interest from processing companies in extending the harvest season for tomatoes to increase the efficiency of the use of machinery and labour in the processing factory and of harvesting machinery in the field. Shortening the length of time required to mature the crop in the field would also allow the use of more marginal sites to grow the crop and would allow more intensive crop rotations to be practiced - particularly the production of late-season tomato crops following peas.

Extending the harvest season for the crop later in the season is not considered desirable because weather conditions are often wet and cool - thus prolonging the ripening period and favouring disease development on the fruit - resulting in poor yields, disruptions to the harvesting schedule and loss of soil structure due to the passage of harvesting machinery over wet soil. Some progress has been made in identifying imported tomato cultivars which produce high, early yields (Burgmans & Bussell, 1983) and a breeding programme aimed at producing early-maturing cultivars with acceptable yield and quality characteristics has been commenced in New Zealand (Malone, 1983). However, the major commercial emphasis in advancing once-over harvest dates for tomato crops has been a reassessment of the use of transplants to establish the crop.

Increased charges by nurserymen for box-grown, bare-root transplants led to the development of systems whereby tomato growers can produce bare-root transplants for their own use. The currently adopted method is to produce seedlings at plant densities of 700-1000 m<sup>-2</sup> in raised seed-beds under plastic cloches or cold frames. The seed is sown from early August and the plants are transplanted from early October. During the final 1-2 weeks before transplanting the protective covers are removed to 'harden' the plants and the seedlings are sometimes 'wrenched' using an undercutting bar at a depth of 70-100 mm. The preferred stage for transplanting is a plant 100-150 mm long with 4 to 5 true leaves (Anon., 1981; Orchiston, 1982).

The relationship between maturity times of the earliest direct seeded crops and transplanted crops is very much dependent upon field conditions in a particular season but commercial experience indicates that, on average, the use of bare-root

transplants, raised as described above, provides an advancement in maturity of 2 to 3 weeks as compared to the earliest direct seeded crops in the Hastings district (Geelen, 1983; Bussell & Burgmans, 1983).

The increased interest in transplanting is also partially due to the poor establishment of direct-seeded tomato crops which is often observed, particularly in early sowings, in both of the major tomato production districts in New Zealand. For example, in the 1982-83 season, 28% of the total tomato crop area in the Hastings district required re-sowing due to poor establishment of the initial sowing (Esson et al., 1983). Field surveys have revealed a number of edaphic and biotic factors causing reduced establishment (Esson et al., 1983) but, as yet, no consistently effective means of ensuring acceptable establishment has been found (Esson, 1985). Poor establishment is particularly a problem with crops sown early in the season and causes considerable disruption to harvesting and processing schedules. Low temperatures, wet weather and a lack of alternative food sources pre-dispose seed and small seedlings of early-sown tomato crops to attack by a range of pests and pathogens. Difficulties with seed-bed preparation for early season sowings undoubtedly contribute to the establishment problem. Establishment of tomato crops by transplanting facilitates greater flexibility of timing and quality of soil preparation, conservation of increasingly expensive seed, and avoidance of factors causing reduced establishment of direct seeded crops.

Despite a wide range of materials being available for chemical weed control in process tomato crops in New Zealand (Cox, Ingle & Kerr, 1984; O'Connor, 1984) some weed species still present major problems, particularly in direct-seeded tomato crops. Solanaceous weeds, especially black nightshade (*Solanum nigrum* L.), are particularly troublesome as biochemical selectivity between these weeds and the tomato crop is difficult to obtain because of their close taxonomic relationship. Plug-mix planting with activated carbon incorporated in the plug-mix has been shown to be effective in protecting tomato seedlings from herbicide treatments effective against black nightshade under New Zealand conditions (Swain, 1980) but the technology has not found favour with local growers.

Difficulty with obtaining control of black nightshade during the early stages of crop growth without risk of crop damage using pre-emergence, soil-applied herbicides (e.g. Stevenson, 1977) has led growers to rely upon the 'stale seed-bed' technique, followed by manual weeding at the time of thinning of the direct-seeded crop (Anon., 1977). Another advantage of transplanting, as compared to direct seeding, is that it allows the weed control afforded by the 'stale seed-bed' technique to be pushed several weeks later into the growth period of the crop, i.e. by the amount of time that it would take direct-seeded crop to reach the growth stage of a newly transplanted crop. Thus, the use of transplants to establish the crop might reduce labour costs in the field by obviating the need for manual thinning and weeding of the crop.

Control of solanaceous weeds later in the growth of commercial dwarf tomato crops in New Zealand is currently dependent upon the triazinone herbicide metribuzin (Geelen, 1984b). Susceptibility of both the crop and solanaceous weed species to this herbicide decrease with increasing plant size (Fortino & Splittstoesser, 1974a,b; Stevenson, 1977) and selectivity between the crop and the weed is partially dependent upon the maintenance of a difference between crop and weed plant size. Thus, the use of transplanting, as compared to direct seeding, to establish tomato crops offers several potential advantages in terms of weed control: (i) the avoidance of weed competition and herbicide phytotoxicity to the crop during the susceptible early stages of growth; (ii) maintenance of a 'weed-free' state until later in the growth of the crop, and (iii) improved selectivity where herbicides are used later in the growth of the crop thus obviating the need for manual weeding.

In tomato crops established from bare-root transplants the application of post-transplanting herbicide and its incorporation by close inter-row cultivation (the 'layby' treatment) is often delayed by the slow and uneven establishment of the crop, particularly where control of crop seedling growth during raising of the transplants has been poor. The potential for greater control of seedling growth (Fisher & MacKay, 1988) and more rapid and uniform establishment resulting from the use of module-raised transplants may be of considerable benefit in improving the efficacy of post-planting crop management techniques.

Potential advantages of the use of module-raised transplants, as compared to bare-root transplants, for the establishment of field-grown vegetable crops have recently been reviewed by Salter (1982) and McKee (1981a,b). In view of the above discussion, several of these advantages can be expected to be of immediate importance in the production of processing tomatoes in New Zealand. More rapid establishment of module-raised transplants, as compared to bare-root transplants, would be of importance due to the potential for further reducing in-field crop duration and thus advancing the commencement of the processing season. More uniform establishment of module-raised transplants, as compared to bare-root transplants, could be expected to increase yields in once-over harvested processing tomato crops. Raising of transplants in modules of soilless media in greenhouses could be expected to aid in increasing the efficiency of seed usage and increasing control over transplant growth, as compared to raising of bare-root transplants in seed-beds under cold frames.

## 1.2 Aspects of production of green sprouting broccoli

### 1.2.1 Introduction

There is increasing interest in the production of green sprouting broccoli (*Brassica oleracea* L. var. *italica* Plenck) as both a fresh market and a processing crop in New Zealand. The following is a review of published literature on aspects of the production of broccoli relevant to the evaluation of the field performance of broccoli transplants described in Chapter 3. Reference is also made to relevant published reports concerning the cauliflower (*Brassica oleracea* L. var. *botrytis* DC), a closely related and more widely researched crop.

### 1.2.2 Rationale for the current use of transplants to establish the crop

Green sprouting broccoli is a crop not limited to a particular production season in New Zealand and there are no intrinsic difficulties in the germination of broccoli seed - although poor field emergence can sometimes be a problem (e.g. Hutchison, Ferguson & McErlich, 1985). Despite the lack of limitations on direct seeding, broccoli crops produced for processing and fresh market are often established from bare-root transplants raised in seed-beds in the field. The major company processing broccoli in the Manawatu district require their growers to use transplants: partly because of the limited expertise and equipment of local growers and partly because they consider it easier to organise the crop for the district on this basis.

The alternative to transplanting is to direct seed the crop in the field. Direct seeded crops, however, require a higher quality of soil preparation and precise timing of pre-emergence herbicide applications, both of which are greatly influenced by environmental conditions and degree of grower expertise. Field conditions are also more likely to affect the timing of direct seeding than transplanting. Thus, processors feel that they can circumvent these possible causes

of disruption to the cropping programme and poor establishment of direct seeded crops by providing growers with transplants, thus better ensuring the desired flow of crop into the factory (Price, 1984). The use of transplants also shortens the time that the crop occupies the field and therefore makes the scheduling of crop rotations more straightforward.

F<sub>1</sub> hybrid cultivars of broccoli are used almost exclusively and high levels of emergence are considered important due to the relatively high cost of hybrid seed. High pre-emergence losses in direct seeded broccoli crops are recognised as a problem in the Canterbury district (Hutchison, Ferguson and McErlich, 1985). The level of field emergence of broccoli seeds is sensitive to a number of edaphic factors including nitrogen fertiliser level, soil moisture content, soil temperature, soil compaction, soil capping and biotic factors (Page & Cleaver, 1983; Weaver 1980; Hegarty & Royle 1976, 1978; Royle & Hegarty, 1978; Hegarty, 1976). Greater control can be exerted over those factors influencing emergence where seed is sown in a specially prepared seed-bed for the production of transplants.

Despite evidence that establishment of cauliflower crops from bare-root transplants results in less uniform maturity than in direct seeded crops (Salter & Fradgley, 1969a), it was noted that cauliflower growers in England also preferred establishment by means of bare-root transplants. Salter, Ward & Whitwell (1972) attributed this preference to the following advantages of transplanting over direct seeding: (i) a transplanting programme is less likely to be interrupted by unfavourable weather conditions; (ii) weed control is less likely to be a problem in transplanted crops; and (iii) transplanted crops occupy the field for a shorter period of time thus possibly reducing rotational problems. Sterrett, Coale & Savage (1991) concluded, from an economic analysis of broccoli crop production options in Virginia, that crop establishment was the largest component of production risk. They recommended that, despite higher production costs, growers consider the use of transplants rather than direct seeding to establish the crop so as to reduce the risk of poor plant establishment and consequent reductions in yield and quality.

## 1.2.3 Cultural treatments influencing yield and uniformity of maturity

### 1.2.3.1 Method of establishment

Salter (1969) showed that variability in the time of maturity of individual plants within a cauliflower crop was partially caused by variability in the time of curd initiation of different plants. This implies that any cultural or environmental factor influencing inter-plant variability in the time of curd initiation can influence the length of the maturity period of a cauliflower crop.

For example, when seeds were sown on the same day for transplanted and direct seeded crops of autumn cauliflower, crops established from bare-root transplants raised in field seed-beds matured later (time from sowing to 50% harvest) and had a greater spread of maturity (time from 5% to 95% harvest) than direct seeded crops. These effects were attributed to the check to growth at transplanting and the variability of that check respectively (Salter & Fradgley, 1969a).

Grading of seed and plant selection at thinning time successfully reduced variability of harvest time in direct seeded cauliflower crops but seed grading and selection for a uniform size and type of plant at transplanting time were unsuccessful in reducing the harvest period of crops established from bare-root transplants (Salter & Fradgley, 1969a). These results suggest that, for the crops established from bare-root transplants, the degree and variability of the transplanting check to growth were the predominant factors influencing the variability of maturity time.

It is probable that the results reviewed above for cauliflower would apply in principle to the closely related broccoli crop where the harvested part of the plant is also a terminal inflorescence. Hence, the use of module-raised transplants to establish crops such as cauliflower and broccoli would appear to be a logical first step towards obtaining uniformly maturing transplanted crops as this would have a direct effect in reducing the degree and variability of the transplanting check to growth. This conclusion is in agreement with the results of Wilcox-Lee & Moyer (1986) who recorded much greater spreads of maturity of cauliflower when established from field-raised bare-root transplants as compared to greenhouse-raised module transplants of various module sizes.

If the predominance of the transplanting check in determining the variability of maturity of these crops can be reduced through the use of module-raised transplants, then further reductions in variability may be able to be achieved through other cultural treatments such as grading of seeds and seedlings as in the direct seeded cauliflower crop (Salter & Fradgley, 1969a). The greater control of the environment around the seed when transplants are raised in modules in a greenhouse, as compared to a field seed-bed, can also be expected to result in increased levels and uniformity of seed emergence. The more uniform growth of module-raised seedlings might also enhance the effects of treatments applied to synchronise the reproductive initiation of the crop - e.g. cold treatment of transplants (1.2.3.3).

#### 1.2.3.2 Stage of growth at transplanting

Salter & Fradgley (1969a) found that the maturity period of cauliflower crops established from bare-root transplants was lengthened when planting out was delayed by two weeks, particularly when the transplants were raised at a high seedling density. Delayed transplanting also resulted in a reduction in marketable yield (Salter & Fradgley, 1969b). The production of module-raised transplants in greenhouses has potential for 'holding' transplants, without a reduction in their performance in the field, should transplanting be delayed by field conditions (Hiron & Symonds, 1985; Wurr, Cox & Fellows, 1986).

An area of concern with transplanted crops of broccoli and cauliflower is the high proportion of small, unmarketable heads and curds, respectively, produced particularly when large bare-root transplants are used to establish the crop. 'Buttoning' of cauliflower has been described as the occurrence of curds which become exposed from their covering leaves, and hence mature, at a small unmarketable stage (Wurr & Fellows, 1984). A similar phenomenon in broccoli, termed 'premature heading', is the production of terminal heads which are unacceptably small at commercial maturity (as assessed by the development of the individual flower buds and the elongation of the main stem).

All other factors being equal, cauliflower plants which are large at transplanting are more susceptible to buttoning than smaller plants. Skapski & Oyer (1964) considered this to be due to the effect of the transplanting check to growth on large plants which had initiated curds prior to transplanting. However, Wurr & Fellows (1984) found that the incidence of buttoning increased with the size of plants at transplanting even when the largest plants had not initiated curds prior to transplanting. Later transplanting was associated with a reduction in eventual leaf size and total leaf weight. Wurr & Fellows (1984) proposed that the predominant factor influencing buttoning was the greater check to leaf development suffered by large transplants, causing the curds to become exposed, and hence, mature, at a small size. Support for this hypothesis comes from observations that buttoning is favoured by establishment conditions after transplanting which reduce vegetative growth, such as low temperatures, low nitrogen availability and low soil moisture (Wiebe, 1981; Whitwell, Jones & Williams, 1982; Salter, 1960b; Carew & Thompson, 1948).

Baggett & Mack (1970) found that the incidence of premature heading of broccoli increased with increasing age of transplants and with increasing size of transplants of the same age. Only limited conclusions can be drawn from this work as no assessments of leaf development or the times of head initiation of the transplants were made, however, it seems likely that the premature heading of broccoli is due to the greater transplanting check suffered by large transplants as has been shown for cauliflower (Wurr & Fellows, 1984). Increased nitrogen levels in the field soil did not reduce the level of premature heading and the tendency towards premature heading decreased with increased temperature during establishment (Baggett & Mack, 1970).

Broccoli cultivars differed widely in their tendency to form premature heads (Baggett & Mack, 1970). Cauliflower cultivars also differ in their susceptibility to buttoning and this is partially attributed to the differing numbers of leaves produced before curd initiation. Late-maturing cultivars produce a larger number of leaves and appear to be able to withstand some loss of leaf development without significant levels of buttoning taking place (Wurr, Fellows & Crisp, 1982; Wurr & Fellows, 1984). Further studies of the growth of broccoli plants and their

constituent parts are required to discover which factors are responsible for premature heading and to assist growers using bare-root transplants in avoiding loss of yield due to premature heading in commercial broccoli crops.

It is not certain to what degree the reduced level of transplanting check associated with the use of module-raised transplants might assist in the reduction of buttoning in cauliflower or premature heading in broccoli. A far more significant potential benefit of the use of module-raised transplants, as compared to bare-root transplants, in reducing yield losses due to buttoning and premature heading is the much greater control which can be exerted over the growth and development of module-raised transplants thus obviating the need for growers to risk using over-sized transplants should transplanting be delayed (Hiron & Symonds, 1985; Wurr, Cox & Fellows, 1986). Even when premature heading is not a problem, failure to control the growth of module-raised transplants of broccoli can result in poor establishment if transplanting is delayed (Kahn & Motes, 1988).

#### 1.2.3.3 Direct manipulation of initiation of reproductive growth

Investigations into the factors influencing the initiation of reproductive growth of the broccoli plant have important implications in the culture of the crop, particularly in view of the capacity to manipulate the early growth of plants in a transplanted crop. As with other *Brassica* crop plants - e.g. cauliflower (Wurr, Akehurst & Thomas, 1981) and Chinese cabbage (Guttormsen & Moe, 1985a,b) - attention has been focussed on the effect of temperature on the initiation of the reproductive parts of broccoli.

The annual forms of green sprouting broccoli do not appear to have an absolute (obligate) cold requirement for the initiation of inflorescent head formation. Thus, seedlings of cv. 'Coastal' (Gauss & Taylor, 1969b), cvs. 'Coastal' and 'Gem' (Wiebe, 1975), and cvs. 'Waltham 29' and 'Green Mountain' (Fontes, Ozbun & Sadik, 1967) grown at 29 °C, 27 °C, and 21 °C to 27 °C, respectively, initiated inflorescences (heads).

However, plants of at least some of these cultivars do exhibit a facultative low temperature response. Low temperatures - e.g. 13 °C for cv. 'Coastal' (Gauss & Taylor, 1969b) - retarded vegetative growth so that plants differentiated floral primordia and produced heads 10 mm in diameter at a younger morphological age (lower number of nodes, smaller stem diameter, lower shoot weight) than plants not exposed to low temperatures (Gauss & Taylor, 1969b; Fontes, Ozbun & Sadik, 1967; Wiebe, 1975). Miller (1988) induced earlier (chronologically and morphologically) flowering in plants of four broccoli cultivars by subjecting them to chilling regimes involving 14°/2° C diurnal fluctuations.

Under the experimental conditions of Fontes, Ozbun & Sadik (1967) broccoli plants which were 3 weeks old at the beginning of cold treatment were not 'induced to flower' whereas all plants which were  $\geq 5$  weeks old at the commencement of treatment had produced floral primordia after 3 weeks of cold treatment (4 °C) and 1 week of further growth at 21 °C. Hence, Fontes, Ozbun & Sadik (1967) postulated the existence of a 'juvenile' phase through which the plants must pass before low temperature was effective in inducing the initiation of floral primordia. However, the 'juvenile' (3 week-old) plants were chronologically younger at assessment than plants subjected to cold treatment at an older chronological age. Thus, cold treatment of 'juvenile' plants might well have been found to be effective in inducing chronologically earlier reproductive differentiation compared with control plants not exposed to low temperature had all plants been assessed at the same chronological age.

Miller (1988) recorded progressively earlier flowering of 14-day old seedlings of four broccoli cultivars with increasing duration of 14°/2° C diurnal chilling regimes up to 28 days. Seedlings exposed to the chilling regimes for 49 days commencing from sowing of seed flowered earlier than seedlings maintained at day/night temperatures of 22°/18° C. Reducing the duration of the chilling period by delaying its commencement up to 21 days after seeding had little effect on flowering time or final leaf number. Plants exposed to the chilling regimes for 31 days immediately following seeding flowered at a lower node number but not chronologically earlier than plants which were not chilled. Increasing the duration of the chilling period immediately following seeding to 38 or 45 days reduced both

time to flowering and final node number compared to unchilled plants. If a 'juvenile' phase exists for these cultivars (Apollo, Bravo, Early One and Futura) then the plants were able to pass through it and receive adequate chilling to induce early flowering under the chilling regimes applied. Furthermore, Gauss & Taylor (1969b) and Fujime & Hirose (1979) have found that, under some conditions, seed chilling is effective in promoting chronological and morphological earliness of reproductive differentiation indicating that, in at least some broccoli cultivars, the cold requirement for early initiation can start to be satisfied at germination.

Little is known of possible control mechanisms of induction of floral primordia in broccoli. Gauss & Taylor (1969b) postulated that a low temperature-mediated phytochrome system might be involved. Fontes & Ozbun (1972) found floral induction to be associated with an accumulation of carbohydrate in broccoli shoot tips under some conditions but not under others. Gibberellic acid promoted flowering at warm temperatures (Fontes & Ozbun, 1972) but Fontes, Ozbun & Powell (1970) could find no evidence of the involvement of endogenous gibberellins in floral induction in broccoli. Sadik (1967) was unsuccessful in attempts to accelerate flowering of non-cold treated plants of cv. 'Spartan Early' when cold-treated scions of the same cultivar were grafted onto them.

Although knowledge of the physiological mechanisms controlling reproductive growth of broccoli is scanty, the possibility exists that cultural treatments may be able to be used to improve the harvest uniformity of broccoli crops through the manipulation of the flowering response. Salter (1969) established that there was a positive relationship between the length of the curd initiation period and the length of maturity period in cauliflower crops. Following unsuccessful attempts to reduce variability of maturity in transplanted cauliflower crops by orthodox cultural treatments (Salter & Fradgley, 1969a), attention was then focussed on other means of inducing uniform curd initiation, particularly cold treatment of transplants (Salter & Ward, 1972). Attempts to develop a commercial treatment of this type have been reviewed by Wurr, Akehurst & Thomas (1981).

The possibility of reducing the time period over which inflorescences initiate and mature by exposing young plants to low temperatures before transplanting has yet to be investigated with modern broccoli cultivars. The optimal ranges of treatment temperature, duration of treatment and stage of growth of the plant at treatment may differ amongst cultivars, as with cauliflower (Wurr, Akehurst & Thomas, 1981; Wurr, 1981). In some cultivars, the optimal stage of growth for cold treatment may occur when the plants are too large to be successfully established by transplanting (Wurr, Akehurst & Thomas, 1981). The effects of photoperiod (Gauss & Taylor, 1969b), grading of plants prior to cold treatment (Salter & Ward, 1972), application of plant growth substances (Thomas & Comber, 1970; Fontes & Ozbun, 1970, 1972), and temperature conditions prior to cold treatment (Salter & James, 1974) and after induction of reproductive growth (Salter & James, 1974; Fontes, Ozbun & Sadik, 1967) may all be worthy of investigation in formulating a commercial treatment.

#### 1.2.3.4 Lateral head production and plant breeding

This review has concentrated on cultural techniques for the production of uniformly maturing terminal heads within a desired size range. An alternative approach, which has received considerably less research attention and which may be economically viable where small heads are desired, is to manipulate the plants so as to achieve uniform maturity of secondary (lateral) inflorescences (Pressman, Shaked & Aviram, 1985; Palevitch & Pressman, 1973). Lateral shoot growth can be stimulated by removal of the terminal apex by hand or by the use of chemical pinching agents (Palevitch & Pressman, 1974).

In addition to improvements in agronomic practices, the development of improved cultivars has potential as a means of increasing yield, uniformity and quality of broccoli (Pink & Innes, 1984). The brassica breeding programme at IHR, Wellesbourne has demonstrated the potential for incorporation of desirable morphological and uniformity characteristics from the *italica* and *botrytis* groups of *B. oleracea* into new crops fulfilling the specifications of processors and other users of broccoli (Gray, Crisp, Ives & Angell, 1984). In the U.S.A., a cultivar has been developed which produces no lateral heads prior to maturity of the terminal head

(Honma, 1986).

## 1.2.4 Harvesting regimes and the importance of harvest uniformity

### 1.2.4.1 Introduction

Any significant improvement in the uniformity of maturity of the broccoli crop, such as might result from the use of module-raised rather than bare-root transplants, will be beneficial whether the crop is harvested selectively or 'once-over'. The benefits of uniform maturity under both harvesting regimes are discussed in the following sections.

### 1.2.4.2 Selective harvesting

Selective hand harvesting, where individual heads are harvested as they mature, is the predominant method used for broccoli crops produced in New Zealand. Secondary (lateral) heads, which mature after the primary (terminal) heads, are sometimes harvested for fresh market (Bussell & Dobson, 1985) and processing (Geelen, 1984a). However, they tend to have a greater spread of maturity than terminal heads (Thompson & Taylor, 1976; Chung, 1985b), and are more expensive per unit of weight to harvest and handle after harvesting. Hence, the attention of researchers has been concentrated on the manipulation of size, harvest uniformity and quality of terminal heads.

In a work study on selective hand harvesting of cauliflower, Wheeler & Davies (1968) showed that cutting time per curd decreased with an increase in the proportion of curds mature at a single harvest. Wheeler & Salter (1974) evaluated the effects of decreases in spread of maturity on the economics of harvesting cauliflower crops in the U.K.: reductions in maturity period achieved through a cold treatment of transplants (Salter & Ward, 1972; Salter & James, 1974) were sufficient to bring about an increase in economic return (net of harvesting costs) through a reduction in the number of harvesting passes required to clear the crop. In some cases, the uniformity of maturity was such that the adoption of a harvesting regime of several selective harvests followed by a final, destructive harvest was profitable. In other cases, the maturity period was reduced sufficiently

that a single, once-over harvest was more profitable than making a series of harvests.

Bussell & Dobson (1985) noted that the popularity of the standard fresh market broccoli cultivars grown in New Zealand was partially due to their tendency towards a long harvest period from a single sowing or planting date. Prolonged harvesting, due to uneven maturity, was considered desirable because of its 'smoothing' effect on short-term fluctuations in market price. However, non-uniform maturity does increase harvesting costs: for example, Wheeler & Salter (1974) have shown that net economic returns can be increased by improvements in the uniformity of maturity of cauliflower crops. Thus, the harvesting of a series of smaller areas of compact maturity would appear to be a more efficient means of obtaining a period of continuous production.

Where broccoli is established by direct seeding, the successional maturity of these smaller areas could be achieved by sowing a single cultivar on several occasions or by simultaneous sowing of several cultivars taking different lengths of time to reach maturity. This sequence could be repeated several times to achieve a long period of maturity (Salter, 1972). Successional maturity of crops raised from transplants might possibly be achieved by the use of several cultivars or by raising successive batches of seedlings. Difficulties with raising successive batches of seedlings might possibly be overcome by manipulating the pre-transplanting growth of seedlings from a single sowing, to provide a range of maturity dates in the field. Reductions in the levels of nutrition (Hiron & Symonds, 1985) and temperature (Hiron & Symonds, 1985; Wheeler & Salter, 1974) have been used to 'hold' cauliflower transplants for this purpose.

#### 1.2.4.3 Once-over harvesting

Improved cultural techniques resulting in increased uniformity of maturity have obvious benefits in increasing yield when the crop is harvested on a 'once-over' basis. However, even under the most uniform cultural conditions possible, individual plants of current broccoli cultivars are inherently variable in their maturity time: the harvesting problem then becomes one of selecting a harvest

date which will optimise returns.

Harvest date has an important influence on yield of once-over harvested broccoli crops because marketable yield changes rapidly from day to day (Chung, 1982; Bussell, 1978; Brendler, 1970, 1971). Once-over harvest yield is determined by the weight of heads in the marketable grade which is in turn determined by: the rate at which immature heads reach the mature stage, the rate at which mean head weight increases in the marketable grade, and the rate at which the most advanced heads in the marketable grade become over-mature. The rates of these processes are determined by cultivar and environmental factors. Further complications in determining an optimum date of harvest might be expected to occur when quality characteristics for a particular market are superimposed on the crop maturity pattern, as described for fresh market cauliflower crops by Wheeler & Salter (1974). No published, detailed economic analysis on optimising harvest regimes for the broccoli crop is available, however several authors have proposed empirical schemes for scheduling once-over harvests of the crop.

Bussell (1978) found that maximum once-over yields of broccoli occurred 3 days after 5% of the terminal heads in the crop were over-mature (i.e. had at least one open flower). A similar timing of harvest was recommended by Cutcliffe (1971). Bull (1980) found that maximum single harvest yields, for several cultivars sown at three spring planting dates, were obtained when 5 to 25% of the heads were over-mature and that the length of this optimum harvest period was typically 3 to 4 days. Chung (1982) proposed that the once-over mechanical harvest date be timed several days before the time of maximum marketable yield, arguing that the cost of the resultant yield reduction might be recouped through a reduction in processing costs due to the absence of over-mature heads.

Bussell (1978), Cutcliffe (1971) and Chung (1982) recorded yields of marketable whole heads: the harvest timing decision is more complex where an attempt is made to salvage additional yield by processing acceptable parts of low quality or over-mature heads. In the latter situation, total yield continues to increase after the time of peak yield of high quality heads and optimum harvest date is determined by the economics of harvesting, trimming and processing lower quality

heads (Brendler, 1970, 1971; Chung, 1985b).

## 1.2.5 Plant spacing of broccoli: research results and current practices

### 1.2.5.1 Yield-density relationship

The results of studies using either selective or once-over harvesting regimes have shown that the relationship between marketable yield and plant density of broccoli is generally asymptotic or, in some cases, a flat-topped parabola. Chung (1982) found that broccoli terminal head yield approached its asymptote at a plant density of c. 20 m<sup>-2</sup>. Thompson & Taylor (1976) estimated that the asymptotic yield was approached by populations of 10 to 20 m<sup>-2</sup>. Salter, Andrews & Akehurst (1984) concluded that terminal head yield of 'neo-calabrese' was relatively insensitive to plant density above 20 m<sup>-2</sup>. Cutcliffe (1975b) demonstrated that the yield response to density varied amongst cultivars and that the asymptotic yield was approached at plant densities between 9 and 20 m<sup>-2</sup> for most of the nine cultivars investigated.

Chung (1985a) showed that the asymptotic level of yield and the relationship between plant density and head diameter for cv. 'Futura' were affected by the time of year at which the crop was grown. Hence, the range of plant densities suitable for the production of a high proportion of heads within a required size range and the economic return of the crop varied with the date of sowing. Optimum spacings can also be expected to vary with levels of crop nutrition (Zink, 1968) and irrigation. The yield-density relationship can also be expected to vary with the definition of 'marketable' yield; particularly with respect to the length of stem remaining after trimming of the head.

There is a general agreement in the published literature that higher yields of broccoli are obtained using square (rectangularity = 1:1) rather than rectangular planting arrangements at constant plant density (Salter, Andrews & Akehurst, 1984; Bussell, 1978; Palevitch, 1970).

### 1.2.5.2 Plant density and mean head size

Terminal head size varies inversely with plant density (Chung, 1982; Cutcliffe, 1975b; Dufault & Waters, 1985; Salter, Andrews & Akehurst, 1984). Once at the asymptotic level of marketable yield, the mean head diameter of the crop can be manipulated, without loss of yield, by altering the plant density at which the crop is grown. Thus, to produce high yields of terminal heads with diameters in the range 25 to 70 mm (with a mean diameter of approximately 45 mm) suitable for individual quick freezing, researchers in Scotland (Thompson & Taylor, 1976), Tasmania (Chung, 1982) and England (Salter, Andrews & Akehurst, 1984) recommend plant densities in excess of 40 m<sup>-2</sup>. The limited published data available suggests that similar results would hold under New Zealand conditions (Bussell, 1978).

### 1.2.5.3 Plant density and crop maturity

There is some conflict in the literature as to the effect of plant density on the maturity date of broccoli: some authors have reported slightly earlier maturity dates with increased plant densities (Salter, Andrews & Akehurst, 1984; Thompson & Taylor, 1976) while Cutcliffe (1971, 1975b) and Kahn et al. (1991) recorded delays in maturity as plant density increased.

Salter, Andrews & Akehurst (1984) could find no obvious relationship between plant density and plant-to-plant variability in maturity of selectively harvested terminal heads of 'neo-calabrese', however, the coefficient of variation of head diameter was found to increase with plant density. Chung (1985a) found no effect of plant density on the proportion of immature, mature and over-mature plants at once-over harvest. However, the results of Thompson & Taylor (1976) indicate an increase in the number of days from 5% to 95% of final yield of terminal heads with increasing plant density over the range 3.5 to 97 plants m<sup>-2</sup>.

#### 1.2.5.4 Plant density of process crops grown in the Manawatu

The current recommendation for plant spacing of broccoli crops for processing in the Manawatu is 700 mm x 500 mm, giving a plant population of 2.86 plants m<sup>-2</sup> (28 570 plants ha<sup>-1</sup>). The processing company has made the decision to have the crop produced at relatively low plant densities using cultivars which produce terminal heads with a narrow angle of branching. The large, deeply-branched heads produced using this approach can be readily sectioned to produce smaller segments of a size suitable for freezing (Bussell, 1984b).

The recommended plant spacing results in a considerably lower plant density than the range of densities over which the asymptotic yield has been estimated to occur in published research reports (1.2.5.1). Given the preference of the processing company for minimising the number of heads to be cut per unit of yield, one plant density deserving investigation is one at a point where the yield-density function for the crop begins to closely approach the asymptote. At such a spacing, the grower is utilising the minimum number of heads per hectare required to produce the asymptotic yield for the given cropping conditions: this results in the lowest hand harvesting costs and the largest head size possible at the asymptotic level of yield.

It is likely that plant spacings corresponding to this region of the yield-density relationship would be within the capabilities of modern transplanting equipment: for example, 16 plants m<sup>-2</sup> could be achieved by spacing plants at 250 mm x 250 mm. One means of obtaining higher plant densities in a mechanically transplanted broccoli crop would be to use multi-seedling modules. Westcott & Callan (1990) found that increasing the number of seedlings from 1 to 3 per module resulted in reduced head size and yield of transplanted broccoli over the range of plant densities where marketable heads were produced. Hence, attempts to increase broccoli yield through manipulation of plant spacing should first be concentrated on single-plant modules. However, consideration should also be given to possible economic benefits of the use of multi-seedling modules (e.g. reduced handling and transplanting costs) in comparison to the use of single-seedling modules to

establish the same plant density in the field.

## CHAPTER 2

### FIELD EVALUATION OF TWO TYPES OF TOMATO TRANSPLANT

#### 2.1 Introduction

Advantages of transplanting as compared to direct seeding to establish processing tomato crops in New Zealand were discussed in Section 1.1 and include: conservation of seed, greater flexibility of the quality and timing of soil preparation, improved weed control and shortening of the length of time required to mature the crop in the field. The main impetus behind the commercial use of bare-root transplants for the crop has been the fact that commercial and research experience has shown that early-season harvest dates can be advanced by 2 to 3 weeks by the use of bare-root transplants as compared to direct seeding (Geelen, 1983; Bussell & Burgmans, 1983).

Given the acceptance of transplanting as a method of establishing the crop, consideration should then be given to the various means of raising and establishing tomato transplants. The potential advantages of the use of module-raised transplants to establish processing tomato crops under New Zealand conditions were discussed in Section 1.1.3 where it was stated that reductions in the degree and variability of the transplanting check to growth resulting from the use of uniform lines of module-raised transplants, at a suitable stage of development, would be expected to be reflected in earlier and higher once-over yields, as compared to tomato crops established from bare-root transplants.

The following experiment was conducted to investigate whether establishment of a determinate tomato crop from module-raised transplants produced in a greenhouse, as compared to field-raised bare-root transplants, might provide any advantage in crop establishment, once-over yield or earliness of maximum once-over yield under the growing conditions of the Hastings district.

## 2.2 Materials and Methods

### 2.2.1 Introduction

An early-season planting of the two transplant types was established at the Ministry of Agriculture and Fisheries (M.A.F.) Horticultural Research Station near Hastings and a series of harvests were taken to record vegetative growth and the pattern of fruit yield with time for the two types of transplant. Soil preparation and routine maintenance of the experiment after transplanting until harvest were carried out by M.A.F. staff.

### 2.2.2 Selection of cultivar and source of seed

The cultivar used in this study was the hybrid 'Castlehy 1204 Improved'. This is a cultivar which has rapidly become one of the principal cultivars of tomato grown for pulp and paste processing in New Zealand (Burgmans, 1984) and is the preferred cultivar for transplanting for early production (Burgmans & Bussell, 1983). Seed was obtained from J. Wattie Canneries Ltd., Hastings and seed from a single commercial seed lot was used to produce both module-raised and bare-root transplants for this experiment.

### 2.2.3 Methods of raising transplants

#### 2.2.3.1 Bare-root transplants

The bare-root transplants used in this experiment were raised at Hastings, as part of a commercial seed-bed, according to normal commercial practice for the district (Anon., 1981) under the supervision of field staff of J. Wattie Canneries Ltd. The soil type at the site was a Mangateretere clay loam.

On 12 May 1983, a 1.0 m wide raised bed was formed and pellets of Basamid Granular<sup>R</sup> (dazomet) soil fumigant were applied at the rate of 50 g a.i. m<sup>-2</sup>. The pellets were incorporated by rotary hoe and the bed was sealed with black polythene. The seed-bed was aerated for two weeks before application of a paraquat herbicide on 12 August 1983. A dressing of 25 g m<sup>-2</sup> of an 8-14-13 N-P-K compound fertiliser was applied and incorporated by rotary hoe. Seeds of cv.

'Castlehy 1204 Improved' were sown 10 mm apart in 10 rows spaced 100 mm apart using a 'Planet Junior' seed drill on 19 August. After sowing, the seed-bed was covered by polythene cold frame covers (Plate 2.1). Thereafter the seed-bed was ventilated for several hours daily on warm days. A single irrigation was considered necessary (on 8 September). After 17 September the seed-bed was left uncovered except on those nights when a frost was considered likely. The pesticide programme used during raising of the seedlings is detailed in Appendix 2.

Emergence of the seedlings in the seed-bed was patchy due to the method of sowing used by the grower (Plate 2.1). Seedlings used in the experiment were obtained from an area of the seed-bed where seedling growth had been relatively uniform. Seedlings were lifted from the seed-bed, using hand trowels, on the day of transplanting (11 October). The bare-root transplants were kept covered and moist in a cardboard box until they were transplanted.

#### 2.2.3.2 Module-raised transplants

Module-raised transplants used in this experiment were produced at the Plant Growth Unit, Massey University. The seedlings were raised in 16 'Plixi-pot' plastic seedling trays (Plix Products Ltd, Hastings). Each tray was 555 mm x 300 mm and consisted of 77 compartments or modules, resulting in a potential seedling density of 462 m<sup>-2</sup> with one seedling per module. Drainage holes in the modules were enlarged to 13 mm diameter before use.

On 8 September 1983, each module was filled with growing medium which consisted of 60:40 (by volume) sieved (5 mm mesh) sphagnum peat moss: coarse washed river sand, with 3.0 kg m<sup>-3</sup> dolomite and 1.5 kg m<sup>-3</sup> agricultural lime incorporated. Each module contained approximately 36 cm<sup>3</sup> of growing medium. Seed of cv. 'Castlehy 1204 Improved' was dusted with a fungicide containing captan (at 1.6 g a.i. per kg of seed) and one seed per module was sown approximately 5 mm deep and covered with sieved peat:sand medium.

The medium was thoroughly watered and the trays were placed on a heated (21 °C) capillary bench in a glasshouse heated to 14 °C and fan-ventilated at 20 °C. The growing medium was watered daily as required. Nine days after sowing, after most seedlings had emerged, the trays were moved onto a capillary bench in a glasshouse heated to 16 °C and fan-ventilated at 22 °C (on occasions the glasshouse air temperature reached 28 °C at bench level). Seedlings were carefully transferred from three of the trays to provide thirteen trays with a full complement of seedlings.

Commencing nine days after sowing, seedlings were irrigated with a complete nutrient solution (Appendix 1) as required (up to twice daily). A single pesticide application was made to the seedlings on 9 October (Appendix 2). The stage of development of the plants 5 days before transplanting is illustrated in Plate 2.2.

The thirteen trays of seedlings were transported to Hastings by car on 10 October 1983. On arrival, the trays were placed outdoors on a capillary bed of sand and watered. Trays were left on the capillary bed overnight and watered as necessary until the seedlings were transplanted the following day.

## 2.2.4 Transplanting method and maintenance of experiment in the field

### 2.2.4.1 Preparation of experimental area prior to transplanting

The field experiment was conducted at the Ministry of Agriculture & Fisheries Horticultural Research Station near Hastings. The soil type at the experimental site was a Mangateretere clay loam.

In early September 1983, an area of land, approximately 50 m x 25 m, was cultivated and formed into fifteen 50 m long raised beds spaced at 1.5 m centres. A dressing of 200 kg ha<sup>-1</sup> of 15 % potassic superphosphate was broadcast over the area and incorporated into the soil. In the first week of October an application of Roundup<sup>R</sup> (glyphosate) herbicide was made to control the growth of a high population of couch (*Agropyron repens*) arising from buried rhizomes. A further 200 kg ha<sup>-1</sup> of 15 % potassic superphosphate was broadcast over the area on 10 October.



Plate 2.1 Bare-root tomato transplants in seed-bed on day of transplanting (53 days after sowing). Patchy growth of seedlings was due to sowing of seed in two passes of a 5-row seed drill.



Plate 2.2 Module-raised tomato transplants in trays on greenhouse bench, 28 days after sowing (5 days before transplanting).

#### 2.2.4.2 Transplanting method

On 11 October, bare-root and module-raised transplants were transplanted into the field area (53 and 33 days after sowing, respectively). Plants were transplanted into the beds in a single row per bed with 200 mm between plants in the row. Planting holes were opened using a hand trowel and plants were firmed in by hand to a depth part of the way between the cotyledonary node and the node of the first true leaf.

Size grading of bare-root transplants was considered necessary and only sturdy plants of commercially acceptable size (at least 100 mm long with 4 or more true leaves) were transplanted. Module-raised transplants from around the edges of the trays were transplanted into buffer areas in the field: plants from which data were to be recorded were taken from the centres of the trays. Transplanting was carried out one block (2.2.5.1) at a time, with the whole experiment (including buffer areas at the ends of the rows) being planted over an 8-hour period. After the completion of transplanting, 30 mm of water was applied to the field area through a sprinkler irrigation system.

#### 2.2.4.3 Maintenance of experiment after transplanting

The pesticide programme used in the field is outlined in Appendix 2. In addition to herbicide applications (Appendix 2), the experimental area was weeded manually 51, 69 and 89 days after transplanting and irrigations of 30 mm and 60 mm were applied 86 and 112 days after transplanting, respectively.

### 2.2.5 Experimental design, data collection and analysis

#### 2.2.5.1 Experimental design

Treatments were randomly assigned to plots as appropriate for a 2 x 10 (transplant types x harvests) factorial set of treatments in a randomised complete block design with eight blocks. Each plot was 2.0 m long and consisted of eight plants from which data were recorded and buffer areas of one plant at each end of the plot. The first harvest from the plots was of whole plants (2.2.5.2.2) and

the remaining harvests were of fruits (2.2.5.2.3).

A buffer area of 0.6 m (i.e. 3 plants) was established by transplanting at either end of each experimental bed. A buffer area of three beds in the centre of the experimental area (to allow the passage of a tractor for pesticide applications) and single buffer beds on either side of the experiment were established by direct seeding 2 days after transplanting of the experimental beds.

## 2.2.5.2 Collection of data

### 2.2.5.2.1 Harvest at transplanting

A dry weight harvest was taken to assess the stages of growth of the bare-root and module-raised transplants at the time of transplanting. A sample of bare-root transplants was moistened and placed in a polythene bag on the day of transplanting. The bag was placed in a coolstore at 5 °C overnight. The following day the plants were graded using the same criteria as had been used to select plants suitable for transplanting (2.2.4.2) and unacceptable plants were discarded. Three ten-plant samples were selected at random from the remaining plants and dissected into roots, stems (including leaf laminae <15 mm in length) and leaf laminae. The division between 'root' and 'stem' was made at the level where the surface of the seed-bed soil had been (this point was defined by a colour change on the hypocotyl).

Three ten-plant samples of the module-raised transplants were selected at random from seedling trays and the growing medium was carefully rinsed from the roots before dissection into roots, stems and leaf laminae as described above. The number of true leaves with a terminal leaflet >15 mm in length was recorded for all plants. Tissue was bulked into a single sample of each plant component for each ten-plant sample. Leaf areas were measured using a photoelectric area meter (Li-Cor Model 3100). Root, stem and leaf samples were dried for 48 hours in a vacuum chamber (Haslemore, Warrington & Roughan, 1980) and the dried samples were equilibrated in an air-conditioned room (21 °C, 50% relative humidity) for 24 hours before weighing.

#### 2.2.5.2.2 Harvest following establishment

The first harvest of plants growing in the field at Hastings was taken on 15 November 1983 (35 days after transplanting). Plants were harvested from one plot of each transplant type from each block (2.2.5.1). The eight central plants of each of these plots were lifted carefully from the soil using a garden fork. Plants were placed in large polythene bags and transported to Palmerston North where they were stored overnight in a coolstore at 3 °C. The following day, soil was carefully rinsed from the roots and the plants were dissected into roots, stems and leaf laminae. Adventitious roots arising from the cotyledonary node were excised and included as 'roots' but the division between 'root' and 'stem' was made at the top of the main root system. Tissue was bulked into a single sample of each plant component from each plot and samples were dried and weighed as described for the plants harvested at the time of transplanting (2.2.5.2.1).

#### 2.2.5.2.3 Fruit fresh weight harvests

Harvests of fruit were carried out on nine occasions as outlined in Table 2.1. Harvested plants were cut at ground level using secateurs leaving buffer plants undisturbed. The foliage of the harvested plants was shaken to dislodge the bulk of the fruit and fruits adhering to the plants were removed by hand. Fruits from each plot were graded into 3 grades: green, process and rotten. The process grade consisted of fruits considered acceptable for processing by local standards: these were sound fruits with a minimum of 90% red surface colour.

Table 2.1 Dates on which fruit yield data were collected

Harvest number	Date of harvest	
	calendar date (1984)	days from transplanting
1	3 Feb.	115 <sup>a</sup>
2	10 Feb.	122
3	15 Feb.	127
4	21 Feb.	133
5	28 Feb.	140
6	7 Mar.	148 <sup>a</sup>
7	16 Mar.	157 <sup>a</sup>
8	21 Mar.	162
9	27 Mar.	168

<sup>a</sup> Counts of fruit number in each grade recorded for four replicates  
(see Section 2.2.5.2.4)

As each plot was harvested, the total fresh weight of fruit in each grade was recorded to an accuracy of  $\pm 0.025$  kg using an electronic weighing scale. With the exception of 21 March, all harvesting and weighing was completed between 0800 and 1100 hours on each harvest occasion. Data for the 15 February, 28 February and 27 March harvests were collected by M.A.F. staff.

#### 2.2.5.2.4 Fruit numbers

On three harvest occasions (see Table 2.1) after weights had been recorded, the numbers of fruit in the green and process grades were recorded for harvested plots in four of the eight replicates.

### 2.2.5.3 Analysis of data

#### 2.2.5.3.1 Harvest at transplanting

Dry weight and leaf area data from the harvest taken at transplanting time were analysed separately for each treatment. Means and standard errors of means were calculated from data for the three ten-plant samples of each treatment. Means and standard errors were then converted to the per-plant scale.

#### 2.2.5.3.2 Harvest following establishment

Dry weight data from the harvest taken 35 days after transplanting were converted to the per-plant scale before being subjected to an analysis of variance using the MANOVA procedure of the SPSS computer software package (Hull & Nie, 1981).

#### 2.2.5.3.3 Fruit fresh weight harvests

Raw data for green, process, rotten and total (= green + process) fruit fresh weights were transformed from 'kilograms per plot' to a 'tonnes per hectare' scale and analysed using the GENSTAT V 4.04B computer program (Alvey et al., 1977). Due to deterioration of the plants and highly variable fruit yields, data from the ninth harvest (27 March) were excluded from analysis. Only one of the plots harvested on 3 February yielded any rotten fruit: hence data from that harvest were excluded from all analyses of variance carried out on the rotten fruit yield data.

Initially, data for each fruit grade were analysed in an analysis of variance with a factorial set of treatments consisting of two transplant types x eight harvests (seven harvests in the case of the rotten fruit yield). However, as might be expected for sets of data covering a wide range of values, scatter diagrams of error residuals plotted against fitted values from these analyses revealed a marked pattern of increasing variation with increasing size of the fitted values for yields of green fruit and rotten fruit and a slight tendency towards a similar pattern for yields of process grade fruit and total fruit. In order to investigate the relationship between the standard deviation and the mean for each variable, separate analyses of

variance were carried out on data for each harvest date. Scatter diagrams revealed a tendency for the standard deviation to be proportional to the harvest mean for all four variables, indicating that a logarithmic transformation of the data would be appropriate to obtain homoscedasticity across harvests (Rayner, 1969, p.552).

Data were transformed to natural logarithms and analyses of variance, incorporating the transplant types x harvests factorial set of treatments, were carried out on the transformed data. Scatter diagrams of error residuals plotted against their respective fitted values for the analyses of the transformed data showed a trendless random scatter for each variable, demonstrating that the transformation had been effective in each case.

Due to a harvesting error, there was one missing plot in the third (15 February) harvest. The resultant missing observation in each analysis of variance described above was estimated by the computer program using an iterative procedure to minimise the residual sum of squares and one degree of freedom was deducted from residual and total degrees of freedom.

#### 2.2.5.3.4 Fruit numbers

Fruit count and yield data from the four replicates from which fruit counts were recorded on three of the harvest dates (Table 2.1) were used to derive the following variables: number of green fruit per plot, number of process grade fruit per plot, total number of fruit (i.e. green plus process) per plot, number of fruit in the process grade as a percentage of the total per plot and fresh weight of factory grade fruit as a percentage of the total yield per plot.

To avoid possible difficulties in presentation - where data for some variables required transformation, because of heteroscedasticity across harvests, while others did not - separate analyses of variance were conducted on data for individual harvests. The MANOVA procedure of the SPSS computer package (Hull & Nie, 1981) was used for these analyses and scatter diagrams of error residuals plotted against fitted values from these analyses revealed a trendless random scatter in all

cases indicating homoscedasticity within individual harvests for all variables.

## 2.3 Results

### 2.3.1 Harvest at transplanting

The two types of transplant compared in this experiment are illustrated in Plates 2.1 and 2.2. The patchy emergence and non-uniform growth of the bare-root transplants in the seed-bed (Plate 2.1) can be attributed in part to the fact that the seed was sown in two passes of the seed drill resulting in some disturbance of the first-sown rows during the second pass.

Module-raised transplants had higher mean dry weights of roots and shoots, higher leaf areas and were more advanced in terms of leaf number than bare-root transplants (Table 2.2).

Table 2.2 State of plants at transplanting. Means of three 10-plant samples (converted to the per-plant scale). Standard errors of sample means in parenthesis.

Transplant type	Root dry weight (mg)	Shoot dry weight (mg)	Leaf area ( $\times 10^{-4}$ m <sup>2</sup> )	Number of true leaves
bare-root	33.0 (1.6)	87 (11)	11.7 (1.1)	3.8
module	44.7 (3.6)	334 (25)	66.7 (2.8)	4.2

### 2.3.2 Harvest following establishment

Results from analyses of variance of dry weight data collected in the whole-plant harvest 35 days after transplanting are presented in Table 2.3. Representative plants of the two transplant types at the time that this harvest was taken are shown in Plate 2.3. Complete recovery of the root systems from the field soil was

not practicable, but differences between treatments in the amounts of root system which were recovered were large (Table 2.3 and Plate 2.3).

Table 2.3 State of growth of plants 35 days after transplanting. Means of eight 8-plant plots expressed on a g plant<sup>-1</sup> scale. Standard errors of differences between means in parenthesis.

Transplant type	Dry weight of plant component (g plant <sup>-1</sup> )		
	Root	Shoot	Total
bare-root	0.23	4.01	4.24
module	0.47	7.18	7.64
	(0.05)	(0.59)	(0.64)

No further quantitative data were gathered until the commencement of the harvest of fruits. However, weekly observations of the experiment were made by M.A.F. staff and it was noted that, after canopy closure in-the-row, it became increasingly difficult to distinguish visually between plots of the two transplant types (e.g. Plate 2.4).

### 2.3.3 Fruit fresh weight harvests

The logarithmic transformation of the fruit yield data resulted in improved conformability of the data to the assumption of homogeneous variance, as compared to analysis of the untransformed data (2.2.5.3.3). However, the only significant differences between the two transplant types were for rotten fruit yield and, in general, the analyses of transformed and untransformed data agreed quite well: transformation had little effect on the conclusions to be drawn from the results. Hence, for ease of presentation, the results from the analyses of



Plate 2.3 Representative plants, established from bare-root (left) and module-raised (right) transplants, 35 days after transplanting. Fully open flowers are visible on the module-raised plants but not on the plants established from bare-root transplants.



Plate 2.4 End view of five of the experimental beds, 90 days after transplanting, at Hastings.

untransformed data are presented (Fig. 2.1) rather than the results (or their de-transformed equivalents) from the analyses of the transformed data. Observed differences between means of the two transplant types at each harvest were compared with the least significant difference ( $P < 0.05$ ) on both the untransformed and transformed scales. Instances where the results of these tests on the untransformed and transformed data did not concur are described in the following paragraphs.

Analysis of the transformed data for green fruit yield revealed no significant differences between means for transplant types at any of the harvest dates. Thus, the significant difference between the untransformed means for green fruit yield for the 10 February harvest (Fig. 2.1) can be attributed to experimental error.

There were no significant differences between process grade fruit yields for the two transplant types on the transformed scale at any of the harvest dates except at the 3 February harvest. There were no significant differences between transplant type means for process grade fruit at any harvest on the untransformed scale. For rotten fruit yields observed differences between transplant types were significant under the logarithmic transformation at the 15 February and 21 February harvests (not significant for untransformed analysis) and not significant for the 7 March and 16 March harvests (significant for the untransformed analyses).

There were no significant differences between transplant types for total (green plus process) yield on the transformed scale and only one significant difference (at the 10 February harvest) on the untransformed scale.

#### 2.3.4 Fruit numbers and maturity indices

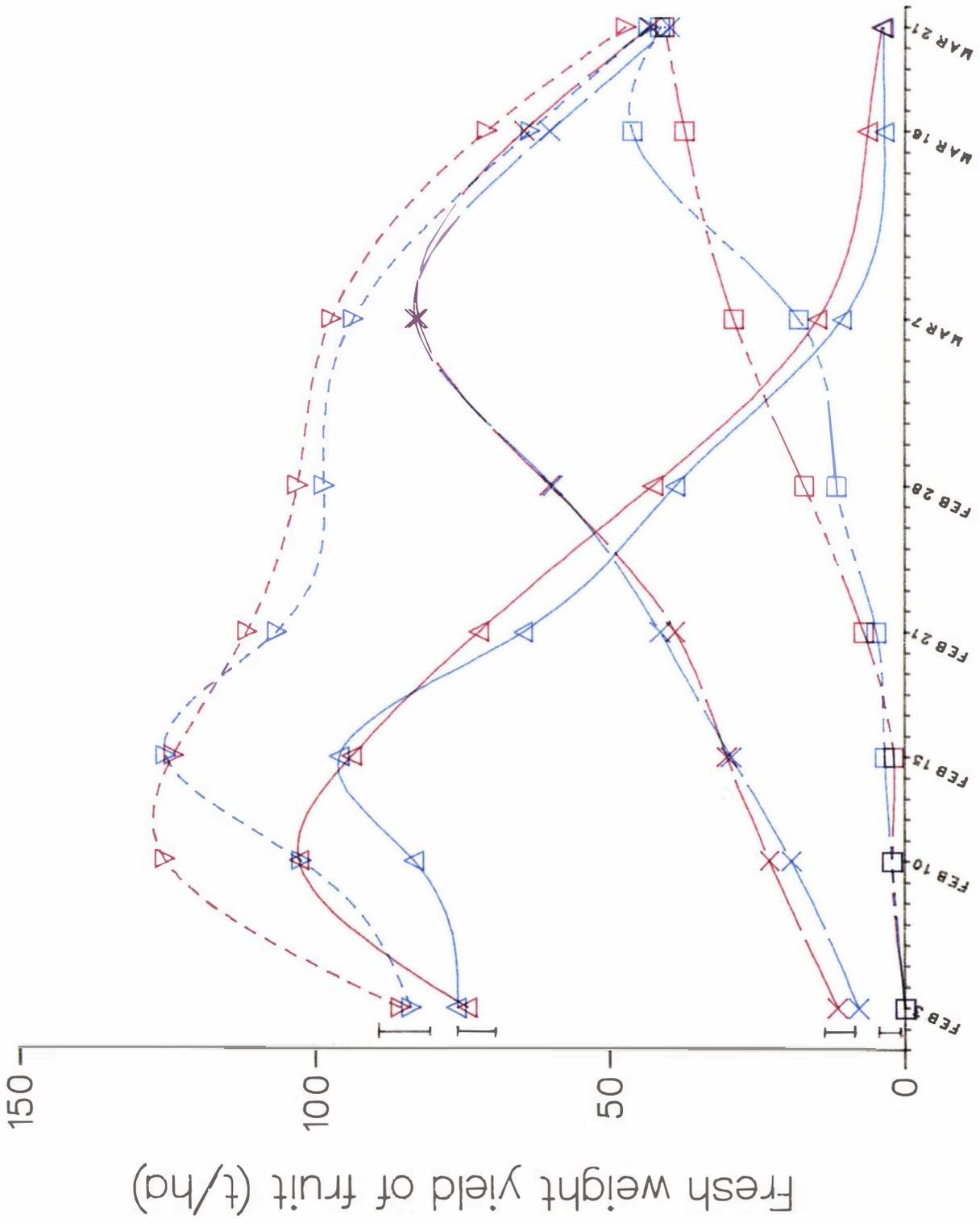
Mean numbers of fruit in each grade harvested from plots in four of the experimental blocks on each of three harvest occasions (see footnote to Table 2.1) are presented in Table 2.4 along with means of two types of 'maturity index' (Swain, 1980).

**Figure 2.1** (following page):

Fruit fresh weight yields ( $\text{t ha}^{-1}$ ), in four grades, from bare-root and module-raised transplants of tomato at Hastings. Total = green + process. Means of 8 plots per transplant type at each harvest. Vertical bars = standard errors of differences (104 d.f.) between any two means, for each fruit grade (unadjusted for missing observation in Feb. 15 harvest).

Legend

- △ bare-root, green
- △ modular, green
- × bare-root, process
- × modular, process
- bare-root, rotten
- modular, rotten
- ▽ bare-root, total
- ▽ modular, total



Date of harvest

Fresh weight yield of fruit (t/ha)

Table 2.4 Means of fruit numbers and 'maturity indices' for two transplant types at each of three harvest dates. Means of four 8-plant plots. Standard errors of differences between means in parenthesis.

Transplant type	Mean number of fruit per plot			'Maturity index' (% process grade)	
	green	process	total	by number	by weight
Harvest 1 (3 Feb.)					
bare-root	639	40	679	5.9	10.1
module	602	46	649	7.1	12.1
	(108)	(10)	(116)	(0.9)	(2.8)
Harvest 6 (7 Mar.)					
bare-root	88	415	503	82.9	87.4
module	118	444	563	79.4	84.9
	(27)	(68)	(67)	(5.8)	(4.4)
Harvest 7 (16 Mar.)					
bare-root	29	293	322	90.6	94.1
module	46	373	418	89.0	93.0
	(7)	(65)	(64)	(3.0)	(1.6)

The number of process grade fruit increased from the 3 February harvest to the 7 March harvest and then declined whereas the percentage of process grade fruit (by weight and by number) increased with time over the three harvests. There was a decline in the number of green fruit with time (reflecting fruit ripening) and a decrease in the total number of fruit (reflecting losses due to fruit rotting after 10 February). There were no significant differences between transplant types at any harvest.

## 2.4 Discussion

### 2.4.1 Raising of transplants

It was the objective of this experiment to compare the field performance of two possible commercial alternative methods of raising tomato transplants. Sowing dates for the two transplant raising methods were selected so as to provide plants of each type suitable for transplanting on or about 11 October. This was achieved for the module-raised transplants: plants of that type were at a suitable stage for transplanting with the roots holding the modules of growing medium intact upon withdrawal from their respective seedling trays. The bare-root transplants used in the experiment were at an earlier stage of growth than that commercially recommended for transplanting (Anon., 1981; Orchiston, 1982) and commercial transplanting from the seed-bed in which they were raised did not commence until 10 days after the transplanting date for the current experiment. Hence, at the time of transplanting, the bare-root transplants had a lower mean shoot dry weight, a lower mean leaf area and were at an earlier stage of development (in terms of leaf number) than the module-raised transplants (Table 2.2).

This illustrates one of the advantages of the use of greenhouse-raised module-raised transplants for the tomato crop: production times in the greenhouse are reasonably predictable whereas scheduling of transplant production for a particular transplanting date is more difficult to achieve when transplants are raised in field seed-beds.

## 2.4.2 Field establishment and early growth

Favourable growing conditions resulted in rapid establishment of both transplant types with very few plants failing to establish. Thirty-five days after transplanting mean shoot dry weight of plants established from module-raised transplants was 80% higher than that of plants established from bare-root transplants (Table 2.3). Open flowers on plants established from module-raised transplants were first observed 26 days (6 November) after transplanting (cf. Plate 2.3) whereas open flowers were not observed on plants established from bare-root transplants until 41 days (21 November) after transplanting.

## 2.4.3 Post-establishment growth and yield

### 2.4.3.1 Introduction

Despite the considerable differences in dry weight of vegetative growth recorded 35 days from transplanting (Table 2.3 and Plate 2.3), the yield/maturity patterns of plants established from the two types of transplant were very similar (Fig. 2.1). Records of individual plants were not taken but module-raised transplants were visually more uniform at transplanting and during early growth after transplanting. However, the greater uniformity of the module-raised transplants was not reflected in a greater concentration of fruit maturity; i.e. the use of module-raised transplants did not result in a higher optimum once-over yield of process grade fruit (Fig. 2.1).

### 2.4.3.2 Time of maturity

The growth of experimental plants was not assessed quantitatively between the harvest 35 days after transplanting and the commencement of harvests of fruit (115 days after transplanting). Hence, insufficient data were gathered to provide a clear explanation of why the early advantage in vegetative growth after establishment of the module-raised transplants as compared to the bare-root transplants was not translated into an earlier date of optimum yield.

Gray, Steckel & Ward (1979) reported earlier flowering and earlier fruit ripening of bare-root transplants (raised under Dutch light frames or under low polythene tunnels) compared with block-raised transplants (grown in a heated glasshouse). They hypothesised that the earlier development of the bare-root transplants may have been due to the exposure of the young seedlings in the seed-bed to low temperatures. Exposure to low temperatures (10 °C to 13 °C) commencing shortly after cotyledon expansion has been shown to reduce the number of leaves formed before the first inflorescence, and to increase flower numbers in the first and second inflorescences of determinate tomato cultivars resulting in increased early fruit set and increased early yields (Tiessen, 1962; Wittwer & Teubner, 1956).

In the current experiment, exposure of the bare-root transplants to low temperature during plant raising may well have had some influence on their subsequent development. However, the module-raised transplants were more advanced in terms of early vegetative growth (Table 2.3) and were observed to flower approximately 15 days earlier than the bare-root transplants (2.4.2). If date of first flowering is assumed to be a reliable indicator of the stage of development of the plants then it would be expected that the early difference would persist until harvest.

One possible explanation for the failure to detect a difference in maturity between the two transplant types is that the difference between the two types of transplant did persist until harvest but that the difference was too small to be detected at crop maturity on the chronological time scale used. To test this possibility, accumulated heat units (Appendix 3) were calculated for the following periods: (i) from 6 November (26 days after transplanting, when the module-raised transplants first flowered) to 21 November 1983 (41 days after transplanting, when the bare-root transplants were first observed to flower); and (ii) from 23 February to 7 March 1984 (a period of 14 days up to and including the date at which the maximum yields of process grade fruit from both transplant types were recorded).

Heat units (°C-days) between the dates of first flowering of the two transplant types ((i) above) totalled 118.9. The mean number of heat units accumulated per day over the two-week period prior to 7 March ((ii) above) was 10.7.

If it is assumed that: (i) after initial field establishment, plants of the two transplant types developed in the same manner; (ii) the date of first flowering is a reliable indicator of a stage of development of the plants; (iii) the growth and development of the plants was directly related to heat unit accumulation; and (iv) plants of the two transplant types were not differentially affected by environmental conditions occurring subsequent to their respective dates of first flowering, then it would be expected that the maximum yield of the module-raised transplants would have been achieved approximately 11 ( $= 118.9/10.7$ ) days prior to that of the bare-root transplants. Had it occurred, such a large difference in optimum once-over harvest dates would have been readily detectable on the chronological time scale (Fig. 2.1)

An alternative explanation for the lack of a difference in optimum harvest times between the two types of transplants is that one (or more) environmental influence(s), during or subsequent to flowering, affected plants of the two types differentially, due to differences in their stages of development at some time, resulting in a loss of the early advantage of the module-raised transplants by the time that harvesting of fruit commenced. For example, differences in the stage of development of the two types of plant may have meant that early fruit set was reduced in the module-raised transplants due to the influence of temperature (Daubeny, 1961; Went, 1944) or water stress (Salter & Goode, 1967, p. 61-63; Wudiri & Henderson, 1985). Similarly, early fruit development in the module-raised transplants may have been delayed by low temperatures (Davis et al., 1969) or water stress (Davis et al., 1965) occurring at some critical stage.

Thus, the results of this experiment illustrate that quite large differences in the growth of the tomato crop resulting from establishment treatments can persist for some time in the development of the crop and yet can be moderated by environmental influences resulting in little difference in the timing of optimum once-over yield. Similar results have previously been reported for the tomato crop: for example, early emergence and advanced early development resulting from seed treatments are not always reflected in earlier maturity (Bussell, 1980; Wolfe & Sims, 1982). Leskovar & Sims (1987) recorded earlier and more uniform

emergence of tomato seedlings due to seed priming treatments but these differences were not always detectable at harvest and the authors suggested that this may have been because low soil temperatures recorded during seedling emergence may have affected seedling development more severely in the early-emerging treatments than in the late-emerging treatments.

Barlow & Haigh (1987) recorded earlier emergence of seedlings from 'primed', as compared to untreated, tomato seeds and these differences persisted during early vegetative growth and flowering of the crops. In each of two growing seasons, earlier maturity of primed treatments was recorded for early-sown crops but not for crops sown later in the season. Alvarado, Bradford & Hewitt (1987) also recorded earlier and more uniform emergence of tomato seedlings from primed seeds than of seedlings from untreated seeds. The advantage of earlier emergence persisted throughout vegetative growth and at flowering but was not reflected in earlier fruit maturity - possibly because of a reduction in early fruit set due to high temperatures at flowering. These results illustrate that, in the absence of absolute knowledge of the factors influencing the ontogeny of a tomato crop, the commercial value of treatments which result in moderate advances in the early growth of the crop can only be assessed by experiments in which the plants are grown through to commercial maturity.

#### 2.4.3.3 Uniformity and yield

There are two likely explanations for the fact that the visually greater uniformity of the module-raised transplants, as compared to the bare-root transplants, at transplanting and during the early stages of establishment in the field was not reflected in a greater concentration of maturity. Dry weight data for individual plants were not recorded at either the transplanting or the establishment harvests and the difference in uniformity between the two treatments may not have been as great as it appeared visually. The second possibility is that variation amongst plants was of negligible importance in comparison to other components of variation in the maturity times of individual fruits. This aspect is considered further in the discussion of the observed overall patterns of yield and maturity which follows (2.4.4).

## 2.4.4 Practical implications of the observed patterns of maturity and yield

### 2.4.4.1 Pattern of yield with time

One important result of the current experiment is the sharp peak of process grade fruit yield with time (Fig 2.1). Due to a lack of published data, it is not known whether such a sharp rise and fall in marketable yield with time is typical of determinate tomato crops in New Zealand.

Large changes in once-over ripe fruit yields between 3 harvests spaced at 5-day and 7-day intervals were recorded at Hastings and Levin by Bussell (1971) but his experiments were conducted using soft-fruited cultivars with supposedly poor vine storage characteristics compared to modern processing tomato cultivars. Green (1981) used a series of once-over harvests to assess yields from an experiment at Palmerston North involving the hard-fruited cultivar 'Castlong'. However, little information can be drawn from her results because of the wide harvest interval used (four harvests at fortnightly intervals). From a series of harvests at 7-day intervals, using cv. 'Castlehy 1204 Improved' established from module-raised transplants, Fisher & Julian (1988) recorded a pattern of red fruit yield with time similar to that recorded in the current experiment. Red fruit yields rapidly increased before, and rapidly declined after, a relatively short period where near-optimum yields were available. Their results indicate a period of approx. 10 days where yields were within 10% of the optimum yield were available at Palmerston North (a cooler climate than at Hastings).

Some overseas data demonstrate rapid accumulation of yields immediately prior to a final once-over harvest: for example, once-over yields of ripe fruit from plants of cv. 'C-17' grown in single-row and twin-row beds at 35 880 plants ha<sup>-1</sup> increased by 11 and 23 t ha<sup>-1</sup>, respectively, over an eight-day period in Indiana (Wilcox, 1970). Data from 4 experiments using cv. 'UC 82B', presented by Barlow & Haigh (1987), indicate mean rates of increase of yield of ripe fruit of up to 4 t ha<sup>-1</sup> day<sup>-1</sup> over the 15 days prior to final harvest. However, there are few data available which indicate the pattern of decline of yield after the optimum once-over harvest date.

A further complication arises from the fact the tomato crops for mechanical harvesting in New Zealand are often treated with the ethylene-generating chemical chlorethephon - (2-chloroethyl)phosphonic acid - before harvest to accelerate ripening of the fruit (Burgmans & Bussell, 1983; Nichols & Bussell, 1980; Anon., 1977; Bussell, 1971). Chlorethephon was not applied in the current experiment nor in the studies of Wilcox (1970) and Barlow & Haigh (1987).

In experiments concerning rates and timing of application of chlorethephon, results are commonly expressed in terms of the length of time required from treatment until an arbitrarily chosen 'optimum' harvest date and the percentage and/or yield of marketable fruit obtained at harvest (e.g. Bussell, 1973; Baqar, Edwards & Lee, 1975). Data are lacking on the effects of pre-harvest chlorethephon applications on the rate at which yield declines as individual fruits in the crop become successively over-mature.

Treatment with chlorethephon when 15 % of the fruits were coloured and 55 % were mature green accelerated ripening and resulted in an increase in the percentage of process grade fruit obtainable at a single harvest of the soft-fruited cultivar 'VF145-B7879'. For cv. 'Castlong', a cultivar with thick-walled fruit, application of chlorethephon at the same stage of maturity accelerated ripening and increased the length of time over which the optimum or near-optimum percentages of process grade fruit were obtainable at a single harvest (Bussell & Halligan, 1982). However, these results were obtained in controlled climate rooms with plants which were pruned to a single shoot.

Plants of cv. 'Castlong' grown in the field at Hastings were treated with chlorethephon by Bussell (1982a) when 19 % of the fruit by number (22 % by weight) were of the process grade. Maximum percentage process grade fruit was reached in early March (similar to the current experiment) but the extended period of % process grade fruit being within 5 % of the maximum, as reported by Bussell & Halligan (1982), was not observed. No comparisons with untreated plants were made.

Dostal & Wilcox (1971) present generalised crop maturity patterns for chlorethephon-treated and untreated crops of cv. 'Campbell 28' based on 2 years' experiments in Indiana. Their data indicate that chlorethephon application could be used to advance the optimum harvest date and to increase once-over yields but also that the decline in yield after optimum harvest was more rapid when chlorethephon was used.

The 'yield plateau' reported by Bussell & Halligan (1982) for chlorethephon-treated plants of cv. 'Castlong' may have been an artefact of the way that the plants were managed (pruned to a single shoot). Thus, there are no published data available to suggest that the pattern of maturity observed in the current experiment is not typical of tomato crops in the Hastings district and the results of Dostal & Wilcox (1971) suggest that had chlorethephon been applied to the crop then the peak of process grade fruit yield with time might have been even more pronounced. This has important implications for research into, and commercial production of, the processing tomato crop in New Zealand.

#### 2.4.4.2 Implications for yield assessments in tomato field research

A range of cultural factors are accepted as affecting the time of maturity of the tomato crop, for example: choice of cultivar (Burgmans & Bussell, 1983); crop establishment treatments (Bussell & Burgmans, 1983); applications of ripening agents (Bussell, 1973; Sims, 1969; Robinson et al., 1968); crop nutrition (Rudich, 1979); and plant spacing (Nichols, Nonnecke & Phatak, 1973; Fery & Janick, 1970, 1971). With the exception of the three references regarding plant spacing, in all of the above reports the destructive harvest dates of plants of the different treatments were chosen subjectively by the experimenter(s) with no attempt to

objectively determine the optimum harvest date for each replicate of each treatment. Thus, for each of these crops - and for the plant spacing experiments of Bussell, Wraight & Burgmans (1975), Zahara & Timm (1973), and Zahara (1970) - reported estimates of differences in treatment maturity times and yields will typically be biased. The results of the current experiment indicate that yield of process grade fruit changes rapidly with the time about the optimum harvest date and hence the magnitude of the bias of estimates derived from experiments in which harvest dates are determined subjectively is likely to be large. The magnitude of the bias is likely to be independent of experimental error (i.e. the bias may be large when the experimental error is small). This is a problem which needs to be addressed if meaningful estimates of the effects of cultural treatments on the optimum yield and maturity date of processing tomato crops are to be obtained.

The most desirable methods of obtaining once-over yield data free from bias are those which require the least additional outlay of resources, e.g. those which require a single plot of each treatment in each replicate of an experiment. For some crops, yields can be adjusted for maturity differences: for example, 'tenderometer' readings are an accepted measure of state of maturity in vining peas and can be used to adjust yield data prior to analysis (e.g. Martin, 1981) or used as a covariate in an analysis of covariance (e.g. Steel & Torrie, 1980, p. 402-403).

However, there is no established relationship between yield and any 'state of maturity' variable for the determinate tomato crop. If, for a given set of cultural conditions, the mean weight of individual fruits and the percentage of fruits in the marketable range at optimum harvest date can be shown to be relatively constant then the optimum once-over yield could be reliably estimated by collecting data on fruit numbers at a single, non-optimal harvest date. However, for experiments involving treatments which affect the maturity pattern as well as once-over yield one or both of these assumptions is likely to be violated.

Swain (1980) used a 'maturity index' - derived by expressing weight of process grade fruit as a percentage of process grade plus green fruit - obtained at a single

early harvest, where the number of rotten fruit was negligible, to assess the effects of herbicide and establishment treatments on the maturity of tomatoes. However, although such a maturity index, based on data from a single non-optimal harvest, may give an easily obtained ranking of maturity times for a set of treatments, this method provides no estimates of any differences in time to optimum harvest or of any differences in yields at optimum harvest unless a series of harvests are taken.

Maturity indices based on the number (e.g. Borkowski, Czapski & Horbowicz, 1983; Bussell & Halligan, 1982; Baqar, Edwards & Lee, 1975) or weight of marketable fruit (e.g. Burgmans & Bussell, 1983; Wolfe & Sims, 1982; Baqar, Edwards & Lee 1975; Bussell, 1973; Sims, 1973) as a percentage of the total yield have often been used as the sole assessments of field experiments with the tomato crop. The presentation of maturity indices without their corresponding absolute yields may be misleading under some conditions: for example, in the current experiment the maturity index (based on either fruit weight or fruit number) increased between 7 March and 16 March harvests (Table 2.4) while mean yields of process grade fruit for both types of transplants declined markedly over the same period (Fig. 2.1). Hence, if maturity indices are to be used then they should be presented in conjunction with corresponding absolute yields or numbers of fruit (e.g. Edwards, Henderson & Saltveit, 1984; Swain, 1980; Bussell, 1971; Nicklow & Downes, 1971).

An effective approach to the problem of estimating once-over yields is that used by Wheeler & Salter (1974) for cauliflowers in which the crop was allowed to grow through to over-maturity and detailed records were kept of the state of maturity of individual curds over the harvest period. However, the large number of harvestable units produced per tomato plant and the difficulty of estimating yield without disturbing the plants make this an inappropriate method for large field experiments with tomatoes.

MacNab & Pennypacker (1981) proposed a 'repeat cumulative harvest method' as one means of following the pattern of 'once-over' yield of marketable fruit over the harvest maturity period in tomato field experiments. In this method, repeated harvests of individual fruits are taken from each of two sub-plots per treatment

replication: in one sub-plot fruits which have attained a commercially acceptable stage of maturity are harvested; in the other sub-plot, fruits are harvested as they become over-mature. Fruits are weighed and counted as they are harvested and estimates of 'once-over' yield and fruit number for each harvest date can be derived from sub-plot differences in cumulative fresh weight and number of fruits respectively. The principal advantages of this method are that it allows an unlimited number of harvesting occasions from a limited experimental area and the labour requirement for individual harvests is relatively low.

However, this method is subject to some important possible sources of error: the most important being that the removal of fruits as they mature is likely to affect the pattern of maturity and/or the size of subsequently maturing fruits. Thus, optimum 'once-over' harvest date, marketable fruit number and marketable fruit yield at 'once-over' harvest calculated by this method are likely to be biased.

Several other assumptions of this method also require verification: for example, the assumption is made that the weight of an individual fruit does not change from the time that it first reaches maturity until it passes out of the desired maturity range. Hence, before the method proposed by MacNab & Pennypacker (1981) could be adopted it would require direct comparison with results obtained from multiple destructive harvests. If accurate estimates of optimum yields and maturity times in field experiments with processing tomatoes are to be obtained then the multiple destructive harvest method used in the current experiment would currently appear to be the only reliable option.

Given the maturity pattern depicted in Fig. 2.1, four harvests spanning a two-week period centred about the optimum yield date would probably provide sufficient information for most purposes. Optimum yields and harvest dates estimated from manual plots of the data could then be analysed statistically. Although not completely objective, this method would represent a considerable improvement over single-harvest methods. Complete removal of all bias could be achieved, if deemed necessary, by fitting mathematical functions to the data. Optimum harvest dates and yields could then be estimated from parameters derived from the fitted functions and then subjected to analyses of variance. The latter method was

originally proposed for the current experiment. However, when a plot of the means (Fig. 2.1) revealed the lack of differences in yield and maturity times between the two types of transplants further analysis was considered unnecessary and alternative analyses (2.2.5.3.3) were used to facilitate discussion of the entire observed maturity pattern.

Further complications arise in conducting tomato field experiments if chlorthephon is to be used to hasten fruit ripening in the experimental plots. To avoid bias, it is necessary that application of chlorthephon be made at the same stage of maturity for all treatments. Accurate estimation of the appropriate stage would require provision for additional harvests, but counts of red, pink and mature-green fruits on several plants of each treatment would possibly suffice.

#### 2.4.4.3 Implications for commercial crop production and direction of field research

In terms of commercial application, the observed maturity pattern (Fig. 2.1) is important in that it is difficult to judge accurately by eye the optimum maturity date for a plot of tomato plants in the field and the results depicted in Fig. 2.1 indicate that the cost of inaccurate estimation of the optimum harvest date may be quite high. For example, from Fig. 2.1 it can be seen that a yield loss of c. 20 t ha<sup>-1</sup> would result if the crop was destructively harvested 8-9 days too early or too late. Thus, any possible advantage gained by improved crop management could easily be lost due to the selection of a non-optimum harvest date.

Even if an accurate method of predicting or assessing the optimum harvest date were available, the difficulties associated with unpredictable weather patterns and scheduling of harvest labour and machinery would need to be overcome to ensure that the crop was harvested on the optimum harvest date. Hence, in the commercial situation, rather than improved methods of predicting or assessing the optimum harvest date what is required are changes to the genetics and/or culture of the crop which will lengthen the period over which optimum or near-optimum yields are obtainable.

Two principal factors contribute to the once-over yield/maturity pattern of a tomato crop: (i) the spread of time over which individual fruits in the crop reach a commercially acceptable stage of maturity; and (ii) the length of the 'vine storage' period for individual fruits i.e. the length of time over which individual fruits remain in a commercially acceptable maturity range on the plant in the field. Attempts to improve the uniformity of maturity of individual fruits - and, hence, once-over yield - will be of little commercial value without adequate vine storage to ensure that optimum or near-optimum once-over yields can be achieved over a range of potential harvest dates. The importance of variation in the maturity of fruits in determining once-over yield decreases as vine storage of mature fruit increases.

There are no data available which give any indication of the length of the vine storage period of individual fruits in a tomato crop under Hastings field conditions. Unfortunately, buffer plants bearing fruits marked for this purpose in the current experiment were destroyed by a tractor wheel before records of vine storage were collected. However, an indication of the length of the vine storage period early in the maturity period of the crop is given by the fact that the first fruit of process grade maturity were observed on 8 January and, with the exception of three fruits at the 3 February harvest, no rotten fruit were recorded until 10 February. Hence, it would seem that vine storage of individual fruits is probably adequate and that the key to increasing once-over yields and extension of the time period over which high once-over yields are available lies in the reduction of the variability in the time at which individual fruits first enter the marketable maturity range.

The potential for improved yields through reductions in the variability of the maturity times of individual fruits can be demonstrated by calculations based on fruit numbers recorded from four of the experimental blocks at the 3 February harvest (Table 2.4). No rotten fruit were recorded in the plots from which these counts were taken, thus the total (process grade plus green) number of fruit recorded can be assumed to represent the total number of fruit set by the plants to that date. The overall mean number of fruit per 8-plant plot recorded at the 3 February harvest was 664 (Table 2.4) and the mean fruit fresh weight of fruits

of the process grade at the date of maximum yield (7 March) was 51.5 grams. The potential yield if the maturity of all of the fruit set could be condensed sufficiently that all fruits were within the process grade at a single harvest can be estimated as follows:

$$\begin{array}{rclcl} \text{mean no. fruit/plot} & \times & \text{mean process grade fruit weight} & = & \text{potential yield} \\ 664/\text{plot} & \times & 0.0515 \text{ kg} & & = 34.2 \text{ kg/plot} \end{array}$$

This is the equivalent of a yield of 142.5 tonnes per hectare and is approximately twice the overall mean yield of process grade fruit recorded on the date of maximum yield (7 March).

The variability in the date at which individual fruits, within a tomato planting in the field, reach a defined maturity stage has several components. One source of variation is due to the fact that not all fruits which eventually attain maturity are set on the same date. Among fruits set at the same time, there is variation in the time taken to reach maturity (Davis et al., 1969).

Davis et al. (1970) present hypothetical examples of how changes in the magnitude of these two sources of variation might influence the overall pattern of fruit maturity in a tomato crop. A further potential source of variability not considered by Davis et al. is that occurring amongst plants within a planting of the crop i.e. variation in the time that individual plants commence the reproductive phase of development.

The relative importance of each of the above components in determining the overall maturity pattern of the crop will be dependent upon the cultivar used and the environmental conditions under which the crop is grown. However, where data are gathered which provide some quantitative assessment of the magnitude of each of these components then, using an approach similar to that of Davis et al. (1970), it should be possible to make rough predictions of the effect on the overall distribution of crop maturity - and, hence, once-over yield - of a change in the magnitude of one or more of the components of variation. Hence, an assessment could be made of changes to the culture of the crop which would be

most likely to bring about an increase in the uniformity of crop maturity.

Once the important sources of variation are identified, then research effort could be directed at estimating the costs and benefits of reducing them. In the long term, genetic manipulation of the tomato plant has the potential to reduce all of the sources of variation discussed above; however, there are a range of cultural treatments which might be worthy of investigation in efforts to reduce one or more of the components of variation in currently existing cultivars.

Variation amongst plants in the time at which they commence reproductive growth could probably be reduced by the use of treatments giving more uniform establishment of the crop in the field. For the direct-seeded crop suitable treatments might include the use of pre-germinated, as compared to raw, seed. Where the crop is transplanted, then a reduction in the variation among plants might be achieved by the use of module-raised, as compared to bare-root, transplants.

The similarity of the maturity patterns for the two transplant types in the current experiment (2.4.3.3) suggests that among-plant variation may have been a relatively unimportant component of the overall variation in maturity of individual fruits in the conditions under which the experiment was grown. However, variation among plants might have a greater influence on the harvest pattern where establishment conditions are more stressful than in the current experiment or if the crop is grown at high plant densities (Nichols, Nonnecke & Phatak, 1973).

Although there is little published information regarding the relative importance of fruit set and fruit maturity rates in determining the maturity pattern of tomato crops in the field, there are some reports of cultural techniques which might be useful in reducing one or more of these components. For example, Mutton (1978a,b) has demonstrated that variation in the time from anthesis to maturity of tomato fruits set at about the same time can be reduced by application of chlorthalipron.

In addition to variation about a mean maturity time amongst fruits set at the same time, there is a further fruit development rate component which can affect the relationship of maturity patterns to fruit set patterns: the mean rate of maturation of successively initiated fruits may be progressively slower (resulting in increased spread of maturity dates) or progressively faster (resulting in a concentration of the harvest pattern).

Data recorded by Davis et al. (1969), indicate that the typical pattern may be one of progressively increasing mean times to maturity and increasing variability about the mean in successively initiated groups of fruits. These increases were particularly associated with the early growth of fruits rather than during their subsequent maturation. Davis et al. (1969) attributed this pattern to the effect of developing fruit load.

A progressive acceleration of mean maturation rate will have the same effect on the overall maturity distribution as a decrease in the variation of dates of fruit set. Hence, cultural treatments which tend to produce a progressive acceleration of maturation rate - such as application of chlorthaliphyron (e.g. Mutton, 1978 a,b; Borkowski, Czapski & Horbowicz, 1983) - may be used to moderate the effect of variation in fruit set on the overall maturity distribution, or to counteract the pattern of progressively decreasing growth rates and increasing variability observed by Davis et al. (1969). However, in light of the conflicting results of Bussell & Halligan (1982) and Dostal & Wilcox (1971), the effect of chlorthaliphyron application on the pattern of decline of yield after the optimum level of once-over yield is first attained requires further investigation with plants of modern tomato cultivars grown in the field (2.4.4.1). One other possible means of reducing this source of variability would be to use applications of plant growth substances to reduce late-season vegetative and/or reproductive growth and hence reduce competition with maturing fruits for assimilates (Frost & Kretschman, 1987; Read & Fieldhouse, 1970).

Plant spacing has frequently been reported as influencing maturity time and once-over yields of mature tomato fruit (e.g. Sims & Rubatzky, 1979; Dostal & Wilcox, 1971; Nichols, Nonnecke & Phatak, 1973; Crowder, 1970). It is generally

accepted that increasing plant density results in a reduction in the number of trusses per plant contributing marketable fruit at once-over harvest (Frost & Kretchman, 1988; Zahara & Timm, 1973; Fery & Janick, 1970) and a reduction in the overall variation of time of fruit set among individual fruits. The end result being a greater percentage of fruit of marketable maturity at optimum once-over harvest. It is possible that the effect of plant spacing on the crop maturity pattern is due not only to the decreased variation in fruit set but also to a concomitant reduction in variation of mean maturation rates of individual fruits, i.e. that uniform fruit set may reduce the 'developing fruit load' effect (Davis et al., 1969) on maturation rates.

Where plant spacing alone is used to control the uniformity of fruit maturation the plant populations required to obtain maximum once-over yields are often much higher than those typically considered acceptable in commercial practice (e.g. Green, 1980; Nichols, Nonnecke & Phatak, 1973; Nicklow & Downes, 1971). A useful compromise may be the use of intermediate plant densities to obtain moderately uniform fruit set followed by the use of chlorthalipron to enhance the concentration of maturity (Bussell, Wraight & Burgmans, 1975).

A potential technique for improving once-over harvest yields and the optimum harvest period is the application of inhibitors of ethylene synthesis or action to retard ripening of the most advanced fruits while allowing continued development of immature fruit to the mature-green stage (Edwards, Henderson & Saltveit, 1984). Chlorthalipron applications could then be used to induce ripening. This approach would allow maximum utilisation to be made of the vine storage of a high proportion of the fruit set by the crop to provide high once-over yields over an extended period of time.

## CHAPTER 3

### FIELD EVALUATION OF TYPES OF GREEN SPROUTING BROCCOLI TRANSPLANT

#### 3.1 Introduction

The use of transplants to establish broccoli crops for processing in the Manawatu is likely to remain commercial practice. The objective of the study described below was to determine whether module-raised transplants produced in a greenhouse might offer advantage(s) over the traditional system of using bare-root transplants grown in outdoor seed-beds.

Greater control of environmental conditions in a greenhouse, compared to an outdoor seed-bed, should result in a reduction in seed requirements and a more uniform line of plants for transplanting. Production of transplants at a required stage of development is more readily programmed when the plants are raised in modules in a greenhouse and, should transplanting be delayed, plants can be 'held' at a stage suitable for transplanting whereas there is limited scope for controlling the growth of seedlings raised in seed-beds. It is also considered that establishing a broccoli crop from seedling transplants raised in modules in a greenhouse may reduce the time period over which the crop occupies the field and might also result in a reduced spread of maturity due to more uniform growing conditions prior to transplanting and/or a less severe and less variable check to growth at transplanting.

A reduction in the length of time that a crop spends under uncontrolled conditions in the field would have obvious advantages in terms of programming the maturity of the crop. At present broccoli is not mechanically harvested in the Manawatu district, nevertheless increased uniformity of maturity is desirable as this would reduce harvesting costs through a decrease in the number of passes that harvesting crews would have to make.

The two experiments described in the following sections were designed to evaluate the field performance of broccoli plants established from bare-root and module-raised transplants which had been produced under both field and greenhouse conditions. An observational experiment and a fully replicated experiment were planted on the same day using the same planting material. The observation experiment examined the growth of the plants from the time of transplanting until 32 days after transplanting. The main experiment examined the effects of the establishment treatments on the maturity characteristics, yield and quality of the crop.

## **3.2 Materials and methods**

### **3.2.1 Selection of cultivar and treatment of seed**

The F<sub>1</sub> hybrid cultivar 'Premium Crop' was used in these experiments as it was recommended by Bussell (1984b) as being suitable for summer production and was also considered acceptable for both fresh market (Bussell, 1984a; Bussell & Dobson, 1985) and processing (Bussell, 1983; Hutchison, Ferguson & McErlich, 1985).

Seed was size graded and the median grade (2.007 to 2.616 mm), which comprised 97% by weight of the original seed lot, was used. All seed was dusted with a fungicide containing captan (Appendix 5.2) prior to sowing.

### **3.2.2 The treatments**

In order to produce 'commercially acceptable' bare-root transplants raised in outdoor seed-beds and module-raised transplants produced in a greenhouse for the same transplanting date, it was necessary that there be two sowing dates - an early one in the field and a later one in the greenhouse. To allow comparisons to be made, between bare-root and module-raised transplants, unconfounded by the effects of differing (chronological and physiological) ages and raising environments (field versus greenhouse) two further treatments were added. These were bare-root transplants raised in the greenhouse and module-raised transplants produced in the field.

A fifth treatment was included, in which module-raised transplants produced in the greenhouse had the growing medium carefully washed from their roots immediately prior to transplanting. This treatment was included to examine the value of growing medium around the roots in transplant establishment when there was minimal root damage at transplanting.

The treatments used are outlined in (i) to (v) below. A single batch of each type of plant was raised and provided material for both the observation experiment and the main experiment.

Field-raised transplants:

- (i) Bare-root transplants raised in a seed-bed of fertilised soil (3.2.3.1.1) - hereinafter referred to as the field bare-root treatment.
- (ii) Module transplants raised in trays containing peat:sand medium with nutrient solution applied daily (3.2.3.1.2) - field module treatment.

Greenhouse-raised transplants:

- (iii) Bare-root transplants raised in a seed-bed of fertilised soil (3.2.3.2.1) - greenhouse bare-root treatment.
- (iv) Module transplants raised in trays containing peat:sand medium with nutrient solution applied daily (3.2.3.2.2) - greenhouse module treatment.
- (v) Seedlings raised as in (iv) above, except that peat:sand medium was washed gently away from the root system immediately prior to transplanting. Hence, seedlings were transplanted with bare roots but with minimal root damage - greenhouse washed treatment.

### 3.2.3 Methods of raising transplants

#### 3.2.3.1 Field-raised transplants

##### 3.2.3.1.1 Sowing of field seed-bed

The method of raising bare-root transplants was based on the commercial recommendations of Wood (1977) and Geelen (1984a). The transplants were produced and the experiments were conducted on a site at the horticultural field plot area at Massey University. The soil type at this site is a Karapoti brown sandy loam.

On 3 September 1984, an area of ploughed land (10 m x 2.5 m), was cultivated with a rotary hoe to produce a fine tilth to a depth of 200 mm. A base dressing of fertiliser (Appendix 4.1) had been applied prior to rotary hoeing. Soil was raked up to form a slightly raised seed-bed. The following day the seed-bed was sealed with polythene sheeting and fumigated with methyl bromide (Appendix 5.1). After two days the fumigated area was ventilated but the polythene sheet was left covering the area until seed sowing as a means of reducing leaching of nutrients, reinfestation by weed seeds and soil capping.

The surface of the seed-bed was raked to produce a level surface and a fine tilth and, on 2 October, single seeds were sown to a depth of  $20(\pm 5)$  mm in eight 2.6 m long rows. The rows were 150 mm apart and seeds 10 mm apart in the rows. Seeds were counted as they were sown and plastic labels were used to divide each row into sections containing a known number of seeds.

#### 3.2.3.1.2 Sowing of field seedling trays

Module-raised transplants were produced in 'Plixipot' plastic seedling trays (Plix Products Limited, Hastings). The trays were 555 x 300 mm and consisted of 77 compartments ( $462 \text{ plants m}^{-2}$ ) each containing  $36 \text{ cm}^3$  of growing medium. The growing medium consisted of 60:40 (by volume) of sieved (6 mm mesh) sphagnum peat moss:coarse washed river sand, with agricultural lime ( $1.5 \text{ kg m}^{-3}$ ) and dolomite ( $3.0 \text{ kg m}^{-3}$ ) incorporated. The medium was fumigated with methyl bromide (Appendix 5.1) and then ventilated for 10 days prior to use.

On 2 October 1984, two seeds per compartment were sown. The double sowing of seed was considered necessary because a trial sowing of cv. 'Premium Crop' in peat:sand medium had achieved a final emergence of only 47%. Seeds were sown to a depth of 20 mm and then covered with sieved growing medium. Twenty trays were sown and were then placed on the fumigated seed-bed adjacent to the area sown for bare-root transplant production (3.2.3.1.1).

### 3.2.3.1.3 Management of field-raised seedlings

The two treatments were watered immediately after sowing and watering was then carried out as required (up to twice per day) to maintain the soil/peat:sand medium close to field/container capacity. After emergence, the seedlings in the seedling trays were always irrigated using a complete nutrient solution (Appendix 1). Seedlings growing in the seed-bed were irrigated with water only.

Final seedling emergence counts for both field sowings were made and module-raised transplants were thinned to one plant per module 18 days after sowing. Where two seedlings had emerged in a module, the seedling furthest from the centre of the module was removed: no size grading of the seedlings was carried out.

The pesticide programme used in raising the transplants is detailed in Appendix 5.3. Transplants growing in the seed-bed and trays were protected from wind, birds and rabbits by a shade-cloth/bird-netting enclosure and an electric fence (Plate 3.1). The stages of development of seedlings of the field bare-root and field module treatments on 23 October (21 days after sowing) are illustrated in Plates 3.2 and 3.3, respectively.

### 3.2.3.2 Greenhouse-raised transplants

#### 3.2.3.2.1 Sowing of greenhouse seed-bed

On 3 October 1984, soil was dug from a cultivated, fertilised seed-bed (3.2.3.1.1) in two layers (0-80 mm and 80-160 mm) and placed in a wooden box (internal dimensions: 3.23 m x 1.45 m x 0.16 m). The box was supported at bench height in a greenhouse (Plate 3.4). The box containing the soil and metal bins containing peat:sand growing medium for greenhouse module-raised seedlings (3.2.3.2.2) were sealed with polythene sheeting and fumigated with methyl bromide (Appendix 5.1). After 24 hours the polythene sheet was unsealed and left loosely covering the box and bins for 14 days prior to seed sowing.

The surface of the soil in the box was hand raked to produce a level surface and a fine tilth. On 19 October 1984, seventeen days after the field sowing, seed was sown by the same method as was used for the bare-root transplants in the field (3.2.3.1.1).

#### 3.2.3.2.2 Sowing of greenhouse seedling trays

Forty 'Plixi-pot' trays (3.2.3.1.2) of transplants were produced in the greenhouse on a drained capillary bench adjacent to that supporting the box of soil (3.2.3.2.1). On 19 October 1984, two seeds per module were sown by the same method as was used for the module-raised transplants produced in the field (3.2.3.1.2).

#### 3.2.3.2.3 Management of greenhouse-raised seedlings

Watering of these treatments was carried out immediately after sowing and then as required (up to twice per day) to maintain the respective substrates close to field/container capacity. After emergence, plants in the trays were always irrigated using a nutrient solution (Appendix 1). Final seedling emergence counts for both greenhouse sowings were made and seedlings in the trays were thinned to one plant per module 15 days after sowing (3.2.3.1.3).

The greenhouse was heated to 16 °C with fan-assisted ventilation operating at  $\geq 22$  °C. On occasions the greenhouse air temperature reached 32 °C at bench level. The pesticide programme used during raising of the transplants is detailed in Appendix 5.3.

### 3.2.4 Transplanting of seedlings and maintenance of experiments in the field

#### 3.2.4.1 Introduction

Seedlings raised by the five methods outlined in Section 3.2.3 provided plant material for the two field experiments. Methods of preparing seedlings for transplanting (3.2.4.3) and method of transplanting (3.2.4.4) were identical for the two experiments. Experimental design and methods of data collection and analysis differed between the experiments (3.2.5).

### 3.2.4.2 Preparation of experimental area prior to transplanting

An area of ploughed land (50 m x 10.5 m), adjacent to the site where the field-raised transplants were produced, was prepared for transplanting of the field experiments. Based on the results of a soil test, a base dressing of lime and fertilisers (Appendix 4.2) was applied to the experimental area on 26 October 1984 and incorporated to 0.25 m using a tractor-mounted rotary hoe.

On 7 November 1984, a herbicide containing trifluralin (Appendix 5.3) was applied to the fertilised area and incorporated into the soil to a depth of 100-150 mm using a rotatiller. On 13 November 1984, seven 50 m long beds (1.5 m centre-to-centre) were marked out using a tractor and urea was broadcast over the experimental area at a rate of 217 kg ha<sup>-1</sup> (100 kg N ha<sup>-1</sup>). An irrigation after transplanting was used to move the urea into the soil (3.2.4.4).

### 3.2.4.3 Preparation of seedlings for transplanting

#### 3.2.4.3.1 Transplanting date

Plant material for both experiments was transplanted into the experimental area on 14 November 1984: 43 and 26 days after sowing of the field-raised and greenhouse-raised treatments, respectively. No specific 'hardening' treatment was given to any of the transplants. On the day of transplanting plants of each treatment were prepared for transplanting as outlined in the following sections. Sufficient seedlings were left undisturbed in their respective propagation sites to allow sampling for 'Harvest 1' of the observation experiment (3.2.5.2.1).

#### 3.2.4.3.2 Field-raised bare-root transplants

The outside rows of the seed-bed were not used in the experiments. The six remaining rows of seedlings were lifted, as required, using a spade inserted approximately 150 mm under the soil surface. Seedlings were pulled from the disturbed soil by hand. Soil adhering to the roots after shaking was removed by plunging the roots into a tank of water: overnight rain (6 mm) had dampened the soil and not all soil was removed by shaking alone.

#### 3.2.4.3.3 Field-raised module transplants

To leach mineral nutrients from the peat:sand medium, modules were drenched with water, twice within the 24 hours prior to transplanting. Seedlings were withdrawn from the trays and transplanted with modules intact.

#### 3.2.4.3.4 Greenhouse-raised bare-root transplants

The outside rows of the seed-bed were not used in the experiments. The six remaining rows of seedlings were lifted, as required, using a spade inserted approximately 150 mm under the soil surface. Seedlings were pulled from the disturbed soil and soil adhering to the roots was removed by shaking.

#### 3.2.4.3.5 Greenhouse-raised module transplants

To leach mineral nutrients from the peat:sand medium, modules were drenched with water, twice within the 24 hours prior to transplanting. Seedlings were withdrawn from the trays and were treated in two ways. In one treatment, seedlings were transplanted with modules intact (greenhouse module treatment); in the other, the growing medium was washed from the roots in a tank of water and the seedlings were transplanted with undamaged, bare roots (greenhouse washed treatment).

#### 3.2.4.3.6 Selection of seedlings for transplanting

The nature of the treatments did not allow the randomisation of the experimental design used in the field to be maintained during the raising of the seedlings. To remove any possible 'edge' effect, plants from the outside rows and buffer areas at the ends of the seed-beds in the field, and in the greenhouse, were not transplanted. Similarly, seedlings raised in modules around the edges of individual trays in the greenhouse were used in buffer areas in the field experiments: plants from which data were to be recorded were taken from the centres of the trays.

The stages of development of plants of all treatments at the time of transplanting are illustrated in Plates 3.5 and 3.6. Growth of seedlings in each of the above-mentioned propagation areas was visually uniform and very few plants were considered unsuitable for transplanting. However, some selection of plants grown in modules in the field was required due to variable damage caused by an infestation of leafmining agromyzid flies (probably *Liriomyza* sp.). Symptoms on cotyledons and on first true leaves were first diagnosed 27 days after sowing when the seedlings in the affected treatment were at the 3 true leaf stage. Plants in the adjacent seed-bed were not visibly affected. Following identification of the pests, applications of a chlorpyrifos insecticide (Appendix 5.2) gave excellent control and the problem did not persist after transplanting.

#### 3.2.4.4 Method of transplanting

Plants were transplanted by hand to a depth such that the cotyledons were 0-10 mm below the surface of the soil. A square plant arrangement was used: there were four rows per bed, rows were spaced 250 mm apart with 250 mm between plants in the row. Beds were 1.50 m centre-to-centre, with a tractor wheeling of approximately 300 mm between beds, resulting in an overall plant population of 106,667 plants per hectare (cf. 1.2.5). Planting of both experiments was completed over a seven-hour period and after the completion of planting 20 mm of irrigation was applied to the experimental area (Plate 3.7) using a perforated aluminium spray line which gave a uniform distribution of water in a rectangular pattern.

#### 3.2.4.5 Maintenance of experiments following transplanting

A herbicide containing alachlor (Appendix 5.3) was applied on 17 November 1984 and the sum of rainfall and irrigation within 10 days following application was sufficient to activate the herbicide. A soil water loss of 2.5 mm day<sup>-1</sup> was assumed throughout the experiment and irrigation was applied whenever the estimated soil water deficit approached 16 mm.

Pesticide applications to plants in the field are detailed in Appendix 5.3. An electric fence was erected around the experimental area to protect the plants from

attack by rabbits. No more serious pests or disease symptoms were noted and the level of weed control was such that no hand weeding was required. A general view of the two experiments in the field, four weeks after transplanting, is given in Plate 3.8.

### 3.2.5 Experimental design, data collection and data analysis

#### 3.2.5.1 Experimental design

Recorded plants of both experiments were contained in five four-row beds (3.2.4.4). The field area containing the two experiments was bounded on either side by a two-row bed of buffer plants and by a 1.0 m buffer area at the end of each bed. The two-row buffer beds were transplanted the day after planting of the experimental plots (Plates 3.7 and 3.8).

The observation experiment consisted of five parallel, unreplicated plots 15 m long (i.e. one 15 m length of bed per treatment). The outer rows of each plot were used as buffer plants and ten plants were harvested from the two inner rows of each plot on each harvest occasion (3.2.5.2.1). Harvesting commenced from one end of each plot and progressed systematically along the plot with two plants on the ends of the inner rows being used as buffer plants for each successive harvest.

The main experiment was arranged in a randomised complete block design with eight blocks. Each individual plot consisted of a 3.0 m long section of bed. The four plants at either end of each plot served as unrecorded buffer plants and data were recorded from the remaining forty plants in each plot.

#### 3.2.5.2 Data collection

##### 3.2.5.2.1 Collection of observation experiment data

Samples of ten plants were harvested, on four occasions, from each treatment (Table 3.1). The first harvest, taken one day after transplanting, was of seedlings selected at random from a group of 50 seedlings per treatment remaining undisturbed in their respective propagation sites. Harvests 2 to 4 were of plants which had been transplanted in the field. Data were recorded as described below.

Table 3.1 Dates of harvest for observation experiment (days from transplanting)

Treatment	Harvest number			
	1	2	3	4
field bare-root	1	12	22	31
field module	1	12	22	32
greenhouse bare-root	1	12	22	31
greenhouse module	1 <sup>a</sup>	12	22	31
greenhouse washed	1 <sup>a</sup>	12	22	32

<sup>a</sup> A single sample of 10 seedlings raised in modules in the greenhouse was taken at Harvest 1.

### Harvest 1

This harvest was carried out to give an assessment of the characteristics of seedlings at the time of transplanting. Seedlings raised in the seed-beds were lifted from the seed-beds in the same manner as seedlings transplanted into the field (3.2.4.3). Plants were harvested singly and data recorded for individual plants.

Roots were gently washed clean of substrate and blotted dry with tissue paper. A scalpel was used to excise tissue which had been located below the surface of the substrate - the excised tissue was recorded as 'roots'. The remainder of the plant was partitioned into 'stem' (main stem of the plant and leaf petioles), 'leaves' (leaf laminae) and 'apex' (the stem apical meristem and the small unexpanded leaves surrounding it).

The 'apex' was placed in a capped, labelled vial containing Kahle's fluid (Bradbury, 1973) to await preparation for microscopic examination. Leaves  $\geq 5$  mm in length (petiole and lamina) were counted and leaf area (laminae only) was measured on a photoelectric area meter (Li-Cor Model 3100). Fresh weights of all plant

components - except apices, which had negligible fresh weights - were recorded and the samples were stored in sealed containers at 5 °C, until the end of the day when the lids were removed from the containers and samples were dried in a large vacuum chamber (Haslemore, Warrington and Roughan, 1980). Samples were dried for 48 hours. On removal from the vacuum chamber, dried samples were equilibrated in an air-conditioned room (22 °C and 50% relative humidity) for 24 hours, then weighed.

#### Harvests 2 to 4

Plants for these harvests were taken from the two centre rows of beds in the field. Plants were carefully lifted from the soil using a garden fork. Plants were partitioned as for Harvest 1 except that the division between 'stems' and 'roots' was made at the cotyledonary node. Root fresh and dry weights were recorded for Harvest 2 only: it was not possible to separate the roots of neighbouring plants at later harvests (Plates 3.9 and 3.10). Leaf area was not recorded for Harvests 2 to 4 because the surfaces of the leaves were too undulate for a meaningful measure of leaf area to be obtained.

Leaf number was determined by counting leaves  $\geq 5$  mm in length (petiole and lamina) remaining on the plant plus leaf scars of leaves which had undergone senescence and abscission. Fresh and dry weights were recorded as for Harvest 1. Small lateral shoots had arisen by Harvest 3 and some of these had visible inflorescences on them by Harvest 4. But, as they were small (none of the inflorescences were greater than 10 mm in diameter), they were included as part of the 'stems'.

Stem apices of plants which did not have a terminal inflorescence  $\geq 2$  mm in diameter were placed in vials containing Kahle's fluid as for Harvest 1. At Harvest 4 some plants had terminal inflorescences  $\geq 2$  mm in diameter. These 'heads' were excised at the node of the last leaf without the base of a peduncle of the terminal inflorescence in its axil. The diameter ( $\pm 0.5$  mm) and fresh weight of each excised 'head' were recorded. For plants with a macroscopically visible head, leaf number was recorded as the number of the leaf at whose node

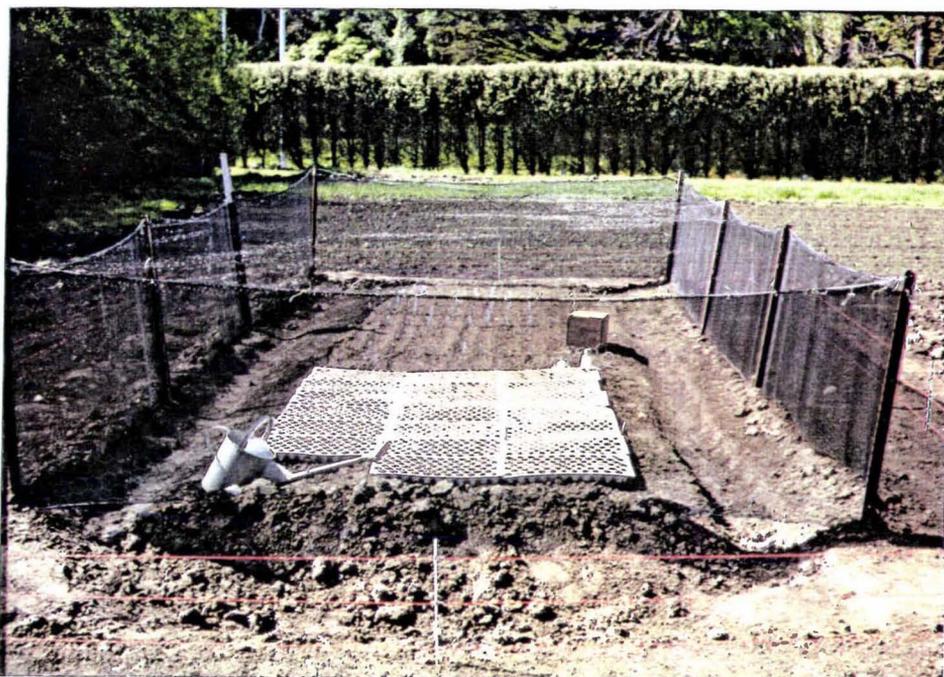


Plate 3.1 Enclosure in which field module (foreground) and field seed-bed (background) broccoli transplants were raised.



Plate 3.2 Broccoli seedlings of field seed-bed treatment on 23 October (21 days after sowing). Scale is in millimetres.



Plate 3.3 Broccoli seedlings of field module treatment on 23 October (21 days after sowing). Scale is in millimetres.



Plate 3.4 Broccoli seedlings of greenhouse seed-bed treatment emerging in seed-bed box on 23 October (4 days after sowing).



Plate 3.5 Stage of development of the two 'commercial' treatments - greenhouse module (left) and field seed-bed (right) - at Harvest 1 of observation experiment (1 day after transplanting date). Scale is in millimetres.



Plate 3.6 Stages of development of broccoli plants of all five treatments at Harvest 1 of observation experiment (1 day after transplanting date). Left to right: greenhouse module, greenhouse seed-bed, field seed-bed, field module, greenhouse washed). Scale is in millimetres.



Plate 3.7 End view of experimental area, following irrigation, on day of transplanting. Main experiment in foreground, observation experiment in background.



Plate 3.8 End view of experimental area 4 weeks after transplanting. Observation experiment in foreground and main experiment in background.



Plate 3.9 Broccoli plant of field-raised module treatment lifted from soil to show root growth 16 days after transplanting.



Plate 3.10 Broccoli plant of field seed-bed treatment lifted from soil to show root growth 16 days after transplanting.

the head was excised (see above). For all other plants leaf number was recorded as for Harvests 1 to 3.

#### Preparation and microscopic examination of stem apex samples

The terminal bud was excised from each plant at the node of the youngest leaf  $\geq 5$  mm in length and immediately killed and fixed in Kahle's fluid - an 18:1:1 (by volume) mixture of 50% ethanol:glacial acetic acid:40% formaldehyde (Bradbury, 1973, p. 215). The vials containing the samples were placed under vacuum to ensure that air pockets were excluded from the tissue.

After all samples had been collected and fixed, each sample was passed through a tertiary butyl alcohol (butan-2-ol) dehydration series (Berlyn & Miksche, 1976, p. 40) and embedded in paraffin wax (m.p. = 52.5 °C). Serial longitudinal sections were cut on a rotary microtome (Type 52164, Cambridge Medical Limited, Cambridge, U.K.) to a thickness of 7  $\mu$ m. Sections were mounted on to glass microscope slides using Haupt's adhesive (Berlyn & Miksche, 1976, p. 66-68). A safranin and fast green staining procedure (Johansen, 1940, p. 80-82) was used to stain the tissue before permanent mounting in D.P.X. synthetic mounting resin.

Complete series of sections were not mounted. Approximately every twentieth section in each series was examined by placing the section on black filter paper (Whatman No. 24) and melting the paraffin wax surrounding the tissue. The shape of the section of tissue was then visible against the black background. This allowed a rapid assessment to be made of the range of sections likely to contain the apical meristem. Several short ribbons (2-3 sections in length), approximately 20 sections (i.e. 140  $\mu$ m) apart, over the selected range were mounted and stained.

The stained samples were examined microscopically to determine the state of development of the apex and the leaf number and length of the last expanding leaf subtending the apex was recorded. Photomicrographs were taken of representative samples of each type of plant using a Nikon M-35 S camera on an Olympus microscope.

The full procedure described above was used only for samples collected at Harvest 1. Modifications made to the procedure for samples from the remaining harvests and reasons for modifying the procedure are presented with the results in Section 3.3.3.4.1.

#### 3.2.5.2.2 Collection of main experiment data

Individual terminal heads (inflorescences) were harvested when each was judged to be mature. The terminal head was cut from the plant leaving the remainder of the plant in place in the field: secondary (lateral) heads were not harvested. Plots were searched for mature heads every second day, commencing on 25 December 1984 (41 days after transplanting) when the first heads were judged to be mature. The criteria used in the subjective assessment of individual curd maturity are outlined in (i) and (ii) below.

##### (i) Individual flower bud size

When the largest flower buds within a head were 2.0-2.5 mm in width the head was harvested. If the head was not harvested at this stage, then the largest buds rapidly reached an over-mature stage at which the yellow petals were readily visible when the buds were prised open.

##### (ii) Stem elongation and cluster separation

Some heads did not conform to the normal pattern of development and the several clusters of buds, which together formed the head, began to separate before the largest buds reached 2.0-2.5 mm across (see Plate 3 of Thompson and Taylor, 1970). Heads following this pattern were harvested when it was considered that to allow them to continue growth until the next harvest occasion would result in a decrease in head quality.

Harvested heads were trimmed to a length of 150 mm from the apex of the head in accordance with local practice and published reports (Chung, 1982; Cutcliffe, 1975a,b; Bull, 1977, 1980). All leaves >10 mm in length were removed from the trimmed heads prior to weighing and fresh weights of individual heads were recorded.

Several precautions were taken to reduce likely sources of error in the fresh weight measurements:

- (i) all harvesting was carried out in the morning;
- (ii) large leaves were removed from each head as it was harvested;
- (iii) on removal from the field, the harvested heads were placed in a coolstore at 5 °C prior to weighing and grading;
- (iv) harvesting and post-harvest handling were carried out on a block-by-block basis in order to control variation.

Measurements taken from samples of harvested heads indicated that the fresh weight loss of individual heads between harvest and weighing under the conditions described above was of the order of 2 to 3 per cent of the initial fresh weight at harvest.

Individual head diameters (to the nearest 5 mm) were recorded. Quality characteristics (uniformity of bud size, cluster separation, head shape and branching angle) of the trimmed heads were scored according to Chung's (1982) modification of the criteria proposed by Chowings (1974). Harvesting of each plot was continued until the terminal head of every plant in the plot was harvested, or, until it was judged that no further heads would mature over the subsequent 7-day period.

The distance (750 mm) between plants in outside rows of adjacent beds was wider than the spacing of rows (250 mm) within the beds. Heads from the outside and inside rows of each plant were harvested and recorded separately. This was done because plants in outer rows of beds in field experiments with broccoli have been reported to produce heavier and larger heads than those in inner rows (Thompson and Taylor, 1976; Bussell, 1984b).

### 3.2.5.3 Data analysis

#### 3.2.5.3.1 Observation experiment

Due to the lack of replication and randomisation no sound estimates of the variance of plant characters were available. Standard errors were calculated using plant-to-plant variation within each ten-plant sample. Comparisons of means amongst samples may be biased because of systematic sampling. For ease of presentation, the standard errors of means for the greenhouse washed treatment only are presented in Figures 3.1, 3.2, 3.3 and 3.6. Standard errors for the other treatments were of a similar order of magnitude.

#### 3.2.5.3.2 Main experiment

Total head fresh weight (yield), number of heads harvested, average head fresh weight and average head diameter were calculated for each plot. The times of maturity of the fourth, twentieth and thirty-sixth heads to mature in each plot were calculated, by linear interpolation, from the raw data. The time at which the twentieth head matured (H20) in each plot (expressed as the number of days from sowing or transplanting) was used as the assessment of plot maturity time. The spread of maturity in each plot (expressed in days) was assessed as the difference between estimated maturity times of the fourth and thirty-sixth heads (H4TO36) to mature in each plot.

Rejection of data from some of the plots was necessary and the loss of data from the greenhouse module treatment was such that this treatment was not included in analyses of variance (3.3.4.1.1). Approximate analyses of variance were carried out on the remaining data using the GENSTAT 4.04B statistical computer program (Alvey et al., 1977). Missing values (3.3.4.1.1) were estimated by the program using an iterative procedure to minimise the residual sum of squares. Total and residual mean squares were calculated after deduction of degrees of freedom for missing observations.

Planned comparisons of treatment means were made using the unrestricted least significant difference procedure. For ease of presentation, 'approximate' least significant differences (lsd) between treatment means are presented in the table of results (Table 3.9). Each 'approximate' lsd is based on the standard error of the difference between the means of two treatments with no missing data. A battery of more precise lsd's for each analysis can be obtained by multiplying the 'approximate' lsd by the ratios presented in Table 3.2 which are based on standard errors of differences estimated by assigning an 'effective number of replicates' to each treatment in each comparison using the scoring system of Steel and Torrie (1980, p.213).

Table 3.2 Ratio of lsd's for specific comparisons of treatment means to 'approximate lsd' presented in Table 3.9

field bare-root	(1)	--			
field module	(2)	1.05	--		
greenhouse bare-root	(3)	1.05	1.00	--	
greenhouse washed	(4)	1.10	1.05	1.05	--
		(1)	(2)	(3)	(4)

Data for the inner and outer pairs of rows in each plot had been recorded separately in order to allow examination of possible differences between inner and outer rows of the beds (3.2.5.2.2). The maturity times (H10) of the tenth heads to mature in the outer rows and inner rows of each plot were calculated from the raw data by linear interpolation. Yields, numbers of heads harvested, average head weights and average head diameter were calculated for inside and outside rows of each plot.

Split-plot analyses of variance were carried out on these data, with transplant type (treatment) as the main-plot factor and row location (i.e. inner versus outer) as the sub-plot factor. The GENSTAT 4.04B computer program was used to analyse the data and missing values were estimated by the program. These 'split-plot'

analyses were not strictly valid: randomisation of row locations was impossible and, thus, no valid estimates of experimental error applicable to sub-plot comparisons were obtainable. Hence, presentation of measures of precision of the data from such analyses would be misleading. Therefore, where the results of the 'split-plot' analyses of variance are examined (3.3.4.1.3), the significance levels of the F-tests for the effects of row location and the row location x transplant type (treatment) interaction are indicated, means corresponding to any significant effect(s) are presented, but no further significance testing was carried out.

### 3.3 Results and discussion

#### 3.3.1 Seedling emergence, seedling densities and size of transplants

##### 3.3.1.1 Seedling emergence and densities

No attempt was made to closely match seedling densities for module and seed-bed raising methods because it was anticipated that differences in emergence levels might occur and because of the lack of prior knowledge of the likely magnitude of the effects of other factors - e.g. nutrition levels, volume of rooting medium - which varied between the seed-bed and module systems. Thus, the potential seedling population ( $462 \text{ m}^{-2}$ ) of the module-raised seedlings was determined by the type of seedling tray used whereas the sowing rate in the seed-bed ( $677 \text{ m}^{-2}$ ) was based upon commercial recommendations (Wood, 1977; Geelen, 1984a).

The level of seedling emergence exceeded 80% in all locations except in the modules in the field (Table 3.3). The lower level of emergence in the modules in the field may have resulted from the interaction of low temperature and physical characteristics of the peat:sand medium (Weaver, 1980). The mean daily minimum temperature recorded at the surface of the seed-bed over the 4 days after sowing was  $2.7 \text{ }^{\circ}\text{C}$  and the seeds were sown deeper (20 mm) than would normally be the case (5-10 mm) in a peat:sand medium.

The possibility that undissipated fumigant gas might have been responsible for reduced emergence in the seedling trays in the field was discounted, despite the high application rate used (Appendix 5.1), because the peat:sand medium was

thoroughly aerated for 10 days at room temperature (10-20 °C) prior to filling the trays.

Table 3.3 Broccoli seedling emergence and plant populations during raising of transplants

Method of raising seedlings	Emergence (%) <sup>a</sup>	Time to emergence (days)	Seedling population after thinning (m <sup>-2</sup> )
field seedbed	82	8	544
field modules	59	9	377 <sup>b</sup>
greenhouse seedbed	86	4	571
greenhouse modules	85	5	453 <sup>b</sup>

<sup>a</sup> Percentage of the total number of seeds sown

<sup>b</sup> Populations existing after thinning of emergents in modules

The effective seedling density in the seedling trays in the field was reduced by the time of transplanting due to leaf miner insect damage which checked the growth of some plants. Small plants of this treatment were graded out at transplanting (3.2.4.3.6).

Seedling emergence was uniform, occurring over a period of 1-2 days for all raising methods: hence, no attempt was made to measure uniformity of emergence. The emergence times given in Table 3.3 are the days on which the bulk of seedlings emerged at each location as assessed visually.

### 3.3.1.2 Transplant size

On the day of transplanting, seedlings raised in the greenhouse and in the field were 26 days and 43 days from sowing, respectively. The first harvest of the observation experiment was taken the following day. The recommended stage for transplanting of bare-root brassica transplants is when the fifth true leaf is

approximately 10 mm in length (Bussell, 1983) but commercial growers generally transplant at a later stage than this (Bussell, 1984b).

At the time of transplanting, the seedlings raised in the field seed-bed were at the approximate stage recommended for transplanting (Table 3.4) and the seedlings raised in modules in the field were several days past the stage where the roots just held the growing medium of the module. The greenhouse-raised module transplants were at a commercially acceptable transplanting stage where root growth was just sufficient to hold together the peat:sand module on withdrawal from the tray. The plants raised in the greenhouse seed-bed were slightly larger than those raised in modules in the greenhouse and appeared to have larger root systems, prior to pulling from the seed-bed, than the module-raised plants.

Table 3.4 State of plants at transplanting. Means of ten plants of each treatment harvested 1 day after date of transplanting

Method of raising seedlings	Root dry weight (mg)	Shoot dry weight (mg)	Leaf area ( $\times 10^{-4} \text{ m}^2$ )	No. of leaves $\geq 5$ mm long
field seedbed	66.3(9.1) <sup>a</sup>	1073(133) <sup>a</sup>	171(17) <sup>a</sup>	5.6
field modules	83.9(13.4)	1170(211)	195(27)	5.8
greenhouse seedbed	34.1(3.8)	450(46)	97.6(8.0)	4.5
greenhouse modules	42.3(3.6)	308(22)	74.4(3.6)	4.4

<sup>a</sup> standard error of mean in parenthesis

Root dry weights in Table 3.4 for bare-root transplants were recorded after pulling from the seed-bed. Due to the loss of roots at harvest for these treatments it was considered that meaningful comparisons between the five treatments could only be made on the basis of shoot growth.

At transplanting, plants raised in the field had higher shoot dry weights, leaf areas and numbers of leaves  $\geq 5$  mm in length than plants raised in the greenhouse

(Table 3.4). In the field, competition effects may have slowed the growth of seedlings in the seed-bed to a greater extent than those in the modules which were at a lower plant density (Table 3.3) and were supplied with nutrient solution daily. In the greenhouse, where shoot dry weights and leaf areas at transplanting were lower than in the field, the higher shoot dry weight of the seedlings raised in the seed-bed compared to those raised in modules (Table 3.4) was possibly due to the earlier emergence of the seedlings in the seed-bed and/or the greater volume of substrate available for root exploration.

### 3.3.2 Environmental conditions during early establishment

Environmental conditions on the day of transplanting (November 14) were conducive to successful establishment of the transplants; the day was overcast, light drizzle fell for much of the day, there was little wind (129 km wind run) and the soil was moist following 6 mm of overnight rain. Overcast conditions prevailed and 6, 9 and 6 mm of rain fell on the first 3 days after transplanting. Hence, environmental conditions after transplanting favoured establishment of the transplants. Plants of all treatments visibly wilted within hours of transplanting but they recovered quickly and, except for the oldest 1-2 leaves on each plant, were turgid and standing erect 2 to 3 days after transplanting.

### 3.3.3 Observation experiment - results and discussion

#### 3.3.3.1 Leaf, stem and shoot growth

Module-raised transplants produced shoot growth more rapidly after transplanting than bare-root transplants which had been raised in the same 'environment' (Figure 3.1). For example, interpolation on Figure 3.1 indicates that 18 days after transplanting the plants established from module-raised transplants produced in the field and in the greenhouse were approximately 7 and 5 days, respectively, more advanced in terms of shoot dry weight than plants from the corresponding bare-root treatments. The slower establishment of the bare-root transplants can be attributed to the greater transplanting check suffered by these plants due to root damage when they were 'pulled' from their respective seed-beds prior to

transplanting.

The rate and pattern of growth of transplants raised in modules in the greenhouse was very similar whether they were transplanted with or without the module of growing medium around their roots (Figures 3.1 to 3.3). This is not in agreement with the work of McKee (1977) who reported that transplanting of Brussels sprout and tomato plants with undamaged root systems, washed free of rooting medium, resulted in higher water deficits within 3 days after transplanting and delayed re-initiation of root and shoot growth compared to plants transplanted with modules intact, under unspecified establishment conditions. Removal of half of the root systems of the bare-rooted tomato plants further increased the degree of water stress and further delayed establishment (McKee, 1977).

It is suggested, however, that under the 'good' establishment conditions of the current experiment the initially more rapid establishment of the module-raised transplants produced in the greenhouse, as compared to the bare-root transplants raised in the greenhouse seed-bed, was probably due to the lack of root damage suffered by the module-raised transplants and not to any effect of the presence of the growing medium around their roots. However, the possibility that the more rapid establishment of the module-raised plants was due to some other characteristic of these plants cannot be discounted since the raising systems differed in factors other than the degree of damage to the roots and the presence or absence of growing medium around the roots - e.g. nutrient supply, rooting medium, and plant spacing during raising of the transplants.

Differences in the post-transplanting growth of the module-raised plants transplanted with and without the growing medium might have been important had field conditions during establishment been more stressful. For example, Cox (1984b) found that the capacity of the module to act as a reservoir of water for newly transplanted seedlings of lettuce and leek was not important under 'good' establishment conditions (irrigation applied immediately after transplanting). However, when irrigation was delayed, planting saturated rather than dry modules increased plant survival, trimmed head weight and marketable yield of lettuce and

increased early root growth and marketable yield of leek.

Relative growth rates are indicated by the slopes of the relationships between  $\log_e$  dry weight and time (Hunt, 1978). Following transplanting, the module-raised transplants initially had higher relative growth rates of both leaves and stems, but the initial differences in dry weight were greatly reduced 31-32 days after transplanting (Figures 3.2 and 3.3). With respect to leaf growth, the module-raised plants showed a fall in relative growth rate after Harvest 3, whereas the bare-root transplants showed little change throughout the experiment. The reduction in relative growth rate of the stems of the module-raised plants after Harvest 3 was less marked than for leaves, whereas the stems of the bare-root plants had increased relative growth rates after Harvest 2.

The above patterns of growth of leaves and stems of the five treatments were reflected in shoot growth (Figure 3.1). Thus, despite early differences in shoot dry weight between the module-raised and bare-root transplants, a convergence of shoot dry weights had occurred by the time of fourth harvest, 31-32 days after transplanting. This appeared to be due to a reduction in the overall relative growth rates of the shoots of module-raised treatments as well as to an increase of the relative growth rates of the bare-root treatments (Figure 3.1). At this stage, plants from the field modules had a slightly higher shoot dry weight than plants of the remaining four treatments.

### 3.3.3.2 Relationships between plant parts

Logarithmic plots of leaf dry weight against stem dry weight (Figure 3.4) and shoot dry weight against root dry weight (Figure 3.5) were used to describe the pattern of development of plant parts following transplanting. For all treatments, the slope of the plot of  $\log_e$  leaf dry weight against  $\log_e$  stem dry weight (Figure 3.4) was initially greater than unity and then it decreased to be less than unity. This indicates that leaf dry weight as a proportion of shoot dry weight initially increased after transplanting and then later began to decrease as the stems visibly thickened and progressive senescence and abscission of the lower leaves commenced.

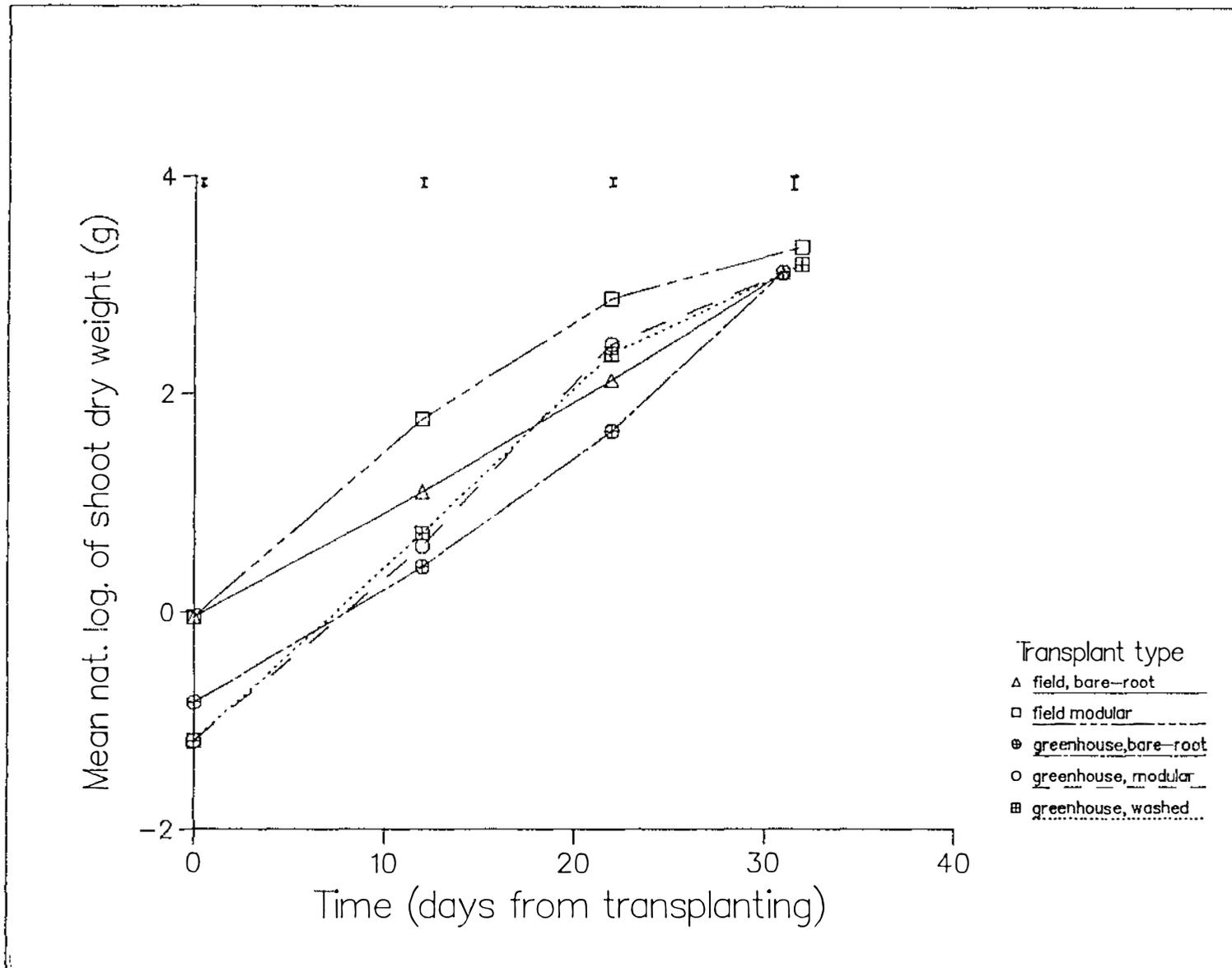
For any given stem dry weight, the field-raised plants - particularly those of the field bare-root treatment - had a lower leaf dry weight than the greenhouse-raised plants (Figure 3.4). Pre-transplanting competition was the probable cause of the lower leaf dry weight (relative to their stem dry weight) of the field-raised bare-root transplants at transplanting (3.3.1.2). Two factors which may have contributed to the maintenance of this initial difference were the possibility of a reduction in leaf growth of the large field bare-root transplants due to a greater transplanting check (Wurr & Fellows, 1984) and, possibly related, a tendency towards more advanced senescence and abscission of lower leaves at any given physiological age (total leaf number or stem dry weight) for the field bare-root plants (cf. Table 3.7 and Figure 3.4) compared to the other treatments.

The relationship between  $\log_e$  shoot dry weight and  $\log_e$  root dry weight was similar for the field-raised treatments and the greenhouse bare-root treatments over the 12-day period after transplanting (Figure 3.5) despite differences in total dry weight and root damage at transplanting. The slopes of the lines in Figure 3.5 for these treatments are  $<1.0$  indicating that over the 12-day period following transplanting there was an increase in root dry weight as a proportion of total dry weight of plants of these treatments. This conclusion is supported by Figure 3.6. With respect to the field bare-root and greenhouse bare-root plants, this was possibly in response to root loss suffered on lifting from the seed-beds and the plants re-establishing the functional equilibrium between shoot and root growth (Brouwer, 1983). The field module plants, on the other hand, were relatively large plants and probably suffered a restriction of root growth in the modules prior to transplanting.

Plants raised in modules in the greenhouse had a higher proportion of total dry weight in the roots at transplanting than the other three treatments and root dry weight as a proportion of total dry weight decreased over the 12-day period following transplanting (Figure 3.6). This was due to a greater relative growth rate of shoots (particularly leaves - Figures 3.2, 3.3, 3.6) as compared to roots (slopes for these treatments in Figure 3.5 are  $> 1.0$ ). It is suggested that the transplants raised in modules in the greenhouse suffered minimal root damage at transplanting

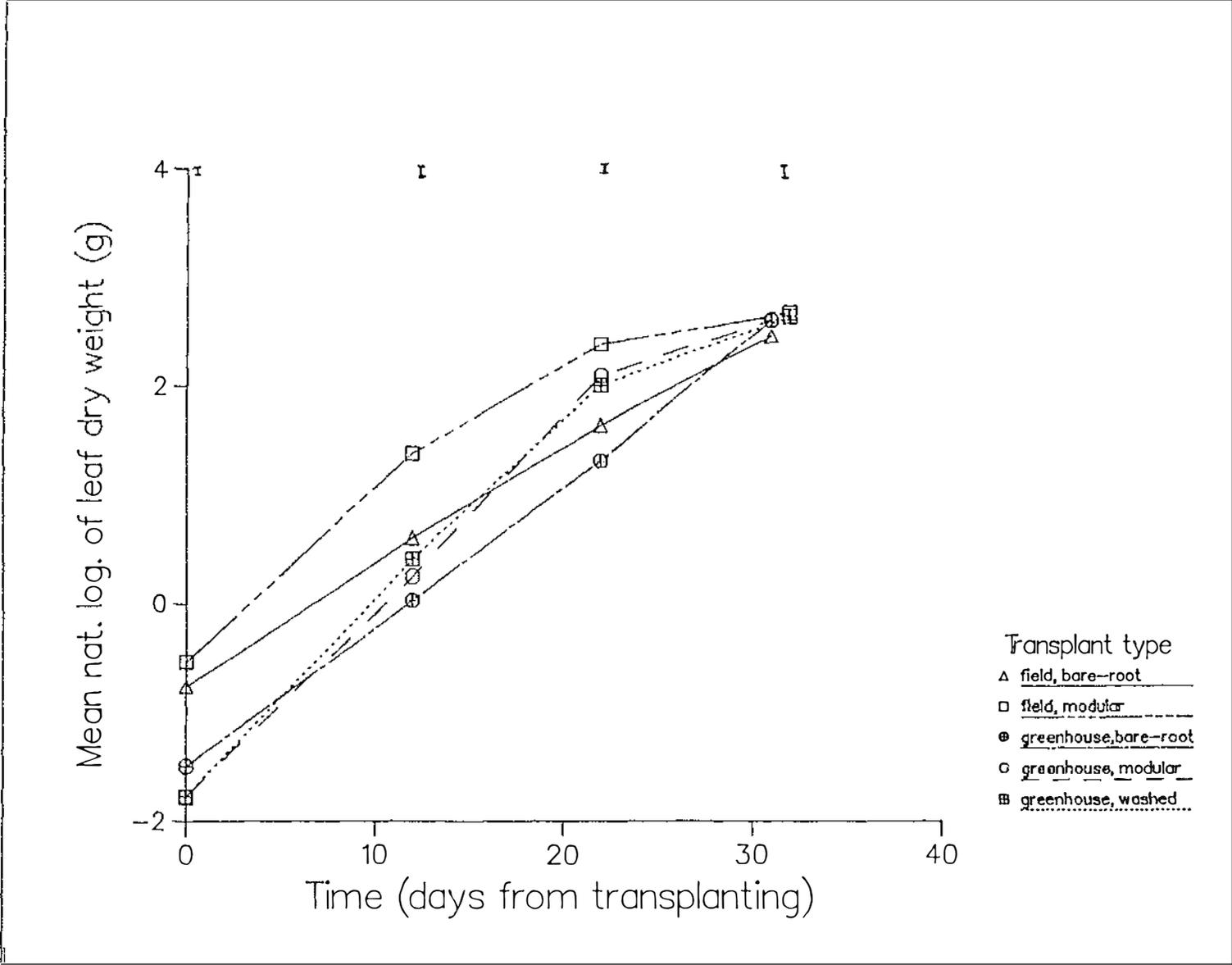
**Figure 3.1** (following page):

Change in natural logarithms of shoot dry weight (grams plant<sup>-1</sup>) with time from transplanting of broccoli plants. Means of ten-plant samples. Vertical bars indicate standard errors of means (9 d.f.) for greenhouse, washed treatment. (see 3.2.5.3.1)



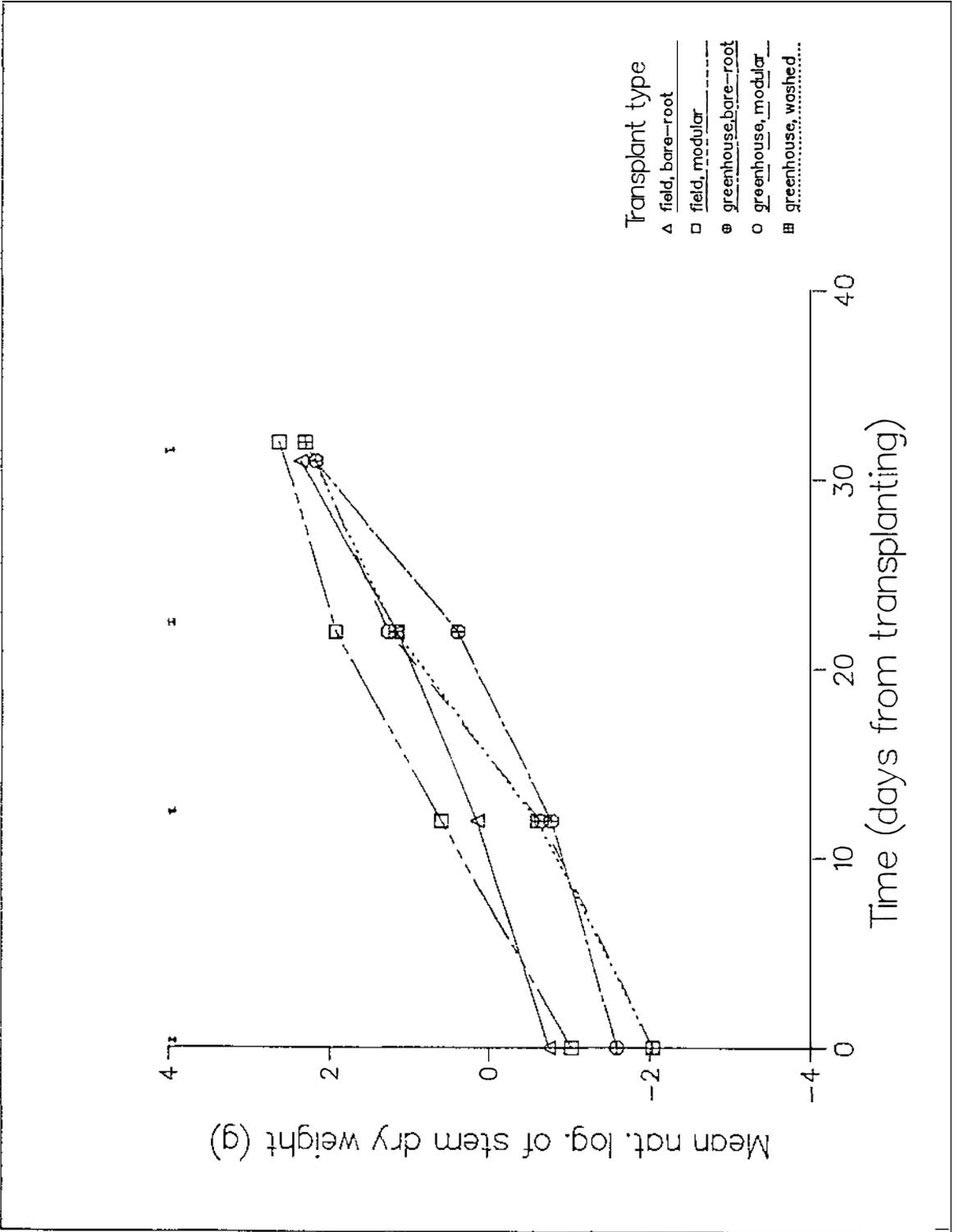
**Figure 3.2** (following page):

Change in natural logarithms of leaf dry weight (grams plant<sup>-1</sup>) with time from transplanting of broccoli plants. Means of ten-plant samples. Vertical bars indicate standard errors of means (9 d.f.) for greenhouse, washed treatment. (see 3.2.5.3.1)



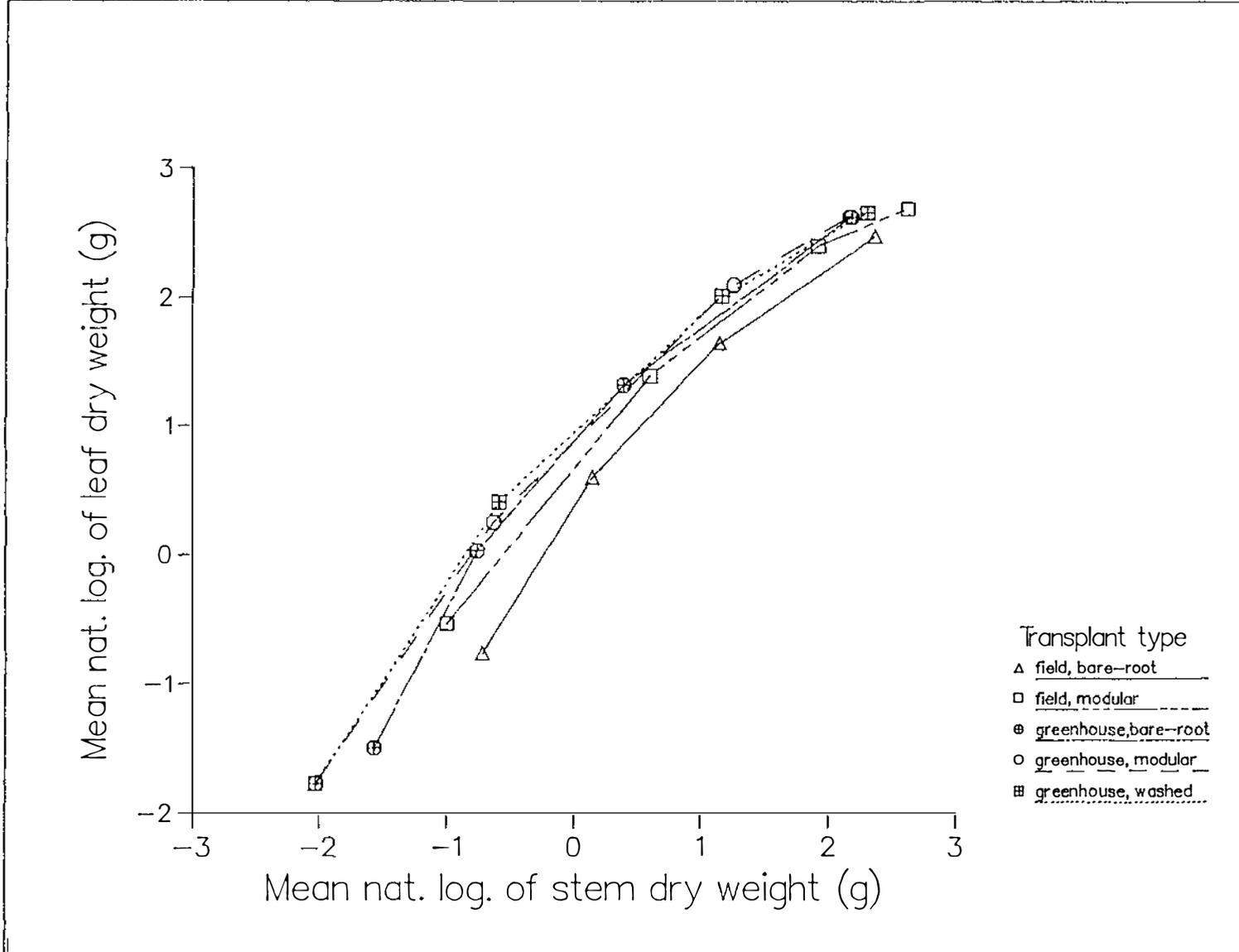
**Figure 3.3** (following page):

Change in natural logarithms of stem dry weight (grams plant<sup>-1</sup>) with time from transplanting of broccoli plants. Means of ten-plant samples. Vertical bars indicate standard errors of means (9 d.f.) for greenhouse, washed treatment. (see 3.2.5.3.1)



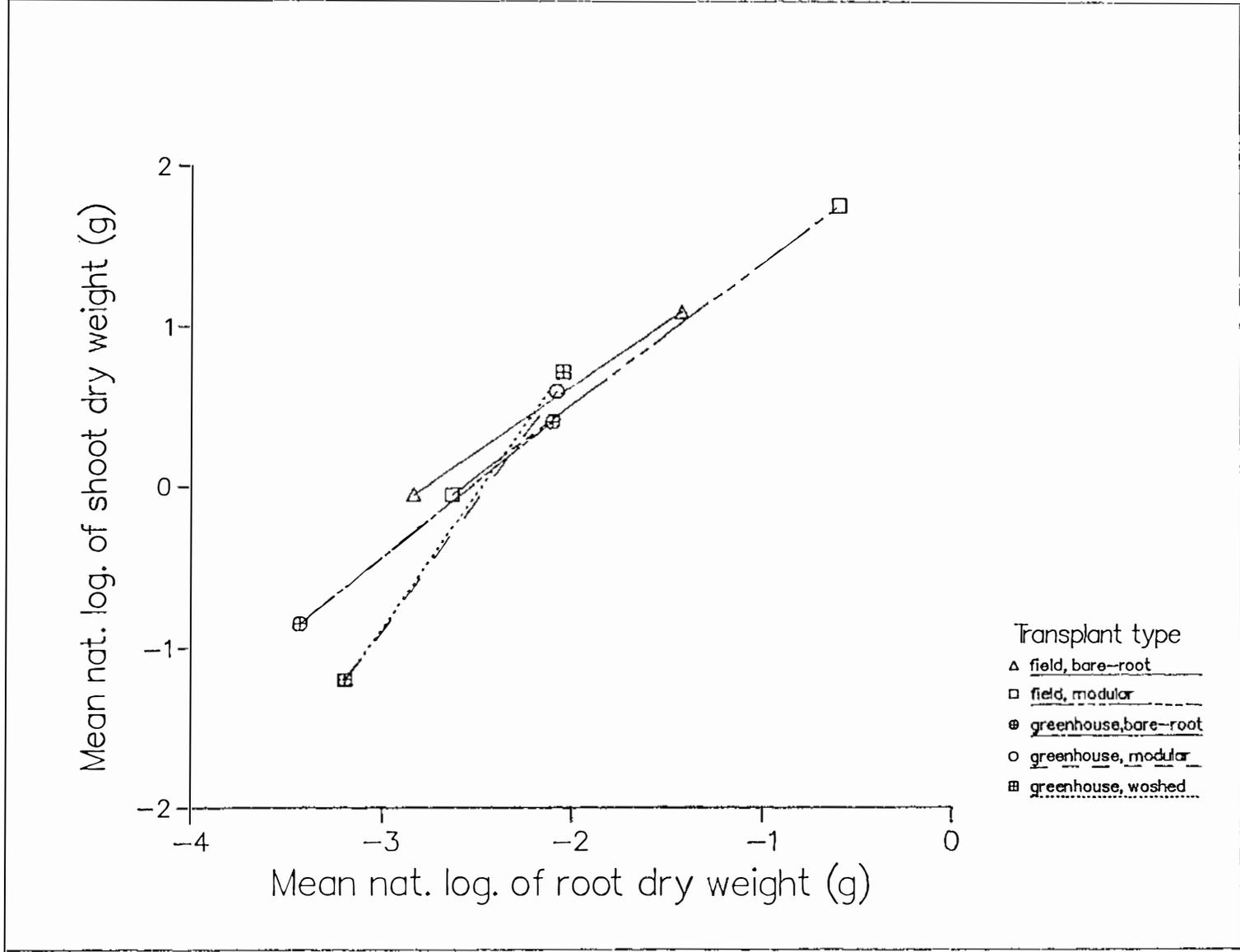
**Figure 3.4** (following page):

Relationship between mean natural logarithm of leaf dry weight and mean natural logarithm of stem dry weight of broccoli plants. Means of ten-plant samples from Harvests 1 to 4 of observation experiment.



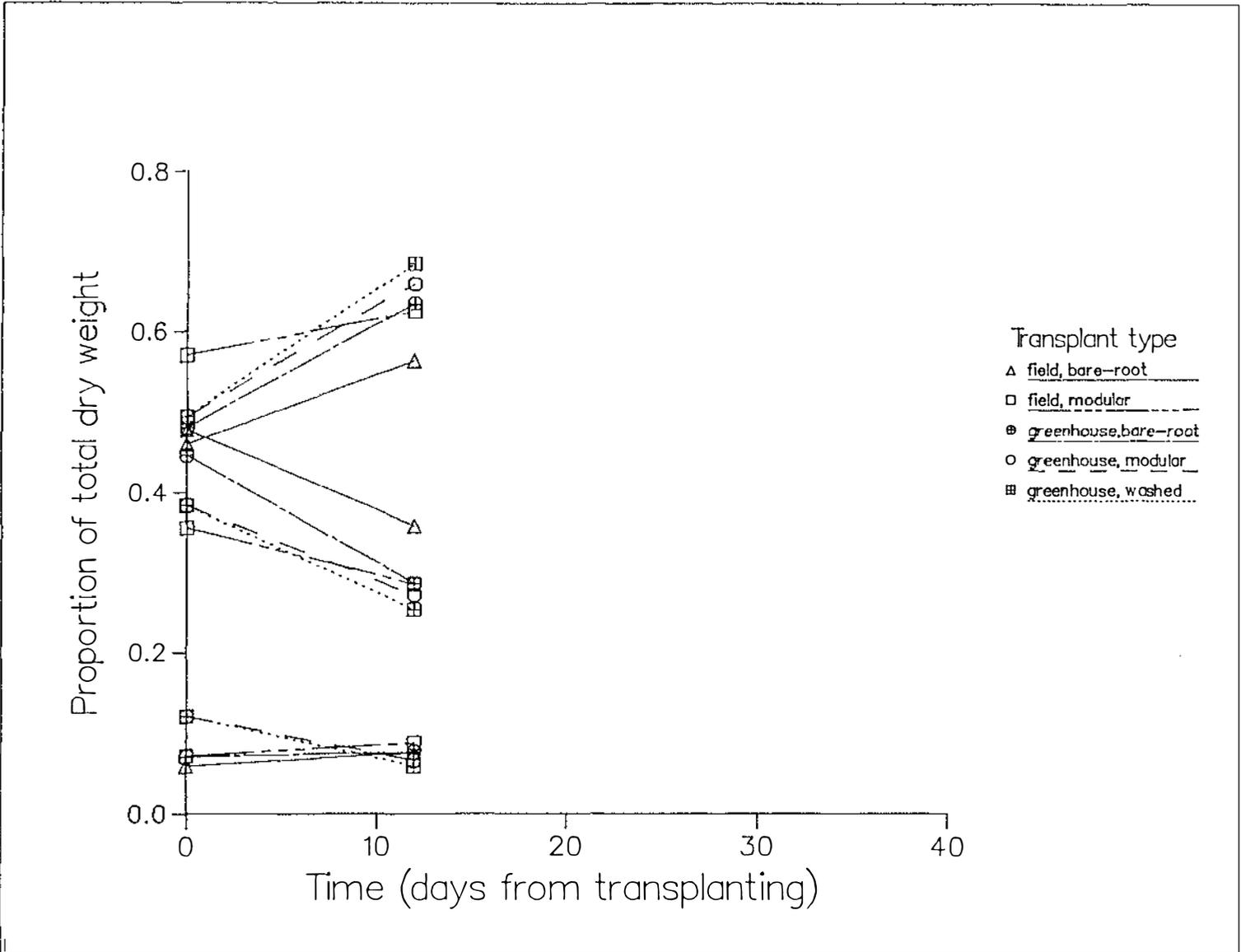
**Figure 3.5** (following page):

Relationship between mean natural logarithm of shoot dry weight and mean natural logarithm of root dry weight of broccoli plants. Means of ten-plant samples from Harvests 1 and 2 of observation experiment.



**Figure 3.6** (following page):

Root, stem and leaf dry weight as proportions of total dry weight of broccoli plants at Harvests 1 and 2 of observation experiment. Means of ten-plant samples. Vertical bars indicate standard errors of means (9 d.f.) for greenhouse, washed treatment. (see 3.2.5.3.1)



and only a slight restriction of root growth prior to transplanting and that the fall in the proportion of total dry matter in the root is possibly a reflection of the aging of the plants rather than a transplanting effect. In a growth study of module-raised broccoli plants, transplanted at the 4-true leaf stage, Diputado (1989) recorded a decline in root dry weight as a proportion of total dry weight as the plants progressed from the seedling stage through head initiation to head maturity.

In the current study, root dry weights were not recorded after Harvest 2 because of intermingling of the root systems of adjacent plants in the field at later harvests. The extent of root growth by plants of the two field-raised treatments, 16 days after transplanting, is illustrated in Plates 3.9 and 3.10.

#### 3.3.3.3 Uniformity of crop establishment

Examination of the coefficients of variation of untransformed data and the standard deviations of the natural logarithms of the data revealed no consistent pattern of variation of shoot dry weight with time from transplanting (Table 3.5). No conclusions can be drawn as to whether the treatments affected inter-plant variability in shoot dry weight following transplanting. The inconsistent pattern of the coefficients of variation of shoot dry weight with time within treatments (Table 3.5) suggests that the individual sample size (ten plants) was too small to provide reliable estimates of the degree of variability amongst plants.

Table 3.5 Coefficients of variation (%) of shoot dry weight

Treatment	Harvest number			
	1	2	3	4
field bare-root	39.3	29.1	47.2	36.4
field module	57.0	42.4	21.0	49.2
greenhouse bare-root	32.6	40.6	45.5	30.7
greenhouse module	22.5 <sup>a</sup>	35.4	21.5	43.5
greenhouse washed	22.5 <sup>a</sup>	24.0	27.6	33.4

<sup>a</sup> a single sample of 10 seedlings raised in modules in the greenhouse was taken at Harvest 1 (3.2.5.2.1)

### 3.3.3.4 Head development and leaf numbers

#### 3.3.3.4.1 Efficacy of methods of examining stem apices

The method of obtaining permanently mounted, stained longitudinal sections of the stem apices (3.2.5.2.1) was selected after a trial run, using several apices from buffer plants harvested prior to Harvest 1, had indicated that the method could be used to produce sections which could be readily assessed by microscopy. This method was preferred to the method of dissecting and examining fresh samples under a dissecting microscope (e.g. Salter, 1960a) because it would allow more thorough recording of the state of the apices (e.g. Gauss & Taylor, 1969a) and allow direct comparison, at any one time, of apices from different harvest dates.

The sectioning method was used for Harvest 1 apex samples but was found to be inefficient: the time required for preparation of the samples was prohibitive and there were some losses of data due to tissue tearing or improper orientation in the microtome block. Leaf counts based on sections of leaf visible in the prepared slides were likely to be inaccurate due to the tendency for the largest of the leaves on the samples to be cupped around and over the apical meristem region. Leaf

counts and location of median thin sections (i.e. longitudinal sections through the centre of the apical dome) would have been easier had a greater number of leaves been removed before the samples were placed in Kahle's fluid. Greater numbers of leaves were not removed because smaller samples were difficult to see and orientate correctly in molten paraffin blocks.

After difficulties had been experienced in obtaining satisfactory results from permanently mounted thin sections for samples of Harvest 1, samples from the remaining harvests were taken from the butan-2-ol:paraffin oil mixture (at the completion of the dehydration series of Berlyn & Miksche, 1976, p. 40) and dissected under a dissecting microscope. This method proved to be more satisfactory as the dehydration/infiltration series had caused the samples to become quite brittle and the leaves remaining on each sample were able to be counted, measured (with an eyepiece micrometer) and removed relatively quickly. The diameter ( $\pm 12 \mu\text{m}$ ) of the apical dome or terminal inflorescence was recorded for each vegetative or reproductive plant.

This latter method was more useful than that used for the Harvest 1 samples as it allowed more rapid examination of the apices from all harvest occasions at a single assessment time. After removal of the larger leaf initials, samples of interest could have been infiltrated with paraffin, sectioned and stained for further microscopic examination, had this been considered necessary.

#### 3.3.3.4.2 Leaf number and head initiation

Due to the problems encountered with preparing permanently mounted apical sections, the results of microscopic examination of apices collected at Harvest 1 were incomplete. From those sections which were examined, signs of head initiation were not noted on any of the apices from plants of any of the treatments at Harvest 1 (e.g. Plate 3.11). The mean numbers of true leaves longer than  $250 \mu\text{m}$  (for those apices for which it could be readily determined) are presented in Table 3.6. No abscission of lower leaves had occurred on any of the plants assessed at Harvest 1 (cf. Harvests 2 to 4, Table 3.7).

Table 3.6 Mean leaf numbers at the time of transplanting (Harvest 1)

Method of raising seedlings	Number of true leaves $\geq 5$ mm long <sup>a</sup>	Number of true leaves $\geq 250$ $\mu$ m long
field, seedbed	5.6	9.0 (7 plants) <sup>b</sup>
field, modules	5.8	8.9 (9 plants)
greenhouse, seedbed	4.5	7.7 (9 plants)
greenhouse, modules	4.4	6.8 (5 plants)

<sup>a</sup> from Table 3.4, means of ten-plant samples

<sup>b</sup> number of plants from which reliable leaf counts could be made from thin sections indicated in parenthesis

Leaf numbers and stages of reproductive development of plants harvested in Harvests 2 to 4 are given in Table 3.7. Leaf (node) numbers and apex diameters are presented for vegetative plants (those with no microscopically visible sign of floral differentiation). Leaf numbers and terminal head diameters are presented for reproductive plants. Sequential leaf senescence had visibly commenced in plants of all five treatments by Harvest 2 and treatment means (vegetative and reproductive plants combined) for the number of main stem nodes at which leaf abscission had occurred are presented in Table 3.7.

Table 3.7 Mean leaf numbers and terminal inflorescence (head) development following transplanting (ten-plant samples, Harvests 2 to 4)

Treatment	<u>Vegetative plants</u>			<u>Reproductive plants</u>			<u>All plants</u>	
	no. of plants	apex dia. (mm)	leaf no. <sup>a</sup>	no. of plants	head dia. (mm)	leaf no. <sup>a</sup>	no. with leaf broad apex <sup>b</sup>	abs. no. <sup>c</sup>
<u>Harvest 2</u>								
field,seedbed	10	0.24	17.6	0	-	-	0	1.1
field,modules	6	0.27	17.7	4	0.81	20.8	7	1.2
greenhouse,seedbed	10	0.20	13.3	0	-	-	0	0.9
greenhouse,modules	10	0.21	14.7	0	-	-	0	0.6
greenhouse,washed	10	0.25	14.2	0	-	-	0	0.3
<u>Harvest 3</u>								
field,seedbed	5	0.29	18.2	5	0.83	21.0	10	1.7
field,modules	1	0.22	19.0	9	1.34	20.6	10	1.2
greenhouse,seedbed	10	0.28	18.6	0	-	-	6	1.1
greenhouse,modules	3	0.31	21.7	7	0.66	21.7	10	0.9
greenhouse,washed	3	0.28	19.7	7	0.62	20.4	10	0.9
<u>Harvest 4</u>								
field,seedbed	0	-	-	10	2.7	20.5	10	3.1
field,modules	0	-	-	10	11.6	19.8	10	2.4
greenhouse,seedbed	0	-	-	10	2.0	20.1	10	1.7
greenhouse,modules	0	-	-	9	2.0	20.3	9	1.8
greenhouse,washed	0	-	-	10	2.2	20.6	10	1.8

<sup>a</sup> mean number of nodes with leaf  $\geq 250 \mu\text{m}$  in length (includes lower nodes where leaf had abscised)

<sup>b</sup> number of plants with visible change in shape of apical dome

<sup>c</sup> number of nodes at which leaf abscission had occurred

The primary stem apices of plants of all treatments became visibly broader as the plants approached the stage at which the inflorescence was first detected under the dissecting microscope. The numbers of plants in each ten-plant sample for which this change in apex shape was observed are recorded in Table 3.7. A similar change in apex shape has previously been described in plants of broccoli breeding lines by Bouwkamp & Honma (1969). If such a macroscopically visible change is typical of a broad range of broccoli cultivars then it may prove to be a useful non-destructive, rapidly-assessed indicator of when floral differentiation is about to commence in individual plants. Wurr (1991) has suggested that, in general, the final leaf number in broccoli is more stable across a range of environmental conditions than is the case for the related cauliflower crop. Where previous experience with a broccoli cultivar under particular cultural conditions indicates that final leaf node number is relatively stable (e.g. Diputado, 1989), then node number may be the most practical indicator of early reproductive development for use in crop monitoring.

Development of the terminal inflorescence was first detected earlier (Harvest 2) for the field module treatment than for the other treatments (Table 3.7). The change to reproductive growth was not detected until Harvest 3 for the remaining treatments except the greenhouse seed-bed treatment for which it was not detected until Harvest 4. At Harvest 4, head diameters were similar for all treatments except for the field module treatment for which head development was clearly more advanced.

After the plants began to initiate terminal inflorescences it became difficult to differentiate between leaf initials and the initials of bracts surrounding the apical dome. Hence, for some treatments, the recorded mean leaf numbers at which heads were initiated were larger at Harvest 3 than at Harvest 4 (Table 3.7). The leaf numbers recorded at Harvest 4 are likely to be the more accurate since development of most plants had by then progressed to a stage where it was possible to differentiate between leaves and bracts ('leaves' having no signs of development in their axils of the peduncle of the terminal inflorescence).

Temperatures recorded (at a meteorological station situated 500m from the experimental area) during the production of the field-raised transplants are summarised in Table 3.8. Due to a failure of the electronic data logger used to record air temperatures at bench height in the greenhouse, records of greenhouse temperature were incomplete: however, mean daily maximum and minimum air temperatures recorded over the period from 14 to 26 days after sowing were 28 °C and 18 °C respectively.

Table 3.8 Five-day means of daily maximum and minimum air temperatures and grass minimum temperatures during raising of transplants in the field <sup>a</sup>

Days from sowing	Mean daily temperatures (°C)		
	air max.	air min.	grass min.
1-5	14.8	4.1	0.8
6-10	15.5	9.2	7.8
11-15	18.4	11.7	9.8
16-20	15.7	10.7	9.2
21-25	16.8	5.9	3.8
26-30	19.4	9.3	5.9
31-35	19.8	12.4	10.3
36-40	20.4	11.4	8.5
41-43	20.4	13.7	12.5

<sup>a</sup> mean temperatures derived from records of meteorological station situated 500 m from the experimental field

The daily minimum temperatures experienced by the field-raised transplants were within the range over which floral development of broccoli has been reported to have been induced at an earlier physiological age than plants grown at higher temperatures (e.g. Gauss & Taylor, 1969b; Fontes, Ozbun & Sadik, 1967; Wiebe, 1975; Fontes & Ozbun, 1972). However, in all of these studies plants were

exposed to constant low temperatures: none describe the behaviour of broccoli under diurnal temperature regimes such as those which occurred in the current experiment. Furthermore, the effects of temperature on the initiation of reproductive growth vary among broccoli cultivars (1.2.3.3) and none of the aforementioned studies included cv. 'Premium Crop':

Miller (1988) found that maturity times and nodes per plant for broccoli plants exposed to 14°/2°C diurnal fluctuations in temperature were similar to those recorded in a previous study (Miller, Konsler & Lamont, 1985) in which chilling temperatures were held constant. From these results, Miller (1988) suggested that raising of temperature during daylight hours resulted in little or no devernalisation effect. Diputado (1989) found that exposure of plants of cv. 'Premium Crop' to continuous temperatures of 10°C for one week at various stages of plant development commencing at the four true leaf stage did not affect head initiation or time to head maturity compared to plants raised under a continuous 20°C. Plants of 'Premium Crop', raised from sowings in every second month of the year and transplanted at the four true leaf stage into a field at the same location as the current experiment, produced similar final leaf numbers regardless of the time of year (Diputado, 1989). These results indicate that ambient spring temperature patterns in the Palmerston North area may not be conducive to morphologically earlier head initiation in cv. 'Premium Crop' plants raised in the field compared to those raised at higher temperatures in a greenhouse.

In the current experiment, the lower temperatures experienced by the field-raised seedlings during the transplant production period, as compared to the greenhouse-raised seedlings, did not appear to influence the node number at which terminal inflorescences were initiated (Table 3.7). However, more comprehensive studies are required to reveal whether cv. 'Premium Crop' exhibits a facultative low temperature flowering response.

### 3.3.4 Main experiment - results and discussion

#### 3.3.4.1 Results of main experiment

##### 3.3.4.1.1 Missing data: causes and handling

Some losses of plants following transplanting were noted 12 days after transplanting, particularly in plots of the greenhouse module and greenhouse washed treatments. No pest damage or disease symptoms were evident and the losses appeared to be due to a physical breaking of the stems at, or just above, the soil surface. At the completion of harvesting, counts of plants remaining in each plot were taken. Plots in which the sum of plants which had died and plants which were very small due to partial breakage of the stem was greater than three were discarded from the results in order to remove the confounding effect of differing plant populations. Results from three plots of the greenhouse module treatment were discarded for this reason. One plot of the greenhouse, washed treatment was also discarded: partially because of the loss of a total of 7 plants and also because of hormone spray damage symptoms (see below) on plants of one outside row of the plot. This was a plot adjacent to one of four plots severely affected by exposure to hormonal herbicide.

The latter four plots contained plants which exhibited downward curling of leaves and the problem was first noticed 22 days after transplanting (Plate 3.12). The symptoms developed as follows:

- (i) faint chlorotic regions on young leaves, incomplete development of leaf laminae, downward curling of leaf margins;
- (ii) swelling at stem nodes, splitting and corkiness of stems;
- (iii) small swellings on the roots.

The symptoms resembled those induced by exposure of Brussels sprout plants to the herbicide 2,4,5-trichlorophenoxyacetic acid (2,4,5-T) as illustrated by Eagle, Caverly & Holly (1981, Figure 13.19) and Scaife & Turner (1983, p.12). The location of the affected plots corresponded to the area where each pesticide spray application commenced and it was subsequently discovered that the lance of the sprayer used to apply pesticides 12 days after transplanting (Appendix 5.3) was

probably contaminated by 2,4,5-T.

The severity of the symptoms declined along the length of the affected area of bed. Plants in three of the plots were severely affected and plants in the fourth plot were affected to a lesser extent. These four plots were discarded from the analysis of the results: this resulted in the loss of data for the greenhouse module treatment in three experimental blocks and for the field bare-root treatment in another block.

After the discarding of data from plots affected by hormone damage and high plant losses only two plots of the greenhouse module treatment remained. Hence, it was decided to analyse the remaining data with the exclusion of that treatment. Means of data derived from the two remaining plots of the treatment are presented in the table of results (Table 3.9) but they are statistically unreliable. Thus, analyses of variance were carried out on data from the four remaining treatments with the two missing plots - one each from the field bare-root and greenhouse washed treatments (3.2.5.3.2).

The rejection of hormone-affected plots prior to analysis of results was carried out arbitrarily, based on a visual assessment of hormone damage symptoms to plants within each plot. It was possible that exposure to 2,4,5-T might have caused undetected effects in other plots and loss of effectiveness of buffer plots in beds adjacent to plots severely affected by hormone. To test this possibility, plots of residuals from each analysis of variance were plotted on field plans of the experiment and the signs and absolute values of the residuals, in relation to their geographical distribution, were examined visually. No unusual pattern was discovered and the original analyses were accepted as being valid. However, a slight, transient downward curling of the leaf margins of some plants in the remaining plots and of some plants in the observation experiment was noted and the results obtained in these experiments must be examined in the knowledge that some effect of the herbicide on the plants from which the results are derived may have occurred.

#### 3.3.4.1.2 Effects of methods of transplant production on yield, maturity and head quality

After the omission of plots in which significant losses of plants had occurred (3.3.4.1.1), treatment differences in numbers of heads harvested in the remaining plots were small (Table 3.9). A minor source of experimental error is indicated by the fact that the mean number of heads harvested in the two field-raised treatments exceeded 40 per plot (Table 3.9). This probably arose through accidental harvesting and recording of secondary (lateral) heads or heads from buffer plants at the ends of plots.

Table 3.9 Effects of method of transplant production on yield and maturity of broccoli

Variable	Treatment means				approx.lsd (19 df)		C.V. (%)	greenhouse module treatment means <sup>c</sup>
	field bare-root	field module	greenhouse bare-root	greenhouse washed	P<0.05 <sup>b</sup>	P<0.01 <sup>b</sup>		
Maturity time, H20; days from transplanting	50	47	54	54	0.9	1.3	1.7	54
Maturity time, H20; days from sowing	93	90	80	80	0.9	1.3	1.0	80
Spread of maturity, H4T036 (days)	10.4	11.7	8.6	8.8	2.22	3.03	21.5	10.0
Yield (kg/plot) <sup>a</sup>	4.35	4.93	4.33	4.35	0.47	0.65	10.1	4.12
No. of heads/plot	41.1	40.1	40.0	39.2	--	--	--	37.5
Av. head weight, grams	106	123	108	111	11.1	15.2	9.5	110
Av. head dia., mm	88	96	92	94	4.9	6.7	5.1	92

<sup>a</sup> t ha<sup>-1</sup> = (kg/plot) x 2.667

<sup>b</sup> precise lsd's for specific comparisons can be derived from Table 3.2

<sup>c</sup> mean for greenhouse module treatment (derived from 2 plots, not included in analyses of variance)

Cumulative numbers of heads harvested were plotted against time for several field plots of each treatment to check that data derived by linear interpolation on the raw data accurately described the pattern of maturity within the plots. The maturity pattern of a typical plot (of the greenhouse, bare-root treatment) is illustrated in Figure 3.7. Maturity data (Table 3.10) derived from the raw data by linear interpolation can be seen to give a close approximation to the curve drawn through the raw data in Figure 3.7.

**Figure 3.7** (following page):

Cumulative number of heads harvested from inner, outer and all rows of a single plot of broccoli (greenhouse, bare-root treatment).

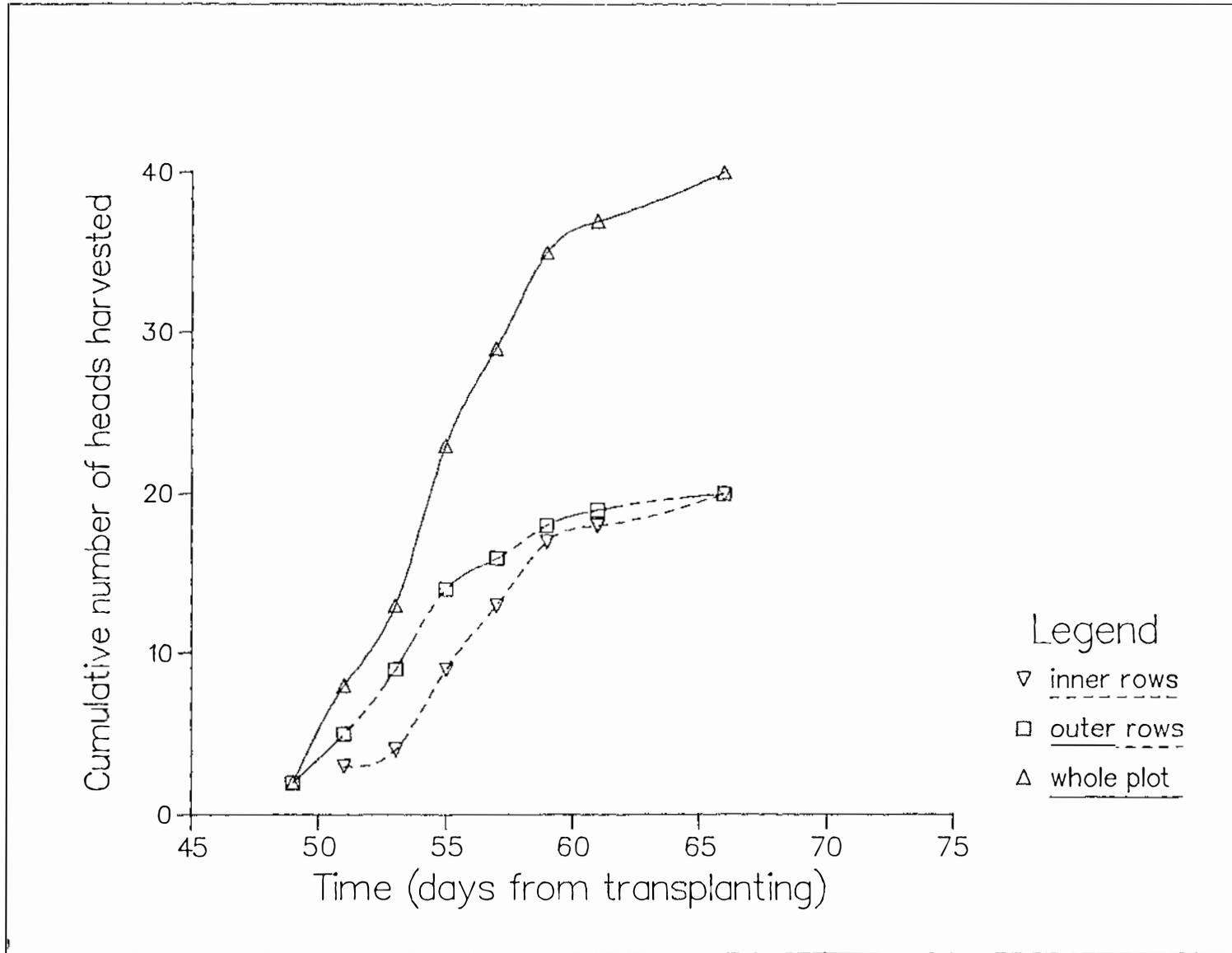


Table 3.10 Maturity data for plot illustrated in Figure 3.7

Variable	Interpolated value
Maturity time (H20, days from transplanting)	54.4
Spread of maturity, 4th to 36th head (H4TO36, days)	10.3
Time to maturity of 10th head in outer rows (H10, days)	53.4
Time to maturity of 10th head in inner rows (H10, days)	55.5

Plots established from field-raised transplants required less time after transplanting to reach maturity than those established from greenhouse-raised transplants (Table 3.9). However, total crop duration (from sowing to harvest maturity) was shorter for the treatments germinated and raised in the heated greenhouse (Table 3.9). Plots established from field-raised module transplants reached maturity 3 days earlier than those of the field-raised bare-root treatment. Although this difference was statistically significant ( $P < 0.01$ ) it is not a large difference from a practical point of view. Maturity times of the greenhouse-raised treatments were very similar.

There were no significant differences in the spread of maturity (H4TO36) amongst treatments in which seedlings were raised in the same 'environment' (Table 3.9). The spread of maturity of the field-raised module treatment was significantly greater than for the greenhouse-raised treatments.

There were significant differences between the field module and the field bare-root treatments in terms of mean yield ( $P < 0.05$ ), mean head weight ( $P < 0.01$ ) and mean head diameter ( $P < 0.01$ ) but no significant differences in mean yield, head weight or head diameter between the two greenhouse-raised treatments (Table 3.9). Yields and head weights of the field bare-root and the two greenhouse treatments were very similar (Table 3.9).

Head quality attributes (3.2.5.2.2) were recorded until some heads from all treatments had been harvested. There was little to differentiate between the treatments in terms of uniformity of bud size, cluster separation, head shape or branching angle and recording was discontinued. The maturity and quality of typical heads, after trimming to 150mm in length, is depicted in Plate 3.13.

#### 3.3.4.1.3 Effects of row location on maturity and head size

'Split-plot' analyses of variance (3.2.5.3.2) revealed significant effects of row location within beds but no 'significant' treatment x row location interactions: hence, only means for row locations are presented (Table 3.11). The effects of transplanting treatments which comprised the 'main plots' of the 'split-plot' analyses are not presented here because valid analyses of those effects have already been presented (Table 3.9).

Mean time of maturity (H10) was approximately 2 days earlier for outer rows of beds compared to inner rows and heads harvested from outer rows were, on average, 37 per cent heavier and had head diameters which were 10 per cent higher than those harvested from inner rows (Table 3.11).

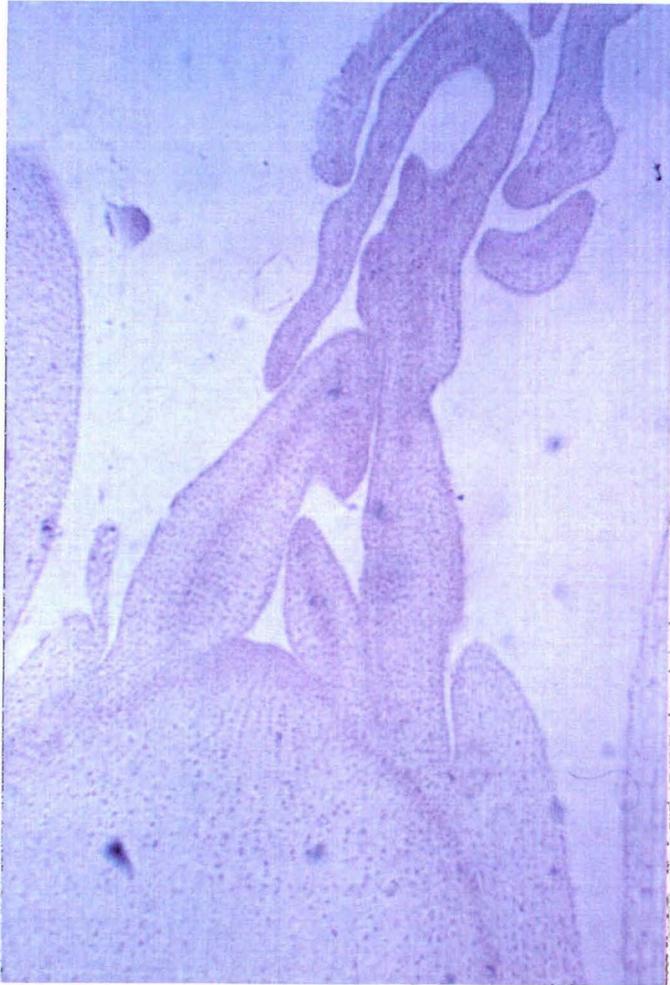


Plate 3.11 Longitudinal section (80x) of vegetative stem apex of broccoli plant of greenhouse seed-bed treatment at Harvest 1 of observation experiment.



Plate 3.12 Plant of greenhouse module treatment showing severe symptoms of 2,4,5-T damage (31 days after transplanting). Scale is in millimetres.



Plate 3.13 Terminal heads of broccoli after harvesting and trimming to 150mm in length. Scale is millimetres.

Table 3.11 Means and significant levels of F-tests from 'split-plot' analyses

Variable	Means for row location		Significance of F for effect	
	Inner	Outer	Row location	Treatment X row location
Maturity time, H10 <sup>a</sup>	52.8	50.6	**	ns
Average head weight (grams)	94	129	**	ns
Average head diameter (mm)	88	97	**	ns

<sup>a</sup> days from transplanting

\*\* significant at  $P < 0.01$ , ns = not significant

### 3.3.4.2 Discussion of main experiment results

#### 3.3.4.2.1 Plant losses

The post-transplanting losses of plants which had been raised in modules in the greenhouse were attributed to wind damage. Kahn, Conway & Fisher (1986) found wind injury to be an important source of seedling losses in two experiments with six broccoli cultivars (including 'Premium Crop'). Hutchison, Ferguson & McErlich (1985) have reported high post-emergence losses of direct-seeded broccoli plants (cv. 'Premium Crop') in the Canterbury district. They attributed plant losses to mechanical damage by wind and losses were reduced by moulding soil around the plants and by use of artificial shelter from wind. Losses were also reduced through the use of field-raised bare-root transplants rather than direct seeding to establish the crop.

Plants raised in modules in the greenhouse in the present study were relatively 'soft' plants raised under conditions of non-limiting nutrition and warm temperatures. Following transplanting, these plants rapidly increased their above-ground dry weight (Figures 3.1 and 3.5). These traits possibly rendered the

plants particularly susceptible to wind damage after transplanting. Two other factors which might have predisposed the plants to wind damage were pest or disease damage to the stems (Kahn, Conway & Fisher, 1986) and mechanical damage during the transplanting operation but these were considered to be unlikely because no pest or disease symptoms were noted while the plants were growing in the greenhouse and because the plants were carefully transplanted by hand.

It may be desirable to slightly 'harden' greenhouse-raised module transplants of broccoli prior to transplanting to confer on them greater physical rigidity to withstand the physical effects of handling at transplanting and physical damage caused by wind after transplanting. Increasing the depth of planting might also be of some benefit in reducing wind damage. Wurr, Cox & Fellows (1986) found that raising of module-raised transplants of cauliflower under a low nutrient regime produced plants which had a higher dry matter content at transplanting time than plants raised under a more 'conventional' liquid feeding regime. The 'low-feed' plants were sufficiently robust to withstand rough handling and did not wilt after transplanting unlike plants fed at 'normal' rates (Cox, Wurr & Howkins, 1985). The nutrient feeding regimes during raising of the transplants were found to have little effect on subsequent curd yield, time of maturity and spread of maturity (Wurr, Cox & Fellows, 1986).

#### 3.3.4.2.2 Time to maturity

Field-raised module transplants matured 3 days earlier than bare-root transplants raised in field seed-beds but there was no difference in mean maturity time between the greenhouse-raised treatments. Harvesting of this experiment was conducted in mid-summer and this difference of three days would represent a greater difference, chronologically, under cooler conditions. Transplants raised in modules in the greenhouse and transplanted with or without growing medium around the roots appeared to develop similarly throughout the observation experiment (3.3.3) and it is assumed that maturity times for these two treatments would have been approximately the same, as indicated by the mean maturity time

obtained from the two remaining plots of greenhouse module-raised transplants (Table 3.9). Thus, under the conditions of this experiment, it would appear that module-raised transplants gave a slight advantage over bare-root transplants in terms of earliness of maturity when the large, field-raised transplants were used but no such advantage was obtained when the smaller, greenhouse-raised transplants were used.

The lack of any difference in maturity between the greenhouse module and greenhouse bare-root treatment could have been due to a smaller difference in transplanting check between these treatments compared to that between their field-raised counterparts. This conclusion is consistent with results recorded in the observation experiment (3.3.3). Transplanting treatment had no effect on the amount or distribution of shoot dry weight 31-32 days after transplanting for the smaller (at transplanting) greenhouse-raised transplants whereas for the larger, field-raised transplants early differences in shoot dry weight and distribution of shoot dry weight between module-raised and bare-root transplants were not completely lost by Harvest 4 of the observation experiment (3.3.3). Terminal head development was similar for the three greenhouse-raised treatments 31-32 days after transplanting whereas terminal heads were more advanced in the field module than in the field bare-root treatment (Table 3.7)

The results of the main experiment suggest that, in the case of the field-raised treatments, the differences between module-raised and bare-root transplants recorded at the final harvest of the observation experiment persisted, to some extent, through to the time of head maturity. Thus, under the relatively favourable establishment conditions of this experiment, it appears that any additional transplanting check, due to root loss and/or post-transplanting water stress, suffered by the greenhouse bare-root transplants compared to the greenhouse module-raised transplants was sufficient to affect early post-transplanting growth (3.3.3) but insufficient to affect final time to maturity. However, for the larger field-raised transplants the additional transplanting check suffered by the bare-root transplants was such that time to 50% maturity was delayed compared to the module-raised transplants.

The assumption that the larger, field-raised transplants suffered a greater transplanting check to growth is supported by the results of the observation experiment : initial shoot growth rates of the greenhouse module and greenhouse bare-root transplants were greater than their respective field-raised counterparts (Figure 3.1). Furthermore, the longer time from sowing to maturity of the field-raised compared to greenhouse-raised treatments (Table 3.9) can only partially be explained by more rapid growth of the seedlings raised in the heated greenhouse because the field-raised transplants were larger at transplanting (Table 3.4, Figure 3.1). Salter & Fradgley (1969a) found that delayed transplanting of cauliflowers raised in field seed-beds resulted in increased time from sowing to maturity particularly when the seedlings were raised under competitive conditions in the seed-bed.

The data recorded in the current experiments do not demonstrate clearly why the initial advantage in post-transplanting growth of the greenhouse washed and greenhouse module treatments compared to the greenhouse bare-root treatment (3.3.3) was eventually lost resulting in a similar time to maturity for all three treatments. However, the convergence of shoot dry weights (Figure 3.1) and the similarity of the relationship between leaf and stem dry weights (Figure 3.4) for these three treatments towards the end of the observation experiment suggest that the initial differences were moderated during the early part of the post-transplanting growth period so that by the time of the final harvest of the observation experiment plants of these three treatments had reached a similar stage of vegetative (Figures 3.1, 3.2, 3.3 and 3.4) and reproductive (Table 3.7) development.

Wurr, Cox & Fellows (1986) have reported a similar result with transplant age and pre-transplanting nutrition treatments applied to module-raised seedlings of two cauliflower cultivars. The plant-raising treatments produced plants which differed in dry weights, leaf number and dry matter percentage at transplanting. Treatment means for shoot dry weight converged rapidly with time after transplanting so that by the time of 50% curd initiation for each cultivar differences in shoot dry weight were small. There were no significant differences amongst plant-raising treatments

in the time of 50% curd initiation, final leaf number, time to 50% curd maturity, spread of curd maturity, or marketable yield. In a subsequent experiment, similar plant-raising treatments applied to seedlings of one cultivar again produced transplants of a range of sizes and differences were reduced rapidly after transplanting with only small differences in times of curd initiation and maturity (Wurr, Cox & Fellows, 1986).

These results are consistent with the proposal of Bleasdale (1966, 1982) that differences in plant weight (i.e. biological yield) established early in the growth of two populations of a crop can be moderated or completely lost due to the effects of inter-plant competition later in the growth of the crop. According to Bleasdale's model, once total weight differences between plants of the two populations have been removed then subsequent growth should occur at the same rate for both populations. However, this model considers only total dry matter and the situation can be more complex for crops such as broccoli and cauliflower in which economic yield consists of a plant part, rather than the whole plant, since factors causing early differences in total dry weight and/or distribution of dry weight may also influence the initiation and development of the harvested part.

McKee (1981a) has stated that the effects of the transplanting check are often more deleterious to normal development for physiologically older transplants and that this is probably due to the fact that such plants have less opportunity for readjustment of their vegetative development prior to the onset of the reproductive phase of growth. In the current experiments the smaller transplanting check experienced by plants of the field module treatment as compared to the field bare-root treatment (Figures 3.1, 3.2 and 3.3,) resulted in an early advantage in vegetative growth which remained, to some extent, at the time at which reproductive growth commenced (Table 3.7) and persisted until harvest resulting in earlier maturity of the former treatment (Table 3.9).

### 3.3.4.2.3 Spread of maturity

Although there were no differences in mean spreads of maturity (H4TO36) between module-raised and bare-root treatments produced in the same environment (i.e. in the greenhouse or in the field), the field-raised treatments had greater spreads of maturity than those raised in the greenhouse (Table 3.9). No signs of initiation of heads were detected at Harvest 1 of the observation experiment (i.e. at the time of transplanting) in plants raised in either greenhouse or field (3.3.3.4.2). Thus, it would seem that any difference in spread of head initiation (and hence, spread of head maturity), resulting from differences in environmental factors between the greenhouse and field raising environments, would have been caused indirectly through an effect on vegetative growth rather than a direct effect on head initiation itself.

The less uniform maturity of the field-raised treatments may have been due to a more variable transplanting check to growth resulting from a combination of the larger size (at transplanting) of the field-raised transplants and greater variability in the size of the field-raised transplants as a result of greater inter-plant competition prior to transplanting. Salter & Fradgley (1969a) found that delayed transplanting of cauliflower seedlings raised in a field seed-bed resulted in a lengthening of the crop maturity period, compared to seedlings transplanted at an earlier stage of growth, particularly when seedlings were raised at high densities in the seed-bed.

In the current experiment, the suggestion that greater inter-plant competition prior to transplanting of the field-raised transplants, compared to the greenhouse-raised transplants, resulted in greater inter-plant variability, at the time of transplanting, amongst the field-raised transplants is supported by the results of Harvest 1 of the observation experiment (Table 3.5). However, the proposition that differences in spread of head maturity may have been partially due to treatment differences in inter-plant uniformity prior to transplanting and partially due to a more variable transplanting check to growth experienced by the field-raised transplants are not supported by the results of the observation experiment where no consistent pattern

of treatment differences in inter-plant variability of shoot dry weight were detected across the three post-transplanting harvests (Table 3.5). The fact that a clear pattern was not recorded may be a reflection of the small sample size from which the observation experiment data were derived (3.3.3.3).

An important point which the spread of maturity results (Table 3.9) illustrate is that had the two 'commercial' alternatives (viz. field-raised bare-root and greenhouse-raised module transplants) been compared in isolation, then the 'module-raised transplants' might have been declared to have matured more uniformly than the 'bare-root transplants' and this difference might then have been attributed to a less variable transplanting check to growth of the module-raised transplants due to minimal root disturbance and the buffering effect of the module medium on post-transplanting water relations. When the results from all of the treatments included in the current experiment are considered, it is apparent that any recorded difference in the spread of head maturity between a 'module-raised transplant' treatment and a 'bare-root transplant' treatment could well be due to a combination of the effects of plant size at transplanting and/or seedling raising environment as much as to any effects of root damage or improved water relations during establishment due to the presence of the module medium.

#### 3.3.4.2.4 Yield

Greenhouse-raised plants were similar in terms of shoot dry weight, distribution of shoot dry weight, leaf number and development of terminal heads at the time of the final harvest of the observation experiment irrespective of transplanting treatment (3.3.3). Although no further measurements were made before harvesting of the mature heads, it is assumed that plants of these treatments would have subsequently followed similar patterns of growth and development resulting in similar maturity characteristics and yields. The results of the main experiment are in agreement with this conclusion in that there were no significant differences in time to maturity (3.3.4.2.2), spread of maturity (3.3.4.2.3), yield, head weight or head diameter (Table 3.9) between the greenhouse-raised treatments.

Mean yield, mean head weight and mean head diameter for the field module treatment were 13%, 16% and 9% higher, respectively, than for the field bare-root treatment (Table 3.9). Field module plants had a higher shoot dry weight and were more advanced in terms of growth of the terminal head than field bare-root plants at the time of the final harvest of the observation experiment (3.3.3). While it is apparent how these early differences could have resulted in the earlier maturity time of the field module treatment it is not apparent how the observed differences in vegetative growth and distribution of dry matter or initiation of reproductive growth might have resulted in the difference in mean head weight between the field module and field bare-root treatments.

Although there have been a number of studies investigating factors which influence the initiation of reproductive growth in broccoli (1.2.3.3) there is little published information describing the growth of broccoli heads after initiation under either controlled or field conditions. In the current study, there were insufficient sampling occasions in the observation experiment to allow a thorough examination of the growth and development of parts of plants of the various establishment treatments throughout the growing period of the crop.

Head weight is determined by an interaction of components including head diameter and the diameter of the length of stem attached to the head after trimming (butt diameter). Head weight, head diameter, and butt diameter all decrease with an increase in plant density and, on a relative basis, head weight is more responsive to plant density than either of the two components (Chung, 1985a). In the present study, differences between treatment means for head weight were proportionally greater than differences between means for head diameter (Table 3.9). It was noted during harvesting of the experiment that butt diameters appeared to be larger for heads of the field module treatment as compared to those of the other treatments. This observation was not made until 51 days after transplanting, by which time most of the heads of the field module treatment had been harvested: thus, insufficient data could then be gathered to allow an objective analysis of this observation. However, the higher head weight of the field module treatment may have been partly due to plants of that

treatment having thicker stems at the time of maturity. Butt diameter in broccoli has been shown to be affected by plant spacing (Crisp et al., 1986) and may well be influenced by crop establishment method or other cultural practices.

In field experiments with cauliflowers, crop establishment methods have been shown to have marked effects on maturity date and curd weight. The use of methods of propagation which increase early inter-plant competition and produce a transplanting check have been shown to result in increased time from sowing to maturity and decreased curd weight (Kesavan, Crisp, Gray & Dowker, 1976; Crisp & Kesavan, 1978; Salter & Fradgley, 1969a,b). Thus, it appears that unchecked early growth of cauliflower plants results in early maturity and good yield, whereas an early check to growth may result in a reduction in yield, with no compensation by a longer period of growth (Crisp, 1984).

In the context of the current experiments with broccoli, this type of response is consistent with the slightly earlier maturity and larger head size of the field module plants as compared to the field bare-root plants. However, it does not explain why the plants raised in modules in the greenhouse which were smaller at transplanting and presumably suffered less of a transplanting check did not produce heads as large as the field module plants. An explanation for this result is not easily forthcoming but it is possible that temperature differences between the field and the greenhouse during the raising of the transplants hold the key to this pattern.

Although agronomic practices resulting in differences in the early growth of the plants have been shown to result in differences in the marketable yield of cauliflower and (in the present study) broccoli, little is known of the mechanism by which differences in the eventual size of the marketable parts of the individual plants are brought about.

Restricted leaf growth, due to transplanting treatment, during the period of initiation of reproductive growth has been implicated as a factor in the formation of small, unmarketable curds of cauliflowers (e.g. Wurr & Fellows, 1984) and may

also be a factor in 'premature heading' of broccoli (1.2.3.2). Under conditions of negligible inter-plant competition and frequent irrigation, Salter (1960a) found that there was an allometric relationship between leaf and curd growth of cauliflowers and that curd maturity coincided with the time of maximum leaf weight of the plant. Thus, the final weight of the curd at maturity was determined by the amount of leaf material present. However, the relationship between 'amount of leaf' and mature curd size in cauliflowers is not a simple one: for example, Salter (1959) found a positive, linear relationship between leaf area and curd size of cauliflowers at harvest, but the relationship differed for plants grown under different soil moisture conditions. Thus, under different cultural conditions, plants of different sizes can produce curds of similar size and plants of similar size can produce curds of different size.

There are very few published reports relating total plant weight of broccoli plants to yield and no reports relating the effects of propagation treatments on this relationship have been sighted. Across plant densities ranging from 2.8 to 49.0 plants  $m^{-2}$ , Chung (1985a) found a positive, linear relationship between total plant dry matter produced and 'optimum marketable spear yield' for each of three sowings of broccoli cv. 'Futura'. Salter, Andrews & Akehurst (1984) found that harvest index, i.e. the ratio of head fresh weight to above-ground plant weight, was consistent over the density range 20 to 100 plants  $m^{-2}$  for each of three sowings of 'neo-calabrese'. In each of these cases it appeared that head weight was proportional to plant size at harvest, but the relationship differed with sowing date.

While the final size of the yield organ of a cauliflower or broccoli plant will be determined to some extent by the amount of 'available assimilate' (and, hence, will be related to leaf area or leaf weight) it will also be determined by the morphology and development of the yield organ itself (e.g. Hardwick, 1984). Very little is known of factors which determine the morphology of a broccoli inflorescence - e.g. number and eventual size of bud clusters (branches), shape, angle of branching - or of factors which influence the development of flower buds and elongation of the individual peduncles of the head which determine the time at which the head must be harvested.

There is a need for further research describing the growth and development of the whole broccoli plant and of its various organs. In particular, a consideration of source-sink relationships in broccoli might provide important insights into the mechanisms by which propagation conditions and cultural methods influence the relationship between vegetative and reproductive growth and development and, hence, final crop yield.

One of the difficulties in studying source-sink relationships for green sprouting broccoli and in then relating them to cultural practices and economic yields is that broccoli heads are not discrete plant parts and may be harvested with more or less stem attached. In source-sink experiments an acceptable definition for the inflorescence (i.e. 'sink') would be required. The definition of the 'economic sink' varies with end use and local custom. For example, Cutcliffe (1971, 1975a,b), Bull (1977, 1980), Chung (1982) and Dufault & Waters (1985) used 150mm from the top of the head to the butt end of the trimmed 'spear'; whereas Thompson & Taylor (1970) cut stems to a length of c. 40mm greater than the maximum head diameter. Salter, Andrews & Akehurst (1984) did not specify the stem length they used in determining yields in their experiments.

#### 3.3.4.2.5 Row location

The higher head weights and head diameters in outer rows of the beds can be attributed to the effectively lower plant density of plants in the outer rows compared with those in the inner rows. Thompson & Taylor (1976) and Bussell (1984b) have also noted, where broccoli crops were grown in beds, that plants in outer rows produced larger and heavier heads than those in inner rows of beds.

The earlier maturity of the outer rows compared to the inner rows was quite consistent across all plots of the experiment (e.g. Figure 3.7) and it seems likely that this effect was also a consequence of the effectively lower plant density of plants in the outer rows. However, Thompson & Taylor (1976) did not report maturity times of outer and inner rows of beds and no consistent effect of plant density on the maturity time of terminal heads of broccoli has been reported in

experiments where wide ranges of plant densities have been compared (1.2.5.3). Although the difference in mean time to maturity between outer and inner rows of beds was not large it would have contributed towards the spreads of maturity of whole beds in this experiment.

The differences in head maturity times and head sizes between outer and inner rows of beds recorded in this experiment are relatively unimportant in the context of current methods of production for the broccoli crop (1.2.4.2) but they have important implications should a change in cultural techniques be considered. Differences in head sizes and head maturity times can be expected to increase with an increase in the ratio of the distance between outer rows of adjacent beds to that between rows on the same bed. Hence, these differences could be important if the crop were to be grown on beds at high plant densities for once-over harvesting and freezing of whole heads as has been proposed in other countries (e.g. Chung, 1982, 1985b; Salter, Akehurst & Andrews, 1984) because uniformity of maturity and uniformity of head size are of critical importance in that type of production system.

In contrast to selectively harvested crops, wheelings between crop beds are not required for access to the crop for once-over harvesting. Thus, the bed system of growing could be dispensed with in favour of a system in which a constant plant spacing across the field is interrupted by as few wheelings as are necessary to allow the passage of machinery for crop establishment and pesticide application. Adoption of such a system would result in increased uniformity of maturity and uniformity of head size through a reduction in the proportion of the crop growing on the 'edges of beds' and could also be expected to result in increased yields on a per hectare basis through a decrease in the proportion of total crop area taken up by wheelings. Alternatively, a bed system of growing could be used and the 'edge effect' reduced by varying in-row and/or between-row spacing for outer and inner rows of the bed (Sutherland & Benjamin, 1987).

## CHAPTER 4

### SUMMARY, CONCLUSIONS AND GENERAL DISCUSSION

#### 4.1 Summary and conclusions

Over the last decade, there has been a world-wide move towards increased use of module-raised transplants for the establishment of transplanted vegetable crops. In New Zealand, the trend away from bare-root transplants towards module-raised transplants was led by processing tomato growers in Gisborne in the 1984/85 growing season and has since expanded to other crops particularly cabbage, cauliflower, green sprouting broccoli and lettuce. In the late 1980's, there were an estimated 40 million module-raised transplants produced per annum in New Zealand (Wood, 1988). This rapid move away from bare-root transplants to module-raised transplants in the N.Z. vegetable industry has occurred without conclusive evidence of yield or uniformity of maturity advantages from the use of module-raised transplants under N.Z. conditions (Bussell, 1982b).

The experiments reported herein were designed to examine the post-transplanting performance of bare-root and module-raised transplants of tomato and broccoli, two important vegetable crops commonly established from seedling transplants in New Zealand. The conclusions which can be drawn from the two experiments and their practical application to the commercial production of the two crops are discussed below.

(1) The effects of transplant type on early crop establishment of tomato and broccoli. In both the tomato and broccoli experiments, vegetative growth was initially more rapid for module-raised than for bare-root transplants. In the tomato experiment, plants established from module-raised transplants had higher shoot and root dry weights 35 days after transplanting and were observed to commence flowering approximately two weeks earlier than plants established from

bare-root transplants.

In the broccoli experiment it was estimated that, 18 days after transplanting, plants established from module-raised transplants produced in the field and in the greenhouse were 7 and 5 days, respectively, more advanced in terms of shoot dry weight than plants established from the corresponding bare-root treatments. These results were attributed to reduced root disturbance at transplanting for module-raised transplants.

It was observed that the pattern of growth of broccoli transplants raised in modules in the greenhouse was similar, whether they were transplanted with or without the module of growing medium around their roots. It is concluded that, under good establishment conditions, the lack of root disturbance was a more important factor in the more rapid establishment of the module-raised transplants, as compared to bare-root transplants, than the presence of a reserve of water in the growing medium of the module. However, the importance of the module as a reservoir of water for transplanted seedlings may be more important under more stressful establishment conditions (Cox, 1984b).

The more rapid establishment of module-raised, as compared to bare-root, transplants has important implications for the commercial production of both tomato and broccoli crops. Rapid establishment of both crops is important in establishing a crop canopy to improve competition with weeds and in the case of the tomato crop is vital to the efficacy of post-planting herbicide applications (Fortino & Splittstoesser, 1974a,b; Stevenson, 1977). Hence, rapid establishment of tomato and broccoli crops achieved by the use of module-raised transplants may have benefits for commercial producers of the two crops independent of any direct effects on earliness or uniformity of crop maturity.

(2) The effects of transplant type on the timing of crop maturity of tomato and broccoli. In both the tomato and broccoli experiments, observed differences in vegetative growth after transplanting and earlier commencement of the transition from vegetative to reproductive growth for module-raised transplants, as compared to bare-root transplants, were not always translated into earlier crop

maturity. Plants established from bare-root and module-raised tomato transplants had a very similar pattern of maturity of red fruit. The loss of the early development advantage of the module-raised transplants by the time of fruit maturity was not able to be explained by conversion to a thermal time scale.

The advantage in shoot dry weight gained from the more rapid growth during early establishment of broccoli plants established from module-raised transplants, as compared to bare-root transplants, was greatly reduced by 31-32 days after transplanting and final leaf number was not affected by plant raising or transplanting method. Differences in early growth following transplanting between module-raised and bare-root transplants were greater for field-raised transplants than for those raised in the greenhouse. This was attributed to the greater effect of the transplanting check on the field-raised transplants which were larger at the time of transplanting than those raised in the greenhouse. An earlier transition to reproductive growth was recorded for the module-raised plants, as compared to the bare-root plants, regardless of whether they were raised in the field or in the greenhouse. In the case of the field-raised transplants, the more rapid establishment and chronologically earlier initiation of the terminal head of module-raised transplants, as compared to bare-root transplants, was translated into earlier maturity at harvest. There was no difference in the maturity time of module-raised and bare-root transplants raised in the greenhouse.

These results illustrate that quite large differences in the growth of the tomato and broccoli crops resulting from establishment treatments can persist for some time into the growth of the crop and yet can be moderated by environmental influences during subsequent development and result in little difference in maturity at harvest. Similar results have been obtained in comparisons of seed treatments in tomatoes (Bussell, 1980; Wolfe & Sims, 1982; Leskovar & Sims, 1987; Barlow & Haigh, 1987; Alvarado, Bradford & Hewitt, 1987) and transplant-raising methods in cauliflowers (Wurr, Cox & Fellows, 1986). These results are consistent with the proposal of Bleasdale (1966, 1982) that, where significant inter-plant competition occurs for a considerable portion of the growth of a crop, early differences in the growth of two populations of a crop can be moderated or completely lost due to the effects of inter-plant competition during subsequent

growth of the crop. However, the results obtained from the field-raised broccoli transplants and from comparisons of direct-seeding and transplanting of tomato in New Zealand (Bussell & Burgmans, 1983) illustrate that if the early differences are large enough they will often persist through to crop maturity.

These results illustrate the principle that, in the absence of absolute knowledge of the interactive effects of all of the environmental factors affecting the ontogeny of the crop, the commercial significance of differences in early growth of a crop (as brought about by establishment treatments) in influencing the date of crop maturity can only be properly investigated by growing crops to maturity. The results of the tomato and broccoli experiments were obtained from transplants established under less stressful establishment conditions (transplanting by hand, well-prepared field soil, irrigation immediately following transplanting, favourable weather conditions during establishment) than often occur in commercial practice. Further experiments under the range of conditions typical of commercial crop production may establish greater differences in the timing of maturity between plants established as module-raised and bare-root transplants of tomato, broccoli or other transplanted vegetable crops. It can be expected that more rapid progress in this area of research will be made in crops such as lettuce, where the harvested part of the plant represents the bulk of the vegetative growth of the plant.

An interesting observation from the broccoli experiment is that had the two 'commercial' treatments (viz. greenhouse-raised module transplants and field-raised bare-root transplants) been compared in isolation, then any commercial advantage obtained from 'module-raised transplants', as compared to 'bare-root transplants', might have been attributed to a reduction in transplanting check when it could well have been due to a combination of the effects of transplanting size or seedling raising environment as much as to any effects of reduced root disturbance or improved water relations during establishment.

(3) The effects of transplant type on the uniformity of crop maturity of tomato and broccoli. In the tomato experiment, the visually more uniform establishment of module-raised transplants, as compared to bare-root transplants,

at transplanting and during the early stages of establishment in the field was not reflected in a greater concentration of fruit maturity. In the broccoli experiment, no consistent pattern of variability in shoot dry weight during early establishment amongst transplant types was recorded: this may have been due to the small sample size used. The spread of terminal head maturity was slightly reduced for greenhouse-raised transplants compared to the larger field-raised transplants.

As in the discussion on timing of crop maturity (see (3) above), it is postulated that greater differences between module-raised and bare-root transplants in terms of variability of early growth and uniformity of maturity might have been recorded had the experiments been conducted under less favourable field establishment conditions. The significance of probable reductions in the variability of the transplanting check to growth and resultant increases in the uniformity of crop maturity resulting from the use of module-raised versus bare-root transplants needs to be established from further research under a range of establishment conditions similar to those likely to be encountered in commercial crop production.

(4) Transplant production methods for tomato and broccoli. The 'Plixipot' tray (module volume = 36 cm<sup>3</sup>, 462 modules m<sup>-2</sup>) used in the broccoli and tomato experiments was chosen because, at the time that the experiments were conducted, it was one of the few module trays commercially available in New Zealand. Reduction of in-field duration was considered to be an important possible advantage of the use of module-raised transplants of both crops and seedlings of both species raised in this module size were of a size similar to commercially produced bare-root transplants. Thus, transplants produced in the 36 cm<sup>3</sup> modules were expected to provide useful comparisons with bare-root transplants and to be suited to existing transplanting equipment and cultural practices used in the production of the two crops.

In the time since the experiments were completed, a range of module tray types differing in module volume, shape and spatial arrangement have become available in New Zealand (Wood, 1988). The module size currently favoured by commercial producers of broccoli and processing tomatoes in New Zealand is approximately 12 cm<sup>3</sup> in trays containing 1300 to 1800 modules m<sup>-2</sup>. A proportion of processing

tomato transplants are also often produced in 5 cm<sup>3</sup> modules in trays containing 1800 modules m<sup>-2</sup>. There is a need for further research into production methods for module-raised transplants to guide the choice of growers and nurserymen in such areas as module size and shape (Cox, 1984a), module growing media and nutritional regimes (Wurr, Cox & Fellows, 1986; Fisher & MacKay, 1988), and the provision of optimal conditions for establishment in the field (Kratky, Cox & McKee, 1980; Cox, 1984b), if the full benefits of the use of module-raised transplants in rapidly establishing a uniform stand of seedlings in the field are to be realised.

#### 4.2 General discussion

The experiments conducted on tomato and broccoli have raised several aspects of the physiology and crop production of the two species which are worthy of further research attention. These are discussed below.

(1) The role of 'hardening' in the production of module-raised transplants. Post-transplanting plant losses in the broccoli experiment were attributed to physical damage by the wind. It is suggested that it may be desirable to slightly 'harden' greenhouse-raised module transplants to withstand physical damage during transplanting and early establishment in the field. McKee (1981b) reviewed the literature concerning hardening or conditioning of transplants and concluded that hardened plants are typically smaller than unhardened ones after recovery from the transplanting check and that this difference was unlikely to be made up by the time of harvest.

However, subsequent research has shown that moderate hardening treatments may have little or no deleterious effects on crop maturity and yield of module-raised transplants (e.g. Wurr, Cox & Fellows, 1986). Furthermore, the ability to control the growth of module-raised seedlings and 'hold' them for delayed transplanting, should field conditions be unsuitable for transplanting is often cited as one of the major reasons behind the adoption of module-raised transplants for tomatoes, brassicas and other vegetable crops (Fisher & MacKay, 1988; Hiron & Symonds, 1985). This is an important benefit to the use of module-raised transplants

because there is limited scope for controlling the growth of bare-root transplants raised in a seed-bed.

Further research is required to establish the best means of temporarily retarding the growth of module-raised transplants during periods of unsuitable transplanting conditions in the field and to investigate methods of producing transplants better able to withstand handling during transplanting and physical damage during early establishment in the field. This research should evaluate 'traditional' hardening methods - altered irrigation, nutrition and temperature regimes (McKee, 1981b) - as well as the potential for the use of 'mechanically-induced stress' (Biddington & Dearman, 1985, 1986) in the production of module-raised transplants.

(2) The effects of environmental conditions on the growth and yield of broccoli. In the broccoli experiment, transplant production methods and the different environmental conditions under which transplants were raised had little effect on final leaf number, even though minimum temperatures experienced by the field-raised seedlings were in the range reported to induce early initiation of reproductive development in broccoli. Further investigations are required to determine the extent to which 'premature heading' is likely to be a problem in broccoli crops grown in N.Z. In particular, research on the responses of various broccoli hybrids to environmental conditions would provide useful information on which seed suppliers and commercial producers could base hybrid selections for particular production localities and times of year.

It is not apparent how the differences in vegetative growth, distribution of dry matter and initiation of reproductive growth between the broccoli plants raised in modules in the field and the field-raised bare-root transplants might have resulted in the recorded difference in head weight (i.e. yield). This may have been a result of a greater transplanting check to growth suffered by the bare-root transplants (e.g. Crisp, 1984) but this does not explain why the smaller module-raised transplants produced in the greenhouse did not produce heads as large as their field-raised counterparts.

Apart from studies of the role of temperature in the initiation of reproductive growth, there is little published research on the influence of environmental factors on the growth and development of the broccoli plant. Controlled environmental studies investigating the influence of environmental factors on leaf production, and initiation and morphology of the terminal inflorescence would provide valuable insights into the mechanisms by which propagation conditions and crop cultural methods influence the relationship between vegetative and reproductive growth and, hence, crop yield.

(3) Plant spacing effects in sprouting broccoli. In the broccoli experiment, terminal heads produced in the outer rows of the four-row beds were heavier, had a larger diameter and matured earlier than those produced by plants located in the inner rows. This effect was attributed to the effectively lower plant density of plants in the outer rows. Further research is required, under a wider range of conditions, to determine the importance of this source of variation in head maturity and size in broccoli crops grown on beds. The development of cropping systems for the production of broccoli heads of uniform size at a single harvest may require a reduction of these size and maturity variations through a reduction in the proportion of the crop taken up by tractor wheelings or by variation of row spacings (Sutherland & Benjamin, 1987).

Plant spacing *per se* was not investigated in the broccoli experiment, but high yields of heads of a size considered commercially acceptable for processing and fresh market use were achieved from plants grown at a much higher density than is currently recommended for the broccoli crop in New Zealand. Further investigations are required to determine whether increased yields achieved from higher density plantings of broccoli would justify the associated increases in crop establishment and harvesting costs under N.Z. conditions.

(4) Components of variation in the maturity of processing tomatoes. Published data (Bussell, 1971; Fisher & Julian, 1988) lend support to the proposal that a sharp rise and fall of red fruit yield about the optimum once-over harvest date, as recorded in the tomato experiment, may be typical for determinate tomato crops grown in New Zealand. This pattern of yield with time has a number of

important implications for both commercial crop production and research into the processing tomato crop.

Due to the sharp peak of red fruit yield with time, there is a high cost attached to inaccurate estimation of the optimum harvest date of a tomato crop. The development of objective methods of predicting and assessing optimum maturity dates would be useful for reducing errors and costs in tomato field research, but will have limited commercial value due to the logistical difficulties associated with harvesting each tomato crop in a programme of sequential plantings within the short period that it is at, or near, its optimum level of yield.

Hence, the development of crop production methods which extend the period over which optimum or near-optimum yields of individual tomato crops are available is an important research need for the processing tomato industry in New Zealand. Observations made in the tomato experiment reported herein indicate that there is considerable potential to extend the period of optimum yield under N.Z. conditions without the development of cultivars or crop cultural practices which extend the vine storage of individual red fruit.

The immediate research requirement is to find means of reducing variability in the timing of maturity of individual fruits within the crop. A basic study of the growth and development of the tomato crop under Hastings or Gisborne field conditions recording flowering, fruit set and the development of individual fruits within-plants and amongst-plants in the crop would form a useful starting point. From such a fundamental study, the important sources of variation in the maturity times of individual tomato fruits could be identified. This would allow an assessment to be made of the relative importance of current cultural practices (such as crop establishment method, plant spacing and chlorethephon application) in influencing the uniformity of crop maturity. Research effort could then be directed towards changes to the culture of the crop most likely to bring about increased uniformity of crop maturity and corresponding increases in yield.

## LITERATURE CITED

- Alvarado, A.D.; Bradford, K.J. & Hewitt, J.D. (1987). Osmotic priming of tomato seeds: effects on germination, field emergence, seedling growth, and fruit yield. *Journal of the American Society for Horticultural Science* 112, 427-432.
- Alvey, N.G.; Banfield, C.F.; Baxter, R.I.; Gower, J.C.; Krzanowski, W.J.; Lane, P.W.; Leech, P.K.; Nelder, J.A.; Payne, R.W.; Phelps, K.M.; Rogers, C.E.; Ross, G.J.S.; Simpson, H.R.; Todd, A.D.; Wedderburn, R.W.M. & Wilkinson, G.N. (1977). *Genstat: a general statistical program*. Rothamsted Experimental Station, Harpendon, Hertfordshire, England.
- Anon. (1977). Growing process tomatoes for machine harvesting in Hawke's Bay. Miscellaneous publication. N.Z. Ministry of Agriculture and Fisheries, Hastings. 19pp.
- Anon. (1981). Raising bare-root tomato transplants in low polythene tunnels. Unpublished leaflet. Agricultural Research Division, J. Wattie Canneries Ltd, Hastings. 2pp.
- Baggett, J.R. & Mack, H.J. (1970). Premature heading of broccoli cultivars as affected by transplant size. *Journal of the American Society for Horticultural Science* 95, 403-407.
- Baker, R.T. (1977). Insect control in brassica crops. pp. 34-43 *In Proceedings of 1977 Brassica Growers Short Course*. Department of Horticulture, Massey University, N.Z.
- Banes, J. (1984). Modules - the next move. *Grower, U.K.* 102, (15) 33, 36, 37.
- Baqar, M.R.; Edwards, R.A. & Lee, T.H. (1975). Chemical regulation of ripening of processing tomatoes in the field. *Australian Journal of Experimental Agriculture and Animal Husbandry* 15, 839-846.
- Barlow, E.W.R. & Haigh, A.M. (1987). Effect of seed priming on the emergence, growth and yield of UC82B tomatoes in the field. *Acta Horticulturae* 200, 153-161.
- Berlyn, G.P. & Miksche, J.P. (1976). *Botanical Microtechnique and Cytochemistry*. Iowa State University Press, Ames, Iowa. viii + 326p.

- Biddington, N.L. & Dearman, A.S. (1985). The effect of mechanically induced stress on the growth of cauliflower, lettuce and celery seedlings. *Annals of Botany* 55, 109-119.
- Biddington, N.L. & Dearman, A.S. (1986). The effects of mechanically-induced stress on water loss and drought resistance in lettuce, cauliflower and celery seedlings. *Annals of Botany* 56, 795-806.
- Bleasdale, J.K.A. (1966). Plant growth and crop yield. *Annals of Applied Biology* 57, 173-182.
- Bleasdale, J.K.A. (1982). The importance of crop establishment. *Annals of Applied Biology* 101, 411-419.
- Borkowski, J.; Czapski, J. & Horbowicz, M. (1983). The influence of different methods of tomato plant treatment by Ethrel on the ripening and level of ethephon residue in tomato fruit. *Acta Horticulturae* 137, 389-394.
- Bouwkamp, J.C. & Honma, S. (1969). The inheritance of frost resistance and flowering response in broccoli (*Brassica oleracea* var. *italica*). *Euphytica* 18, 395-397.
- Bradbury, S. (1973). *Peacock's elementary microtechnique*. 4th edition. Edward Arnold, London. x + 278p.
- Brandon, B.R. (1970). Improving yields of process tomatoes in H.B. N.Z. *Journal of Agriculture* 121, 106, 107, 109.
- Brendler, R.A. (1970). Time of harvest for machine-harvested broccoli. *California Agriculture* 24, (1) 6-7.
- Brendler, R.A. (1971). Once-over harvesting of broccoli for freezing. *California Agriculture* 25, (9) 12-13.
- Brouwer, R. (1983). Functional equilibrium: sense or nonsense? *Netherlands Journal of Agricultural Science* 31, 335-348.
- Brown, I.L. (1958). Commercial outdoor tomato production in Nelson. N.Z. *Journal of Agriculture* 96, 73, 75, 77, 79, 81.

- Bull, P.B. (1977). Weed control in direct drilled green sprouting broccoli. *Proceedings of the 30th N.Z. Weed and Pest Control Conference*, 86-90.
- Bull, P.B. (1980). Growing green sprouting broccoli (*Brassica oleracea* var. *italica*) for continuity of production, from single harvest, in Canterbury. *M. Hort. Sc. thesis*. Lincoln College, University of Canterbury, N.Z. ix + 123p.
- Burgmans, J.L. (1984). Prospects for process tomatoes. *N.Z. Commercial Grower* 39, (1) 34.
- Burgmans, J.L. & Bussell, W.T. (1983). Cultivar testing for direct seeded pulp and paste process tomatoes in Hawke's Bay. *N.Z. Journal of Experimental Agriculture* 11, 257-263.
- Burgmans, J.L. & Lill, R.E. (1985). The need for a high dry-matter tomato for processing. *N.Z. Commercial Grower* 40, (1) 11.
- Bussell, W.T. (1971). Some effects of Ethrel on ripening and yield of dwarf tomatoes. *Proceedings of the Agronomy Society of New Zealand* 1, 139-145.
- Bussell, W.T. (1973). Effects of soil moisture on ripening in dwarf tomatoes after ethephon treatment. *N.Z. Journal of Experimental Agriculture* 1, 381-382.
- Bussell, W.T. (1978). Trials with single-harvested green sprouting broccoli. *N.Z. Commercial Grower* 33, (9) 30-31.
- Bussell, W.T. (1980). Emergence and growth of tomatoes after sowing chitted and unchitted seed. *N.Z. Journal of Experimental Agriculture* 8, 159-162.
- Bussell, W.T. (1982a). Dwarf tomatoes - effect of ethrel on ripening. Unpublished report. Levin Horticultural Research Centre, N.Z. Ministry of Agriculture & Fisheries. 4pp.
- Bussell, W.T. (1982b). The case for high quality vegetable transplants. *N.Z. Agricultural Science* 16, (1) 39-40.
- Bussell, W.T. (1983). Green sprouting broccoli: cultivar testing. Unpublished report. Levin Horticultural Research Centre, N.Z. Ministry of Agriculture & Fisheries. 9pp.

- Bussell, W.T. (1984a). Green sprouting broccoli cultivar testing. *N.Z. Commercial Grower* 39, (1) 33.
- Bussell, W.T. (1984b). Personal communication. Levin Horticultural Research Centre, N.Z. Ministry of Agriculture & Fisheries.
- Bussell, W.T. & Burgmans, J.L. (1983). Earlier harvest of processing tomatoes. *N.Z. Commercial Grower* 38, (7) 38-39.
- Bussell, W.T. & Dobson, B.G. (1985). Fresh market green sprouting broccoli. *N.Z. Commercial Grower* 40, (6) 44-45.
- Bussell, W.T. & Halligan, G. (1982). The interval between application and harvest of chlorthaliprophos-treated single-harvested dwarf tomatoes. *N.Z. Journal of Experimental Agriculture* 10, 419-424.
- Bussell, W.T.; Wraight, M.J. & Burgmans, J. (1975). Spacing of tomatoes for machine harvesting. *Proceedings of the Agronomy Society of New Zealand*, 5, 41-43.
- Carew, J. & Thompson, H.C. (1948). A study of certain factors affecting "buttoning" of cauliflower. *Proceedings of the American Society for Horticultural Science* 51, 406-414.
- Chowings, J.W. (1974). Vegetable variety performance trials technique - brassica crops. *Journal of the National Institute of Agricultural Botany* 13, 168-185.
- Chung, B. (1982). Effects of plant density on the maturity and once-over harvest yields of broccoli. *Journal of Horticultural Science* 57, (3) 365-372.
- Chung, B. (1985a). The effects of sowing time and plant density on the once-over harvest yields of broccoli. *Journal of Horticultural Science* 60, 57-64.
- Chung, B. (1985b). Effect of plant density on the sequential harvest yield of broccoli. *Australian Journal of Experimental Agriculture* 25, 959-962.
- Cooper, A.J. (1979). *The ABC of NFT*. Grower Books, London. x + 181 p.

- Cornforth, I.S. (1982). Soils and fertilisers: soil analysis - interpretation. *Aglink FPP 556*. Media Services, N.Z. Ministry of Agriculture and Fisheries, Wellington. 3p.
- Cox, E.F. (1984a). The effects of shape of compost blocks on the propagation, transplant establishment and yield of four vegetable species. *Journal of Horticultural Science* 59, 205-212.
- Cox, E.F. (1984b). The effects of irrigation on the establishment and yield of lettuce and leek transplants raised in peat pots. *Journal of Horticultural Science* 59, 431-437.
- Cox, E.F.; Wurr, D.C.E. & Howkins, W.E. (1985). Transplant establishment - cauliflower. *National Vegetable Research Station Annual Report for 1984*, 113.
- Cox, T.I.; Ingle, A. & Kerr, R.M. (1984). Herbicides in commercial vegetable crops: a guide. *Aglink HPP 78*. Information Services, N.Z. Ministry of Agriculture and Fisheries, Wellington. 6pp.
- Crisp, P. (1984). Factors causing small curds in cauliflower crops. *Journal of Agricultural Science, Cambridge* 102, 405-413.
- Crisp, P. & Kesavan, V. (1978). Genotypic and environmental effects on curd weight of autumn-maturing cauliflowers. *Journal of Agricultural Science, Cambridge* 90, 11-17.
- Crisp, P.; Gray, A.R.; Angell, S.M.; Salter, P.J.; Akehurst, J. & Sutherland, R.A. (1986). The effects of plant spacing on the breeding of broccoli from an expanded genetic base. *Journal of Horticultural Science* 61, 205-215.
- Crowder, R.A. (1970). High density tomatoes for processing. *N.Z. Journal of Agriculture* 121, (6) 70, 71, 73, 75.
- Cutcliffe, J.A. (1971). Effects of plant population, nitrogen and harvest date on yield and maturity of single-harvested broccoli. *HortScience* 6, 482-484.
- Cutcliffe, J.A. (1975a). Cultivar and spacing effects on incidence of hollow stem in broccoli. *Canadian Journal of Plant Science* 55, 867-869.

- Cutcliffe, J.A. (1975b). Effects of plant spacing on single-harvest yields of several broccoli cultivars. *HortScience* 10, 417-419.
- Daubeny, H.A. (1961). Earliness in tomato varieties with special reference to the ability to set fruit at low temperature. *Proceedings of the American Society for Horticultural Science*, 78, 445-449.
- Davis, R.M. Jr.; Fildes, R.; Baker, G.A.; Zahara, M.; May, D.M. & Tyler, K.B. (1970). A method of estimating the potential yield of a vegetable crop obtainable in a single harvest. *Journal of the American Society for Horticultural Science* 95, 475-480.
- Davis, R.M. Jr.; Smith, P.G.; Schweers, V.H. & Scheuerman, R.W. (1965). Relationships between fruit-set and developing fruit load in tomato. *Proceedings of the American Society for Horticultural Science* 86, 557-564.
- Davis, R.M. Jr.; Smith, P.G.; Schweers, V.H.; Scheuerman, R.W. & Millett, A.H. (1969). Components of variation in tomato harvest patterns. *Journal of the American Society for Horticultural Science* 94, 538-541.
- ✓ Diputado, M.T. (1989). Growth and development studies with broccoli (*Brassica oleracea* var. *italica*). *Ph D thesis*. Massey University, N.Z. xvii + 149p.
- Dostal, H.C. & Wilcox, G.E. (1971). Chemical regulation of fruit ripening of field-grown tomatoes with (2-chloroethyl)phosphonic acid. *Journal of the American Society for Horticultural Science* 96, 656-660.
- Dufault, R.J. & Waters, L. Jr. (1985). Interaction of nitrogen fertility and plant populations on transplanted broccoli and cauliflower yields. *HortScience* 20, 127-128.
- During, C. (1972). Fertilisers and soils in New Zealand farming. *Bulletin No. 409 (2nd edition)*. N.Z. Ministry of Agriculture and Fisheries, Wellington, Government Printer. ix + 312pp.
- Eagle, D.J.; Caverly, D.J. & Holly, K. (1981). Diagnosis of herbicide damage to crops. *Reference Book 221*. Ministry of Agriculture, Fisheries & Food, HMSO, London. v + 70pp.

- Edwards, J.I.; Henderson, W.R. & Saltveit, M.E. Jr. (1984). Yield and quality of processing field-grown tomatoes as influenced by inhibitors of ethylene biosynthesis. *HortScience* 19, 579-580.
- Esson, M.J. (1985). Tomatoes: establishment of early direct seeded crops in Hawke's Bay and Gisborne. *N.Z. Commercial Grower* 40, (3) 18.
- Esson, M.J.; Tate, K.G.; Burgmans, J.L. & Geelen, J.A. (1983). Crop establishment failure following direct seeding. *N.Z. Commercial Grower* 38, (9) 33.
- Fery, R.L. & Janick, J. (1970). Response of the tomato to population pressure. *Journal of the American Society for Horticultural Science* 95, 614-624.
- Fery, R.L. & Janick, J. (1971). Effect of time of harvest on the response of tomato to population pressure. *Journal of the American Society for Horticultural Science* 96, 172-176.
- Fisher, K.J. & Julian, A.P. (1988). Some effects of delayed planting of tomato cell transplants on later crop performance. pp. 156-162 *In Proceedings of the International Conference on Stand Establishment for Horticultural Crops*. Pennsylvania State University, University Park, Pennsylvania.
- Fisher, K.J. & MacKay, B.R. (1988). The nutrition of tomato cell transplants. pp. 144-151 *In Proceedings of the International Conference on Stand Establishment for Horticultural Crops*. Pennsylvania State University, University Park, Pennsylvania.
- Fontes, M.R. & Ozbun, J.L. (1970). Effect of growth retardants on growth and flowering of broccoli. *HortScience* 5, 483-484.
- Fontes, M.R. & Ozbun, J.L. (1972). Relationship between carbohydrate level and floral initiation in broccoli. *Journal of the American Society for Horticultural Science* 97, 346-348.
- Fontes, M.R.; Ozbun, J.L. & Powell, L.E. (1970). Are endogenous gibberellin-like substances involved in floral induction? *Nature* 228, 82-83.
- Fontes, M.R.; Ozbun, J.L. & Sadik S. (1967). Influence of temperature on initiation of floral primordia in green sprouting broccoli. *Proceedings of the American Society for Horticultural Science* 91, 315-320.

- Fortino, J. Jr. & Splittstoesser, W.E. (1974a). Response of tomato to metribuzin. *Weed Science* 22, 460-463.
- Fortino, J. Jr. & Splittstoesser, W.E. (1974b). The use of metribuzin for weed control in tomato. *Weed Science* 22, 615-619.
- Frost, D.J. & Kretchman, D.W. (1987). Use of growth retardants to improve ripening uniformity and yield of processing tomatoes. *HortScience* 22, 422-423.
- Frost, D.J. & Kretchman, D.W. (1988). Plant spacial arrangement and density effects on small- and medium-vined processing tomatoes. *Journal of the American Society for Horticultural Science* 113, 51-55.
- Fujime, Y. & Hirose, T. (1979). Studies on the thermal requirements for curd formation and development in cauliflower and broccoli. I. Effects of low temperature treatment of seeds. *Journal of the Japanese Society for Horticultural Science* 48, (1) 82-90. [*Horticultural Abstracts* 50, abstract 1805.]
- Gauss, J.F. & Taylor, G.A. (1969a). A morphological study on the time of reproductive differentiation of the apical meristem of *Brassica oleracea* L. var. *italica*, Plenck, cv. 'Coastal'. *Journal of the American Society for Horticultural Science* 94, 105-108.
- Gauss, J.F. & Taylor, G.A. (1969b). Environmental factors influencing reproductive differentiation and the subsequent formation of the inflorescence of *Brassica oleracea* L. var. *italica*, Plenck, cv. 'Coastal'. *Journal of the American Society for Horticultural Science* 94, 275-280.
- Geelen, J.A. (1983). Personal communication. J. Wattie Canneries Ltd, Hastings.
- Geelen, J.A. (1984a). Personal communication. J. Wattie Canneries Ltd, Hastings.
- Geelen, J.A. (1984b). Weed control recommendations for direct-seeded tomatoes 1984/85. Unpublished leaflet. Agricultural Research Division, J. Wattie Canneries, Hastings.
- Gray, A.R.; Crisp, P.; Ives, S.J. & Angell, S.M. (1984). Broccoli. *National Vegetable Research Station Annual Report for 1983*, 52-53.

- Gray, D.; Steckel, J.R.A. & Ward, J.A. (1979). The effects of fluid sowing pre-germinated seeds and transplanting on emergence, growth and yield of outdoor tomatoes. *Journal of Agricultural Science, Cambridge* 93, 223-233.
- Green, J.C.S. (1980). Plant density and crop establishment studies with tomatoes. *Acta Horticulturae* 100, 129-133.
- Green, J.C.S. (1981). Plant density and crop establishment studies with tomatoes for mechanical harvest. *M. Phil thesis*. Department of Horticulture & Plant Health, Massey University, N.Z. xv + 111p.
- Guttormsen, G. & Moe, R. (1985a). Effect of plant age and temperature on bolting in Chinese cabbage. *Scientia Horticulturae* 25, 217-224.
- Guttormsen, G. & Moe, R. (1985b). Effect of day and night temperature at different stages of growth on bolting in Chinese cabbage. *Scientia Horticulturae* 25, 225-233.
- Hardwick, R.C. (1984). Sink development, phyllotaxy, and dry matter distribution in a large inflorescence. *Plant Growth Regulation* 2, 393-405.
- Hartill, W.F.T. (1982). Control of downy mildews of brassica seedlings and lettuce with systemic fungicides. *N.Z. Journal of Experimental Agriculture* 10, 69-72.
- Haslemore, R.M.; Warrington, I.J. & Roughan, P.G. (1980). Influence of drying method and post-harvest conditions on total nitrogen, soluble sugar, and starch levels in plant tissue. *New Zealand Journal of Agricultural Research* 23, 355-359.
- Hawthorne, B.T. (1981). Clubroot in brassicas: biology and control. *Aglink FPP 483*. Wellington, Media Services, Ministry of Agriculture and Fisheries. 2pp.
- Hegarty, T.W. (1976). Effects of fertiliser on the seedling emergence of vegetable crops. *Journal of the Science of Food and Agriculture* 27, 962-968.
- Hegarty, T.W. & Royle, S.M. (1976). Impedance of calabrese seedling emergence from light soils after rainfall. *Horticultural Research* 16, 107-114.

- Hegarty, T.W. & Royle, S.M. (1978). Soil impedance as a factor reducing crop seedling emergence, and its relation to soil conditions at sowing, and to applied water. *Journal of Applied Ecology* 15, 897-904.
- Hiron, R.W.P. & Symonds, W. (1985). Vegetable propagation in cellular trays. *Leaflet 909*, Ministry of Agriculture, Fisheries and Food. HMSO, London. 12pp.
- Honma, S. (1986). 'Solohead' broccoli. *HortScience* 21, 1244.
- Hull, C.H. & Nie, N.H. (1981) eds. *SPSS Update 7-9: new procedures and facilities for Releases 7-9*. McGraw-Hill, New York. xxi + 402pp.
- Hunt, R. (1978). *Plant Growth Analysis*. Studies in Biology No. 96. Arnold, London. pp. iv + 67.
- ✓ Hutchison, D.A.; Ferguson, A.M. & McErlich, A.F. (1985). Broccoli plant losses in Canterbury. *Proceedings of the 38th New Zealand Weed and Pest Control Conference*, 131-134.
- Johansen, D.A. (1940). *Plant Microtechnique*. McGraw-Hill, New York. xi + 523p.
- June, R.I. (1951). Growing tomatoes for canning in Hawke's Bay. *N.Z. Journal of Agriculture* 83, 107, 109, 111, 112.
- Kahn, B.A.; Conway, K.E. & Fisher, C.G. (1986). Effects of wirestem, wind injury, and iprodione on yields of six broccoli cultivars. *HortScience* 21, 1136-1139.
- Kahn, B.A. & Motes, J.E. (1988). Comparison of fluid drilling with conventional planting methods for stand establishment and yield of spring and fall broccoli crops. *Journal of the American Society for Horticultural Science* 113, (5) 670-674.
- Kahn, B.A.; Shilling, P.G.; Brusewitz, G.H. & McNew, R.W. (1991). Force to shear the stalk, stalk diameter, and yield of broccoli in response to nitrogen fertilization and within-row spacing. *Journal of the American Society for Horticultural Science* 116, 222-227.

- Kesavan, V.; Crisp, P.; Gray, A.R. & Dowker, B.D. (1976). Genotypic and environmental effects on the maturity time of autumn cauliflowers. *Theoretical and Applied Genetics* 47, 133-140.
- Kratky, B.A.; Cox, E.F. & McKee, J.M.T. (1980). Effects of block and soil water content on the establishment of transplanted cauliflower seedlings. *Journal of Horticultural Science* 55, 229-234.
- Leskovar, D.I. & Sims, W.L. (1987). Emergence and yield of tomato (*Lycopersicon esculentum* Mill.) in response to presowing treatments. *Acta Horticulturae* 200, 145-152.
- Logan, S.H. & Boyland, P.B. (1983). Calculating heat units via a sine function. *Journal of the American Society for Horticultural Science* 108, 977-980.
- McKee, J.M.T. (1977). Water relations of seedling transplants. *National Vegetable Research Station Annual Report for 1976*, 60-61.
- McKee, J.M.T. (1981a). Physiological aspects of transplanting vegetables and other crops. I. Factors which influence re-establishment. *Horticultural Abstracts* 51, 256-272.
- McKee, J.M.T. (1981b). Physiological aspects of transplanting vegetables and other crops. II. Methods used to improve transplant establishment. *Horticultural Abstracts* 51, 355-368.
- MacNab, A.A. & Pennypacker, S.P. (1981). A method for field evaluation of treatments to control fruit rots on single-harvest tomatoes. Tomato Breeders' Roundtable; 1981 National Meeting, Beltsville, MD, USA, Feb. 19-20. 6pp.
- M.A.F., (1985). *New Zealand Horticulture Statistics 1985*. Information Services, N.Z. Ministry of Agriculture and Fisheries, Wellington. 52pp.
- Malone, M.T. (1983). Tomatoes. pp. 155-164 In G.S. Wratt & H.C. Smith (eds.) *Plant breeding in New Zealand*. Butterworths, Wellington. 312pp.
- Martin, R.J. (1981). Yield - tenderometer relationships in vining peas. *N.Z. Journal of Experimental Agriculture* 9, 387-391.

- Miller, C.H. (1988). Diurnal temperature cycling influences flowering and node numbers of broccoli. *HortScience* 23, 873-875.
- Miller, C.H.; Konsler, T.R. & Lamont, W.J. (1985). Cold stress influence on premature flowering of broccoli. *HortScience* 20, 193-195.
- Mutton, L.L. (1978a). Effect of moisture stress on the ethephon response in tomatoes. *Scientia Horticulturae* 8, 299-305.
- Mutton, L.L. (1978b). Effects of vapour pressure deficit and temperature at spraying time on the ripening response of tomatoes to ethephon. *Australian Journal of Experimental Agriculture and Animal Husbandry* 18, 457-460.
- Nahrung, G.C. (1984). Crop establishment. Container grown vegetable seedlings. *Queensland Agricultural Journal* 110, 113-120.
- Neefjes-Fletcher, J. (1984). Holland takes a billion to transplant each year. *Grower, U.K.* 102, (18) 15, 17.
- Nichols, M.A. & Bussell, W.T. (1980). The history of process tomato production in New Zealand. *Acta Horticulturae* 100, 71-74.
- Nichols, M.A.; Nonnecke, I.L. & Phatak, S.C. (1973). Plant density studies with direct seeded tomatoes in Ontario, Canada. *Scientia Horticulturae* 1, 309-320.
- Nicklowsky, C.W. & Downes, J.D. (1971). Influence of nitrogen, potassium and plant population on the maturity of field seeded tomatoes for once-over harvest. *Journal of the American Society for Horticultural Science* 96, 46-49.
- O'Connor, B.P. (1984) ed. *N.Z. Agrichemical Manual*. Agpress/Novasearch, Masterton. 228pp.
- Orchiston, A.R. (1982). Report on bare-root tomato transplant propagation for machine harvest. Unpublished report. J. Wattie Canneries Ltd, Gisborne. 4pp.
- Page, E.R. & Cleaver, T.J. (1983). Effects of nitrogen fertilisers on the emergence of vegetable seedlings. *Journal of the Science of Food and Agriculture* 34, 13-22.

- Palevitch, D. (1970). Effects of plant population and pattern on yield of broccoli (*Brassica oleracea* var. *italica*) in single harvest. *HortScience* 5, 230-231.
- Palevitch, D. & Pressman, E. (1973). Apex removal and single-harvest yield of side-shoots of broccoli. *HortScience* 8, 411-412.
- Palevitch, D. & Pressman, E. (1974). Stimulation of side-shoots of broccoli by chemical pinching agents. *HortScience* 9, 66-67.
- Pink, D.A.C. & Innes, N.L. (1984). Recent trends in the breeding of minor field-vegetable crops for the U.K. *Plant Breeding Abstracts* 54, 197-212.
- Pressman, E.; Shaked, R. & Aviram, H. (1985). Lateral shoot development in broccoli (*Brassica oleracea* var. *italica*): the effect of pinching date. *Scientia Horticulturae* 26, 1-7.
- Price, B.P. (1984). Personal communication. J. Wattie Canneries Ltd, Feilding.
- Rayner, A.A. (1969). *A first course in biometry for agricultural students*. Univ. of Natal Press, Pietermaritzburg. xix + 626 p.
- Read, P.E. & Fieldhouse, D.J. (1970). Use of growth retardants for increasing tomato yields and adaptation for mechanical harvest. *Journal of the American Society for Horticultural Science* 95, 73-78.
- Robinson, R.W.; Wilczynski, H.; Dennis, F.G. Jr. & Bryan, H.H. (1968). Chemical promotion of tomato fruit ripening. *Proceedings of the American Society for Horticultural Science* 93, 823-830.
- Royle, S.M. & Hegarty, T.W. (1978). Soil impedance and its effect on calabrese emergence. *Acta Horticulturae* 72, 259-266.
- Rudich, J. (1979). Growing of processing-tomato plants under water deficiency conditions: mulching with transparent polyethylene. *Scientia Horticulturae* 10, 117-125.
- Sadik, S. (1967). Factors involved in curd and flower formation in cauliflower. *Proceedings of the American Society for Horticultural Science* 90, 252-259.

- Salter, P.J. (1959). The effects of different irrigation treatments on the growth and yield of early summer cauliflowers. *Journal of Horticultural Science* 34, 23-31.
- Salter, P.J. (1960a). The growth and development of early summer cauliflower in relation to environmental factors. *Journal of Horticultural Science* 35, 21-33.
- Salter, P.J. (1960b). Effects of different soil moisture conditions during the seedling stage on the growth and yield of early summer cauliflowers. *Journal of Horticultural Science* 35, 239-248.
- Salter, P.J. (1969). Studies on crop maturity in cauliflowers: I. Relationship between the times of curd initiation and curd maturity of plants within a cauliflower crop. *Journal of Horticultural Science* 44, 129-140.
- Salter, P.J. (1972). An adjustable drilling sequence to compensate for adverse weather conditions and to obtain continuous production of vegetable crops. *Horticultural Research* 12, 57-63.
- Salter, P.J. (1982). Advantages and disadvantages of 'module'-raised vegetable plants. *Scientific Horticulture* 33, 76-81.
- Salter, P.J.; Andrews, D.J. & Akehurst, J.M. (1984). The effects of plant density, spatial arrangement and sowing date on yield and head characteristics of a new form of broccoli. *Journal of Horticultural Science* 59, 79-85.
- Salter, P.J. & Fradgley, J.R.A. (1969a). Studies on crop maturity in cauliflower: II. Effects of cultural factors on the maturity characteristics of a cauliflower crop. *Journal of Horticultural Science* 44, 141-154.
- Salter, P.J. & Fradgley, J.R.A. (1969b). The effects of cultural factors on yield and curd quality of autumn cauliflower. *Journal of Horticultural Science* 44, 265-272.
- Salter, P.J. & Goode, J.E. (1967). *Crop responses to water at different stages of growth*. Commonwealth Agricultural Bureaux, Farnham Royal, Slough, U.K. x + 246 p.

- Salter, P.J. & James, J.M. (1974). Further studies on the effects of cold treatment of transplants on crop maturity characteristics of cauliflower. *Journal of Horticultural Science* 49, 329-342.
- Salter, P.J. & Ward, R.J. (1972). Studies on crop maturity in cauliflower: III. Effects of cold treatment and certain growth regulators on crop maturity characteristics and yield. *Journal of Horticultural Science* 47, 57-68.
- Salter, P.J.; Ward, R.J. & Whitwell, J.D. (1972). Studies on methods of obtaining continuity of production of summer and autumn cauliflowers. I. Kirton, 1963-69. *Experimental Horticulture* 23, 1-22.
- Scaife, M.A. & Turner, M.K. (1983). *Diagnosis of mineral disorders in plants: Vol. 2 - Vegetables*. HMSO, London. 96pp.
- Sims, W.L. (1969). Effects of Ethrel on fruit ripening of tomatoes... greenhouse, field and postharvest trials. *California Agriculture* 23, (7) 12-14.
- Sims, W.L. (1973). Ripen 'em early. *American Vegetable Grower* 21, (3) 32-34.
- Sims, W.L. (1975). Techniques for growing processing tomatoes. *N.Z. Journal of Agriculture* 131, (2) 28-29, 45-46.
- Sims, W.L. & Rubatzky, V.E. (1974). Intensive open-air cultivation of vegetable crops (tomatoes and lettuce) in California, USA. *Outlook on Agriculture* 8, 81-88.
- Sims, W.L.; Zobel, M.P.; May, D.M.; Mullen, R.J. & Osterli, P.P. (1979). Mechanised growing and harvesting of processing tomatoes. *Leaflet 2686*, Division of Agricultural Sciences, University of California, 31 pp.
- Skapski, H. & Oyer, E.B. (1964). Influence of pretransplanting variables on the growth and development of cauliflower plants. *Proceedings of the American Society for Horticultural Science*, 85, 374-385.
- Steel, R.G.D. & Torrie, J.H. (1980). *Principles and Procedures of Statistics - A Biometrical Approach, 2nd Edition*. McGraw-Hill. xxi + 633pp.

- Sterrett, S.B.; Coale, C.W. Jr. & Savage, C.P. Jr. (1991). Comparison of management techniques for broccoli using a systems approach. *HortScience* 26, 599-601.
- Stevenson, M.R. (1977). Evaluation of herbicides for direct-seeded tomatoes. *Proceedings of the 30th N.Z. Weed and Pest Control Conference*, 106-112.
- Suett, D.L. (1988). Application to seeds and soil: recent developments, future prospects and potential limitations. *Proceedings of the 1988 Brighton Crop Protection Conference - Pests and Diseases*, 823-832.
- Sutherland, R.A. & Benjamin, L.R. (1987). A new model relating crop yield and plant arrangement. *Annals of Botany*, 59, 399-411.
- Swain, D.J. (1980). Protection of tomatoes from herbicide injury by plug-mix planting. *Proceedings of the 33rd N.Z. Weed and Pest Control Conference*, 186-189.
- Tate, K.G. (1977a). Evaluation of benzimidazoles for clubroot control in transplanted cabbages. *Proceedings of the 30th N.Z. Weed and Pest Control Conference*, 96-100.
- Tate, K.G. (1977b). Clubroot control in brassicas. *N.Z. Commercial Grower* 32, (2) 15.
- Tate, K.G. (1977c). Disease control in brassicas. pp. 27-33 *In Proceedings of 1977 Brassica Growers' Short Course*. Department of Horticulture, Massey University, N.Z.
- Tate, K.G. (1979). Clubroot control in cauliflower and Brussels sprouts with benzimidazole transplanting drenches and soil pH manipulation. *Proceedings of the 32nd N.Z. Weed and Pest Control Conference*: 165-170.
- Tate, K.G. (1984). Personal communication. Ministry of Agriculture and Fisheries, Horticultural Research Station, Hastings.
- Tate, K.G. & Eales, R.F. (1982). Clubroot control in cabbage and cauliflower using mechanical transplanting drenches. *N.Z. Journal of Experimental Agriculture* 10, 409-412.

- Thomas, T.H. & Comber, M. (1970). Calabrese: effect of gibberellins. *National Vegetable Research Station Annual Report for 1969*, 71.
- Thompson, A.R. & Suett, D.L. (1986). Meeting the demand for reduced insecticide usage in the production of high quality field vegetables. *Proceedings of the 1986 British Crop Production Conference - Pests and Diseases*, 897-906.
- Thompson, R. & Taylor, H. (1970). Calabrese - for fresh market and processing. *Scottish Agriculture* 49, (4) 166-171.
- Thompson, R. & Taylor, H. (1976). Plant competition and its implications for cultural methods in calabrese. *Journal of Horticultural Science* 51, 147-157.
- Tiessen, H. (1962). The influence of various temperatures and (2-chloroethyl) trimethylammonium chloride and (allyl)trimethylammonium bromide on peppers and tomatoes. *Canadian Journal of Plant Science* 42, 142-149.
- Waterer, D.R. & Coltman, R.R. (1988). Phosphorous concentration and application interval influence growth and mycorrhizal infection of tomato and onion transplants. *Journal of the American Society for Horticultural Science* 113, 704-708.
- Waterer, D.R. & Coltman, R.R. (1989). Response of mycorrhizal bell peppers to inoculation timing, phosphorous and water stress. *HortScience* 24, 688-690.
- Weaver, K.N. (1980). Field emergence of calabrese and onion seedlings in response to compaction treatments on the soil surface or at seed depth. *Journal of Horticultural Science* 55, 325-332.
- Went, F.W. (1944). Plant growth under controlled conditions. II. Thermoperiodicity in growth and fruiting of the tomato. *American Journal of Botany* 31, 135-150.
- Westcott, M.P. & Callan, N.W. (1990). Modeling plant population and rectangularity effects on broccoli head weights and yield. *Journal of the American Society for Horticultural Science* 115, 893-897.
- Wheeler, J.A. & Davies, A.C.W. (1968). Method study of cauliflower handling. *Work Study and Management Services* 12, 226-231.

- Wheeler, J.A. & Salter, P.J. (1974). Effects of shortening the maturity period on harvesting costs of autumn cauliflowers. *Scientia Horticulturae* 2, 83-92.
- Whitwell, J.D.; Jones, G.L. & Williams, J.B. (1982). Cauliflowers. *ADAS/MAFF Reference Book 131*. Grower Books, London. 87pp.
- Wiebe, H.-J. (1975). The morphological development of cauliflower and broccoli cultivars depending on temperature. *Scientia Horticulturae* 3, 95-101.
- Wiebe, H.-J. (1981). Influence of transplant characteristics and growing conditions on curd size (buttoning) of cauliflower. *Acta Horticulturae* 122, 99-105.
- Wilcox, G.E. (1970). Influence of row spacing and plant density on single harvest tomato yields. *Journal of the American Society for Horticultural Science* 95, 435-437.
- Wilcox-Lee, D. & Moyer, D. (1986). Long Island tests alternatives to bare-root plants. *American Vegetable Grower* 34, (2) 20, 22, 24.
- Wittwer, S.H. & Teubner, F.G. (1956). Cold exposure of tomato seedlings and flower formation. *Proceedings of the American Society for Horticultural Science* 67, 369-376.
- Wolfe, D.W. & Sims, W.L. (1982). Effects of osmoconditioning and fluid drilling of tomato seed on emergence rate and yield. *HortScience* 17, 936-937.
- Wood, R.J. (1977). Brassica seedbed management. *Leaflet PK012*, N.Z. Ministry of Agriculture & Fisheries, Pukekohe. 4pp.
- Wood, R.J. (1984). *Fertiliser bulletin - outdoor vegetables*. N.Z. Ministry of Agriculture & Fisheries, Pukekohe. 13pp.
- Wood, R.J. (1988). Progress with cell transplants. *N.Z. Commercial Grower* 43, (4) 23-24.

- Wudiri, B.B. & Henderson, D.W. (1985). Effects of water stress on flowering and fruit set in processing tomatoes. *Scientia Horticulturae* 27, 189-198.
- Wurr, D.C.E. (1981). The influence of cold treatments on the uniformity of cauliflower curd initiation and maturity. *Acta Horticulturae* 122, 107-113.
- Wurr, D.C.E. (1991). Trends demand precise planting. *Grower, U.K.* 115, (11) 27, 29, 30.
- Wurr, D.C.E.; Akehurst, J.M. & Thomas, T.H. (1981). A hypothesis to explain the relationship between low-temperature treatment, gibberellin activity, curd initiation and maturity of cauliflower. *Scientia Horticulturae* 15, 321-330.
- Wurr, D.C.E.; Cox, E.F. & Fellows, J.R. (1986). The influence of transplant age and nutrient feeding regime on cauliflower growth and maturity. *Journal of Horticultural Science* 61, 503-508.
- Wurr, D.C.E. & Fellows, J.R. (1984). Cauliflower buttoning - the role of transplant size. *Journal of Horticultural Science* 59, 419-429.
- Wurr, D.C.E.; Fellows, J.R. & Crisp, P. (1982). Leaf and curd production in cauliflower varieties cold-treated before transplanting. *Journal of Agricultural Science, Cambridge* 99, 425-432.
- Zahara, M. (1970). Influence of plant density on yield of process tomatoes for mechanical harvest. *Journal of American Society for Horticultural Science* 95, 510-512.
- Zahara, M. & Timm, H. (1973). Influence of plant density on growth, nutrient composition, yield and quality of mechanically harvested tomatoes. *Journal of the American Society for Horticultural Science* 98, 513-516.
- Zink, F.W. (1968). Hollow stem in broccoli. *California Agriculture* 22, (1) 8-9.

## APPENDIX 1: NUTRIENT SOLUTION APPLIED TO MODULE-RAISED SEEDLINGS

The nutrient solution applied to the modules in all experiments was based on the nutrient film technique solution recommended by Cooper (1979, p.56). Six stock solutions (Table A1.1) were made up by dissolving the solutes in water, making each solution up to a volume of 2.0 litres.

Table A1.1 Formulation of stock solutions

Compound	Amount dissolved in 2 l of stock solution (grams)	Amount of stock solution used in 100 l of nutrient solution (millilitres)
$\text{KH}_2\text{PO}_4$	131.6	300
$\text{KNO}_3$	291.2	300
$\text{Ca}(\text{NO}_3)_2 \cdot 4\text{H}_2\text{O}$	251.2	600
$\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$	256.4	300
$[\text{CH}_2\text{N}(\text{CH}_2\text{COO})_2]_2\text{FeNa}$	117.6	100
$\text{MnSO}_4 \cdot \text{H}_2\text{O}$	15.4 )	
$\text{H}_3\text{BO}_3$	4.2 )	all in
$\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$	0.98 )	one stock
$(\text{NH}_4)_6\text{Mo}_7\text{O}_{24} \cdot 4\text{H}_2\text{O}$	0.92 )	solution
$\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$	1.10 )	

Stock solutions were stored in stoppered brown glass bottles. Stock solutions were used to make up the nutrient solution (Table A1.2) as it was required, in 100 litre batches stored in a covered black polythene tank.

Table A1.2 Nutrient element content of nutrient solution

Element	Concentration (mg l <sup>-1</sup> )	Element	Concentration (mg l <sup>-1</sup> )
NH <sub>4</sub> <sup>+</sup> -N	0.02	Fe	9.0
NO <sub>3</sub> <sup>-</sup> -N	150	Mn	1.5
P	45.0	B	0.23
K	225	Cu	0.08
Ca	128	Mo	0.15
Mg	37.5	Zn	0.08
		S	68.0

**APPENDIX 2: PEST AND DISEASE CONTROL PROGRAMME  
FOR TOMATO EXPERIMENT**

Table A2.1 Pesticides applied during raising of seedlings

Product name	Active ingredient	Rate of active ingredient	Application dates (days from sowing)
<u>Bare-root transplants</u>			
Manzate 200	mancozeb	1.3 g l <sup>-1</sup>	} 33
Metasystox (i) <sup>R</sup>	demeton-S-methyl	0.25 g l <sup>-1</sup>	
Kocide 101 <sup>R</sup>	cupric hydroxide	1.0 g l <sup>-1</sup>	} 41
Agrimycin <sup>R</sup> -17	streptomycin	0.1 g l <sup>-1</sup>	
Kocide 101 <sup>R</sup>	cupric hydroxide	1.0 g l <sup>-1</sup>	47
Manzate 200	mancozeb	1.3 g l <sup>-1</sup>	} 52
Lannate <sup>R</sup> L	methomyl	0.2 g l <sup>-1</sup>	
<u>Module-raised transplants</u>			
Shell Copper Oxychloride	CuOCl	1.0 g l <sup>-1</sup>	} 31
Lannate <sup>R</sup> L	methomyl	0.2 g l <sup>-1</sup>	
Manzate 200	mancozeb	1.6 g l <sup>-1</sup>	

<sup>R</sup> Registered trademark

Table A2.2 Pesticides applied in the field

Product name	Active ingredient	Rate of active ingredient	Application dates (days from transplanting)
Shell Copper Oxychloride	CuOCl	1.0 g l <sup>-1</sup>	} 10,34
Tamaron <sup>R</sup>	methamidophos	1.2 g l <sup>-1</sup>	
Shell Copper Oxychloride	CuOCl	1.0 g l <sup>-1</sup>	17
Fusilade	fluazifop-butyl	500 g ha <sup>-1</sup>	19,72
Sencor <sup>R</sup>	metribuzin	1.1 kg ha <sup>-1</sup>	34 <sup>a</sup>
Shell Paraquat	paraquat	---	41 <sup>a</sup>
Shell Copper Oxychloride	CuOCl	1.5 g l <sup>-1</sup>	} 41,48
Benlate <sup>R</sup>	benomyl	1.0 g l <sup>-1</sup>	
Tamaron <sup>R</sup>	methamidophos	1.2 g l <sup>-1</sup>	
Shell Copper Oxychloride	CuOCl	1.5 g l <sup>-1</sup>	} 59
Manzate 200	mancozeb	0.8 g l <sup>-1</sup>	
Lannate <sup>R</sup> L	methomyl	0.3 g l <sup>-1</sup>	
Kocide 101 <sup>R</sup>	cupric hydroxide	1.0 g l <sup>-1</sup>	} 64,94,96, 116
Manzate 200	mancozeb	0.8 g l <sup>-1</sup>	
Kocide 101 <sup>R</sup>	cupric hydroxide	1.0 g l <sup>-1</sup>	} 72,108
Manzate 200	mancozeb	0.8 g l <sup>-1</sup>	
Tamaron <sup>R</sup>	methamidophos	1.2 g l <sup>-1</sup>	

<sup>R</sup> Registered trademark

<sup>a</sup> paraquat and metribuzin herbicides applied to wheeltracks between beds

### APPENDIX 3: HEAT UNIT CALCULATIONS FOR TOMATO EXPERIMENT AT HASTINGS

N.Z. Meteorological Service records of daily maximum and minimum air temperatures (recorded at a meteorological station situated approximately 100 m from the experimental field site) were obtained and heat units were calculated using the formula:  $Y=(T+t)/2-g$ ;

where Y=heat units per day; T=maximum daily temperature (°C); t=minimum daily temperature (°C); and g=base temperature. The value assigned to g was 7.2 °C (Logan & Boyland, 1983). No adjustments for high temperatures were made since the highest maximum daily temperature recorded over the two periods for which the heat units were calculated (24.7 °C) was lower than the upper threshold of 26.6 °C recommended by Logan & Boyland (1983).

## APPENDIX 4: LIME AND FERTILISER APPLICATIONS FOR BROCCOLI EXPERIMENTS

### A4.1 Lime and fertiliser application to broccoli seed-bed

The soil to which the fertilisers listed in Table A4.1 were applied was used in the raising of bare-root transplants in the field (3.2.3.1.1) and in the greenhouse (3.2.3.2.1).

Table A4.1 Lime and fertilisers applied to broccoli seed-bed

Compound	Rate applied	
	g m <sup>-2</sup>	kg ha <sup>-1</sup>
agricultural lime	250	2500
30% potassic superphosphate	100	1000
urea	7.5	75
borax	2.0	20
sodium molybdate	0.2	2

### A4.2 Lime and fertiliser application to broccoli field experiment area

On 31 July 1984 soil samples were taken, to a depth of 150 mm, from ten locations within the field experiment area. After thorough mixing, a single sub-sample was submitted for the standard Ministry of Agriculture and Fisheries soil test. Details of the soil test methods and units used for expressing the results are described by Cornforth (1982). Soil test results, corresponding 'target' levels and estimated fertiliser and lime requirements based on the guidelines of Wood

(1984) for the soil type and crop in question are presented in Table A4.2 along with the rates of lime and fertilisers applied. Nitrogen (as urea) was applied in a separate dressing (3.2.4.2).

Table A4.2 Formulation of lime and fertiliser application

Test	Soil test level	Target level	Estimated requirement (per hectare)	Fertiliser source & rate applied to meet estimated requirement
pH	6.1	6.7	2500 kg CaCO <sub>3</sub>	agricultural lime @ 2500 kg ha <sup>-1</sup>
P	45	75	320 kg P	superphosphate @ 4000 kg ha <sup>-1</sup>
K	13	14	100 kg K	potassium sulphate @ 250 kg ha <sup>-1</sup>
Ca	11	10	nil	soil test level adequate
Mg	19	12	nil	soil test level adequate
B	--	--	--	borax @ 20 kg ha <sup>-1</sup>
Mo	--	--	--	sodium molybdate @ 2.0 kg ha <sup>-1</sup>

## APPENDIX 5: PEST AND DISEASE CONTROL PROGRAMME FOR BROCCOLI EXPERIMENTS

### A5.1 Methyl bromide fumigation

Rates of product applied in fumigating the various growing media used in raising the transplants are given in Table A5.1: the product used contained 980 g kg<sup>-1</sup> of methyl bromide plus 20 g kg<sup>-1</sup> of chloropicrin. High rates of methyl bromide were used to increase fungicidal activity (see A5.2).

Table A5.1 Rates of methyl bromide application

Medium fumigated	Application rate (of 98% product)
Soil, for field sowing	200 g m <sup>-2</sup>
Peat:sand, for field sowing	4500 g m <sup>-3</sup>
Soil, for greenhouse sowing	600 g m <sup>-3</sup>
Peat:sand, for greenhouse sowing	600 g m <sup>-3</sup>

### A5.2 Precautions taken against clubroot disease

On a previous occasion, the production of broccoli transplants in peat:sand medium at Massey University had resulted in the development of clubroot disease (caused by the slime mould *Plasmodiophora brassicae*) in the seedlings prior to transplanting. The river sand was the suspected source of inoculum. This led to a consideration of options available for control of the disease in these experiments which were carried out over the period of the year in which environmental conditions favour the development of the disease in the field (Tate, 1977b).

Studies undertaken in New Zealand have demonstrated the utility of drench applications of fungicides (e.g. benomyl, carbendazim) at transplanting time for control of the disease during the establishment of cabbage and cauliflower crops (Tate, 1977a, 1979). Tate and Eales (1982) have demonstrated that this is a method which can be incorporated into a mechanised transplanting operation.

Fungicidal drenches were considered to be unsuitable for this experiment for two reasons. The fungicidal treatment can be phytotoxic and brassica crops and cultivars differ in their sensitivity to the fungicides used (Tate, 1977a) and suitable dose rates for green sprouting broccoli have not been investigated (Tate, 1984). Secondly, it was considered that bare-root and module-raised transplants could differ in their response to the fungicide application.

Precautions which were taken against the possible development of clubroot disease in the experiment are outlined below.

- (i) Choice of site: *P. brassicae* is capable of surviving for 7 years, or more, as a resting spore in the soil (Hawthorne, 1981). No previous brassica crop had been grown on the field site used in these experiments.
- (ii) Lime and fertiliser application: Lime was applied to the field 3 weeks prior to planting to achieve a predicted target soil pH of 6.7 (3.2.4.2) a level at which clubroot development is inhibited (Tate, 1979). Urea was selected as the nitrogen fertiliser to be used in the experiment as it has a lower equivalent acidity (per kilogram of N) than other nitrogenous fertilisers in common use (During, 1972).
- (iii) Sanitation: Methyl bromide fumigation of all transplant raising media was carried out (3.2.3) and all seedling trays were disinfected in a strong solution of chloride of lime and rinsed thoroughly before use.
- (iv) Raised beds: Seedling transplants produced in the field were grown in a raised seed-bed and plants transplanted into the field were grown on slightly raised beds to encourage rapid drainage of excess water from the root zone after rain or irrigation.

### **A5.3 Pesticide programme**

Pesticides applied during the course of the experiment are detailed in Tables A5.2 and A5.3. The drench application of metalaxyl/mancozeb in Table A5.2 is based on the work of Hartill (1982). Other sources used in formulating the pesticide programme were: Wood, 1977; O'Connor, 1984; Bussell, 1984b; Tate, 1977c; Baker, 1977; Cox, Ingle & Kerr, 1984; and Geelen, 1984a.

Table A5.2 Pesticides applied during the raising of seedlings

Product name	Active ingredient	Rate of active ingredient	Application dates (days from sowing)			
			field	g <sup>h</sup> ouse		
Orthocide 80W	captan	2.0 g kg <sup>-1</sup>	0	0	a	
Ridomil <sup>R</sup> MZ 72 WP	{ metalaxyl { { mancozeb	0.24 g l <sup>-1</sup>  1.92 g l <sup>-1</sup>	}	13,19	13	b
Lannate <sup>R</sup> L	methomyl	0.24 g l <sup>-1</sup>	}	21	--	c,d
Euparen <sup>R</sup>	dichlofluanid	1.0 g l <sup>-1</sup>	}			
MesuroI <sup>R</sup>	methiocarb	20 g/kg bait		6,19,33	--	e
Manzate 200	mancozeb	1.6 g l <sup>-1</sup>	}	30,33	13,16	d
Lorsban <sup>R</sup> 50W	chlorpyriphos	0.25 g l <sup>-1</sup>	}			
Ridomil <sup>R</sup> MZ 72 WP	{ metalaxyl { { mancozeb	0.2 g l <sup>-1</sup>  1.6 g l <sup>-1</sup>	}	40	23	d
MesuroI <sup>R</sup>	methiocarb	0.75 g l <sup>-1</sup>	}			
Benlate <sup>R</sup>	benomyl	0.75 g l <sup>-1</sup>	}			

<sup>R</sup> Registered Trademark

<sup>a</sup> dry seed dust

<sup>b</sup> drench applied to substrate @ 125 ml/m of row and 100 ml per tray

<sup>c</sup> applied with alkylaryl polyglycol ether (Citowett<sup>R</sup>) @ 25 mg l<sup>-1</sup>

<sup>d</sup> applied by knapsack sprayer

<sup>e</sup> baits spread by hand

Table A5.3 Pesticides applied in the field

Product name	Active ingredient	Rate of active ingredient	Application dates (days from planting)	
Treflan	trifluralin	1.0 kg ha <sup>-1</sup>	-7	a
Yates Alachlor	alachlor	2.5 kg ha <sup>-1</sup>	3	b
MesuroI <sup>R</sup>	methiocarb	20 g/kg bait	0,11,17,31,37	c
Bravo <sup>R</sup> W75	chlorthalonil	1.5 g l <sup>-1</sup>	12	d
Orthene <sup>R</sup> 75	acephate	0.75 g l <sup>-1</sup>		
Benlate <sup>R</sup>	benomyl	0.75 g l <sup>-1</sup>	20	d
Orthene <sup>R</sup> 75	acephate	0.75 g l <sup>-1</sup>		
Yates Zineb	zineb	1.5 g l <sup>-1</sup>		
Orthene <sup>R</sup> 75	acephate	0.75 g l <sup>-1</sup>	32	d
Shell Copper Oxychloride	CuOCl	1.0 g l <sup>-1</sup>		
Vapona Concentrate	dichlorvos	1.1 g l <sup>-1</sup>	37	d
Shell Copper Oxychloride	CuOCl	1.0 g l <sup>-1</sup>		
Yates Carbaryl 80	carbaryl	1.2 g l <sup>-1</sup>	48	d
Shell Copper Oxychloride	CuOCl	1.5 g l <sup>-1</sup>		

<sup>R</sup> Registered Trademark

<sup>a</sup> applied by tractor boom sprayer, 450 l water per ha, at 200 kPa

<sup>b</sup> applied by tractor boom sprayer, 420 l water per ha, at 345 kPa

<sup>c</sup> baits spread by hand

<sup>d</sup> applied by motorised low volume sprayer