



2019 EDITION

GREENHOUSE **CUCUMBER** **PRODUCTION**



Local Land
Services

Hort
Innovation

2019 EDITION

GREENHOUSE **CUCUMBER PRODUCTION**



ABOUT THE AUTHORS

Jeremy Badgery Parker is the director and principal consultant for Primary Principles Pty Ltd, based in South Australia. Previously, Mr Badgery-Parker was the extension horticulturist for greenhouse horticulture with the NSW Department of Primary Industries.

Leigh James was the extension horticulturist for vegetable crops with the NSW Department of Primary Industries. Now retired, he spent over 30 years working with greenhouse and hydroponic growers in the Sydney Basin.

Dr Sophie Parks is a senior research scientist in plant physiology for the NSW Department of Primary Industries based at the Central Coast Primary Industries Centre, Ourimbah. As a specialist in greenhouse horticulture, Dr Parks' research has focussed on plant nutrition and effect of climate on greenhouse productivity.

Dr Len Tesoriero is one of Australia's leading vegetable pathologists, with extensive knowledge of diseases affecting cucurbit crops. Dr Tesoriero was previously employed by NSW Department of Primary Industries and now works directly with growers through Crop Doc Consulting Pty Ltd.

Andy Ryland has more than 30 years experience developing and implementing integrated pest management systems for vegetable crops. His company, Integrated Pest Management Consulting, provides pest management and agronomic advice to growers in the Sydney Basin and beyond.

Dr Jenny Ekman is a research scientist with Applied Horticultural Research. Jenny has more than 20 years' experience investigating and communicating ideas and innovations around market access, biosecurity, postharvest management and food safety of horticultural crops.

ACKNOWLEDGEMENTS

The information in this publication is based on *Commercial Greenhouse Cucumber Production* first published by Industry and Investment NSW in 2010. Local Land Services gratefully acknowledges the NSW Department of Primary Industries' permission to use this original material for this publication.

Revision and updating of this publication has been facilitated by Applied Horticultural Research. Specific sections have been revised by: Jeremy Badgery-Parker; Andy Ryland (Cucumber Pests and their Management; Pesticides, Sprays and their Use in Cucumbers), Len Tesoriero (Cucumber Diseases and their Management), and Jenny Ekman (Food Safety and Biosecurity).

The authors gratefully acknowledge the valued assistance given by the following people in the production of this manual:

Arie Baelde	Dr Tony Haigh
David McKechnie	Dr Alison Anderson
Bill Yiasoumi	Craig Feutrill
Marilyn Steiner	Tony Burfield
Stacey Azzopardi	David Ellement
Jonathan Eccles	Mat Dent
Mark Scott	Paul Humble

For permission to reproduce their pictures and/or sketches the authors kindly thank:

Lowan Turton, Basem Al-Khawaldeh, Jerry Lovatt, Kathy Boladeras, Jonathan Eccles, Syngenta Seeds, Bugs for Bugs, Biological Services, Practical Hydroponics and Greenhouses and Galuka Pty Ltd.

The authors also greatly appreciate the valued input of Nicky Parker, Linda Dickson, Julie Pont, Belinda Gersbach, Bill Noad and Barry Jensen.

DISCLAIMER

The information in this publication is based on *Commercial Greenhouse Cucumber Production* (2010 edition) first published by Industry and Investment NSW. Users are reminded of the need to ensure that information upon which they rely is up to date and to check currency of the information. The State of NSW accepts no responsibility or liability in relation to the use of any information contained in this publication.

ALWAYS READ THE LABEL

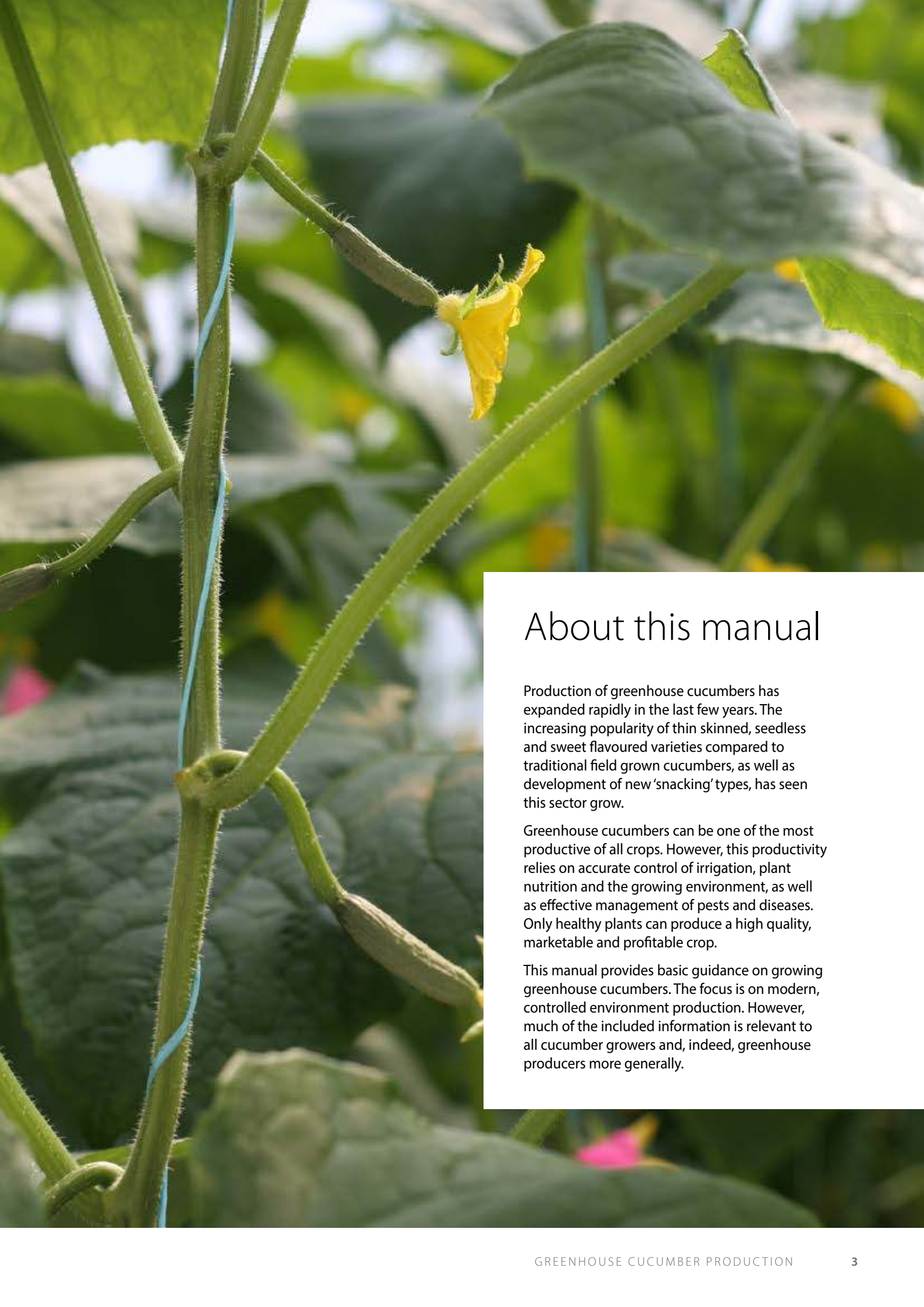
Users of agricultural or veterinary chemical products must always read the label and any permit, before using the product, and strictly comply with the directions on the label and the conditions of any permit. Users are not absolved from compliance with the directions on the label or the conditions of the permit by reason of any statement made or not made in this publication.

ISBN 978 0 7347 1999 7

© New South Wales Department of Planning, Industry and Environment, 2019

This publication is copyright. Except as permitted under the Copyright Act 1968 (Commonwealth), no part of the publication may be reproduced by any process, electronic or otherwise, without the specific written permission of the copyright owner. Neither may information be stored electronically in any form whatever without such permission. The information in this publication is based on *Commercial Greenhouse Cucumber Production* (2010 edition) first published by Industry and Investment NSW.

Designed by **Jihee Park** | Jihee Park Creative



About this manual

Production of greenhouse cucumbers has expanded rapidly in the last few years. The increasing popularity of thin skinned, seedless and sweet flavoured varieties compared to traditional field grown cucumbers, as well as development of new 'snacking' types, has seen this sector grow.

Greenhouse cucumbers can be one of the most productive of all crops. However, this productivity relies on accurate control of irrigation, plant nutrition and the growing environment, as well as effective management of pests and diseases. Only healthy plants can produce a high quality, marketable and profitable crop.

This manual provides basic guidance on growing greenhouse cucumbers. The focus is on modern, controlled environment production. However, much of the included information is relevant to all cucumber growers and, indeed, greenhouse producers more generally.


CONTENTS

ABOUT THIS MANUAL	3	Directing the plant	57
LIST OF TABLES	6	Quick guide to growing conditions	59
INTRODUCTION TO GREENHOUSE CUCUMBER PRODUCTION	7	GREENHOUSE DESIGN AND TECHNOLOGY	61
What is greenhouse horticulture?	8	The greenhouse	62
The Australian greenhouse cucumber industry	8	Types of greenhouses	63
Financial expectations	10	Classifying greenhouses	64
Labour considerations	13	Greenhouse covering materials	66
Record keeping and benchmarking	13	Orientation and siting of a greenhouse	68
Good agricultural practices	15	Ventilation in greenhouses	69
GROWING CUCUMBERS	17	Height of structures	72
The cucumber plant	18	Computer control systems, sensors and monitoring equipment	72
Types of cucumber	20	Heating	74
Pollination	23	Evaporative cooling	79
The production process	24	Screens	81
Cucumber propagation	28	Light	82
Transplanting cucumber seedlings	30	Uniformity in the greenhouse	84
Plant spacing for cucumbers	31	HYDROPONIC SYSTEMS AND TECHNOLOGY	87
Pruning and training cucumber plants	34	Hydroponic systems	88
Picking cucumbers	46	The irrigation system	90
OPTIMISING PRODUCTION	47	Irrigation distribution uniformity	95
Crop observation and monitoring	48	Substrates	98
Vegetative growth	50	FEEDING THE CROP	105
Generative growth	51	Plant nutrition	106
Managing the cucumber plant	52	Monitoring plant nutrition	108
Temperature	52	The nutrient solution	109
Humidity	54	Electrical conductivity	112
Vapour Pressure Deficit	56	pH	112

Nutrient formulae	114	 PESTICIDES, SPRAYS AND THEIR USE IN CUCUMBERS	191	
Volume and frequency of irrigation	124			
Using foliar fertilisers	127		Transporting, storing and handling pesticides	192
Monitoring	127		Applying pesticides	196
			Selecting pesticides	200
 FARM BIOSECURITY AND FOOD SAFETY	129	Calibrating spray equipment	201	
Farm biosecurity	130	Personal Protective Equipment	203	
Food safety	134	Keeping pesticide use records	206	
 CUCUMBER DISORDERS AND THEIR MANAGEMENT	137	 POSTHARVEST MANAGEMENT AND MARKETING	207	
Nutrient disorders	138			
			Postharvest handling	208
 CUCUMBER DISEASES AND THEIR MANAGEMENT	149		Cool chain management	208
Integrated disease management	150		Grading and packing	210
Identifying cucumber diseases	152	Basics of marketing	212	
Fungal diseases	154	Quality Assurance	212	
Bacterial diseases	164	 WASTE MANAGEMENT	213	
Viral diseases	165		Plastics	214
Nematode disease	167		Crop residues	214
			Used substrates	214
 CUCUMBER PESTS AND THEIR MANAGEMENT	169		Waste water	215
Integrated Pest Management	170	 HEALTH AND SAFETY IN THE GREENHOUSE	217	
Sanitation	172			
Physical control	172		Heat related illness	218
Environmental control	172		Air quality in the greenhouse	219
Knowing the pest	172		Lifting, carrying and working at heights	220
Biological control agents/beneficials	173	Risk management	222	
Recognising key biological controls	173	Risk assessments	222	
Biorationals	177			
Recognising key pests	180			

LIST OF TABLES

Table 1. Economic analysis of greenhouse cucumbers with high technology investment	11
Table 2. Economic analysis of greenhouse cucumbers with low technology investment	12
Table 3. Recommended temperatures for propagation of cucumbers	28
Table 4. Example calculations 24-hour temperature	53
Table 5. Target vapour pressure deficits (gm/m ³)	56
Table 6. Example of air and leaf surface temperature differences – Central Coast NSW	57
Table 7. Heat transfer values	76
Table 8. Wind factors	78
Table 9. Potential cooling effect	80
Table 10. Average winter Daily Light Integrals	84
Table 11. A general guide to the type of filter to be selected under varying water qualities	92
Table 12. Types of drip emitters	93
Table 13. Dripper discharge rates	94
Table 14. Changes in the properties of growing substrates	98
Table 15. Effect of container height on substrate porosity	99
Table 16. Summary of general properties of common hydroponic substrates	103
Table 17. Example leaf analysis for cucumber	108
Table 18. Leaf analysis standards for cucumbers	109
Table 19. Ranges of elements for hydroponic cucumbers	114
Table 20. Fertiliser recipe Example 1	115
Table 21. Fertiliser recipe Example 2	116
Table 22. Fertiliser recipe Example 3	117
Table 23. Fertiliser recipe Example 4	118
Table 24. Fertigation optimisation over the cropping season (spring crop)	119
Table 25. Example nutrient solution	122
Table 26. Common soluble fertilisers	123
Table 27. Example of target run-off percentages during the day	124
Table 28. Water quality guidelines for hydroponic cucumbers	126
Table 29. Developing a farm biosecurity plan; issues to consider	133
Table 30. Quick guide to the common nutritional disorders	147
Table 31. Beneficial insects, mites and nematodes available in Australia and their suppliers	178
Table 32. Common pests and biocontrols	179
Table 33. Risk management	223



INTRODUCTION TO GREENHOUSE CUCUMBER PRODUCTION

Successful greenhouse cucumber production requires mechanical, technical and business aptitude. You will need skills in both horticultural crop production and in business. Planning and sourcing information as well as continuing education and training are important steps toward successful greenhouse cucumber production.

THIS SECTION INCLUDES

- Definition of greenhouse horticulture
- An overview of the cucumber industry
- Financial expectations
- Labour considerations
- Record keeping and benchmarking
- Good agricultural practices

What is greenhouse horticulture?

Greenhouse horticulture is the production of horticultural crops within, under or sheltered by structures to provide modified growing conditions and/or protection from pests, diseases and adverse weather. In its broadest definition, greenhouse horticulture includes the use of greenhouses and glasshouses, shade houses, screen houses and crop top structures.

Controlled environment horticulture (CEH) is an intensive, efficient and sustainable agricultural system.

The modern and most sophisticated form of greenhouse horticulture is better described as controlled environment horticulture (CEH) or controlled environment agriculture (CEA). Controlled environment horticulture combines high technology greenhouses with hydroponic (soil-less) growing systems. It integrates the full suite of good agricultural practices, including integrated pest management (IPM), to consistently and reliably produce high quality, safe, fresh cucumbers while minimising any potential adverse impact on the environment and ensuring a safe and healthy workplace.

The capacity to consistently and reliably control or manipulate the growing environment and effectively manage nutrition, pests and diseases is the basis of profitable and sustainable cucumber production.

Controlled environment crops have greater consistency and production is more reliable. Technology is used to manage and manipulate the growing conditions to reduce uncertainty and optimise crop growth. Greenhouses, hydroponics and controlled environment systems generally range in their capacity to provide optimal conditions. Cucumber yields in controlled environment systems are generally greater per unit of input than conventional farming systems.

The Australian greenhouse cucumber industry

There are about 1,000 commercial greenhouse enterprises throughout Australia that produce cucumbers at some point during the year. The vast majority of continental and mini (including snack) cucumbers are grown in protected cropping. Field production of other types is still common.

The majority of growers are on the north Adelaide plains in South Australia and in the Sydney Basin of NSW. The cucumber industry remains predominantly founded on low technology greenhouses*, but there is a strong trend towards higher technology systems, particularly in South Australia, Western Australia and Queensland.

The NSW protected cropping industry mainly produces mini (Lebanese) cucumbers and although it is centred on the Sydney Basin, where around 350 greenhouse vegetable enterprises produce both cucumber and other crops, the industry is rapidly expanding on the mid north coast. In South Australia, the industry is predominantly producing continental cucumbers though a significant volume of Lebanese cucumbers is also produced. The bulk of the South Australian industry is located on the North Adelaide plains. The industry also extends to the Riverland. It is estimated that about 400 greenhouse vegetable enterprises in South Australia produce cucumbers.

Cucumbers (mainly Lebanese) are produced in a number of areas in the south east of Queensland as well as in Bundaberg and Bowen. In Western Australia, there is significant Lebanese and continental cucumber production near Perth and in Geraldton and Carnarvon to the north. Victorian growers are generally located near Melbourne, as well as Sunraysia and near Wangaratta.

Production in the Northern Territory is generally around Darwin.

Production of cucumbers has increased from approximately 60,000 tonnes in 2010 to over 90,000 tonnes in 2018. The following figures are provided as a general guide and are based on market prices#

* There is more information on greenhouse design and technology starting on page 61.

(for the five years to 2018). For up-to-date market price information, contact your central market or Ausmarket Consultants.

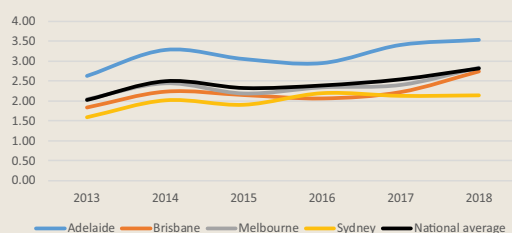
Average prices per tonne increased around 25% since 2010, rising an average of 3% per annum.

Lebanese, continental and green slicing cucumbers are the main types grown. With a current average wholesale cucumber price of \$2.82 per kilogram (excluding snack type), the industry is conservatively valued at up to \$170 million annually. In recent years, 'snack' or 'cocktail' cucumbers have become a premium product with wholesale prices up to \$15 per kilogram. Note, in figures AB and AD, snack type is on a separate scale.

Apple cucumbers often receive a higher price, especially in the South Australian market. Historically, continental cucumbers received a premium but mini cucumbers now generally fetch the higher price, at around \$2.50/kg. Hydroponic mini cucumbers typically attract a 20% price premium over standard cucumbers.

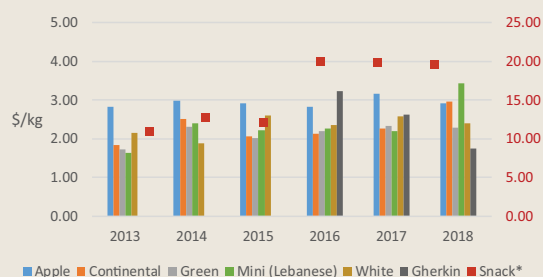
Prices are partially cyclic reflecting the dominance of protected cropping for main types and the relative seasonal costs of production, with prices generally falling in summer.

[AA] Average wholesale cucumber[^] price by market

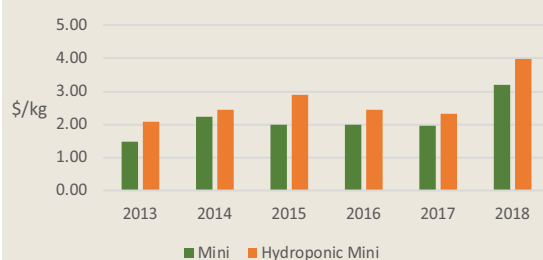


[^] The higher average price in Adelaide can be attributed to higher prices for apple type paid in this market. This chart excludes snack types in all markets.

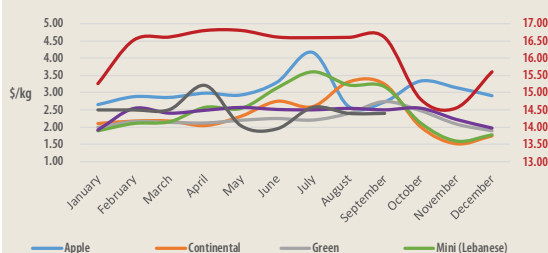
[AB] Average national wholesale price by cucumber type



[AC] Mini cucumber price by production system



[AD] Average seasonal wholesale price by cucumber type



[^] Average prices are calculated from data collected and managed by Ausmarket Consultants.

Average prices are calculated from data collected and managed by Ausmarket Consultants.

Financial expectations

Controlled environment horticulture is capital intensive. However, it is highly efficient, productive and sustainable. Larger operations benefit from significant economies of scale in capital costs, labour and operating inputs.

The costs of growing cucumbers are not easily standardised. Much of the variation in costs is due to crop production decisions.

The costs of growing cucumbers are not easily standardised as they can vary significantly from grower to grower and season to season. Much of this variation can be attributed to crop management decisions. For this reason, financial data provided here can only serve as a guide and should not be relied upon exclusively when making investment decisions.

Capital investment

The greenhouse, the hydroponic system and the computer controls are significant investments. High technology* controlled environment systems will cost around \$150 – \$300 per square metre. The wide cost range reflects the available choice in covering materials and technical options. Facilities at the higher price ranges are unlikely to be feasible as an exclusive production system for standard cucumber products. Medium technology controlled environment systems generally cost around \$80 – \$150 per square metre. Again, the cost range reflects the choice in covering materials, the level of automation and technical options.

While a range of improvements and automated features can be added to increase the level of environmental control in medium level structures, these structures will always have some limitations in production capacity compared with high level greenhouses. The difference is less pronounced in cucumber production compared with other greenhouse crops, but still needs to be recognised.

It is important not to overcapitalise. This is a risk particularly with medium level greenhouses for most crops and for lower value products.

At the low technology end of the industry, a basic polyethylene covered tunnel house may cost around \$20 - \$30 per square metre. There is very little scope to improve production capacity of low technology greenhouses and they are not recommended for large scale commercial cucumber production. Pest and disease management depends generally on non-sustainable control measures and crop productivity is limited.

Overhead costs

Overhead costs are recurring expenses that must be paid even if you don't put in a crop. These include items such as:

- rates, rent and insurance premiums
- wages for permanent employees
- loan repayments
- depreciation on structures and equipment.

Gross margin budgets

Gross margins are commonly used and are valuable tools to assess the economical operation of a horticultural business. These budgets are helpful in making decisions about the enterprise. By definition, the gross margin is the gross income earned minus the variable costs of producing that income. Note the gross margin budget does not include overhead costs. Furthermore, the figure estimated in the gross margin budget is not profit. It indicates the relative profitability of the operation. Overhead costs must be paid for first, before the remainder can be 'kept'.

Expected yields

The yield obtained from a cucumber plant will vary with grower expertise and the growing environment. Yields up to 15 kg per plant (mini cucumber) have been achieved with optimal growing conditions. Typical yields for much of the industry are around 7 – 12 kg. These figures highlight the significant productivity potential in the industry and the value of implementing good agricultural practices in greenhouse cucumbers.

* More information is available in the section 'Classifying greenhouses' on page 64.

Economic analyses

The economic performance of any greenhouse cucumber business will vary between different operators. Tables 1 and 2 provide some guidance as to the financial return potentially attainable in this industry. The analyses are based on estimates of costs, yields and returns and a number of general assumptions. These analyses should not be relied upon for making financial decisions. Any financial decisions made must be based on a thorough assessment of the specific current and expected costs

of production and returns. While significantly more money is invested in a high technology enterprise, the improved productivity and efficiency result in a better return on investment.

When low technology systems are used, substantial gross margins may be realised but the net margin will be well below that attainable with investment in a better technology system.

Costs increase at each step of the supply chain. Careful attention to postharvest management and marketing are important considerations.

Table 1. Economic analysis of greenhouse cucumbers with high technology investment				
Greenhouse cucumbers Economic analysis				
Size of production unit	10,000	m ²		
Number of crops	3	per year		
Plant density	2.5	per m ²		
Number of plants per crop	25,000			
Initial capital investment			\$2,150,700.00	
Typical recurring (annual) costs			\$2,086,787.65	
Discount rate				5.00%
Return on recurring costs			28%	
Return on investment (including recurring costs)			17%	
Average operating cost per kilogram produced	\$0.43			
Average operating cost per kilogram sold	\$1.99			
Real cost per kilogram sold	\$2.17			
Gross margin				\$575,311.48
Gross margin per plant			\$7.67	
Gross margin per hectare			\$575,311.48	
Gross margin per square metre			\$57.53	
Net margin				\$386,246.32
Net margin per plant			\$5.15	
Net margin per hectare			\$386,246.32	
Net margin per square metre			\$38.62	
Yield per plant:	14.00	kg		
Total	1,050,000	kg	Sale price / kg	
Grade 1*	892,500	kg	2.70	
Grade 2*	126,000	kg	2.00	
Unmarketable	31,500	kg	0.00	

Assumptions

Analysis assumes 85% of fruit is top grade, 12% is second grade and 3% is unmarketable

* Grades 1 – 2 are included as generic terms and do not represent specific quality grades

Table 2. Economic analysis of greenhouse cucumbers with low technology investment

Greenhouse cucumbers Economic analysis				
Size of production unit	10,000	m ²		
Number of crops	3	per year		
Plant density	2.3	per m ²		
Number of plants per crop	23,000			
Initial capital investment			\$801,600.00	
Typical recurring (annual) costs			\$1,373,179.68	
Discount rate				5.00%
Return on recurring costs			10%	
Return on investment (including recurring costs)			4%	
Average operating cost per kilogram produced	\$0.73			
Average operating cost per kilogram sold	\$2.21			
Real cost per kilogram sold	\$2.33			
Gross margin				\$132,745.33
Gross margin per plant			\$1.92	
Gross margin per hectare			\$132,745.33	
Gross margin per square metre			\$13.27	
Net margin				\$55,911.26
Net margin per plant			\$0.81	
Net margin per hectare			\$55,911.26	
Net margin per square metre			\$5.59	
Yield per plant:	9.00	kg		
Total:	621,000	kg	Sale price / kg	
Grade 1*	465,750	kg	2.70	
Grade 2*	124,200	kg	2.00	
Unmarketable	31,050	kg	0.00	

Assumptions

Analysis assumes 75% of fruit is top grade, 20% is second grade and 5% is unmarketable.

* Grades 1 – 2 are included as generic terms and do not represent specific quality grades.

Heating and labour are significant costs in controlled environment horticulture. The cost of heating structures is strongly influenced by the greenhouse design, use of thermal screens, type of covering materials and local climatic conditions at the site. There are significant economies of scale for labour and capital investment. Packaging and freight can be very significant costs.

Labour considerations

Greenhouse horticulture is a full-time job. It is highly intensive. A 1,000 square metre area of production requires around one full-time person. Improved efficiencies are gained with larger production areas reducing labour to around 7 – 8 labour units per hectare (production and postharvest). Although research continues into robotics, no commercially suitable labour substitutes are available for growing or picking in cucumber production.

Economies of scale and improved management systems can potentially reduce labour by up to 40%. The use of rail and trolley systems and automated trolley return systems can further improve the efficiency of a greenhouse operation. Larger operations which use pipe rail (hydronic) heating systems, automated trolleys and good management processes can operate effectively with 5 – 6 full time labour units per hectare. Other important labour considerations are 1) access to reliable technicians to install and maintain equipment and 2) availability of reliable, trained employees. The latter is particularly important because once planted, a crop grows quickly and poor management impacts crop production and returns.

Beyond the challenge of producing a high yielding, high quality cucumber crop, the logistical management of moving substantial volumes of product from the plants to the consumer can have large cost and labour implications.

Record keeping and benchmarking

Records are an invaluable tool for achieving good horticultural and business practices. Some records, such as a pesticide use record are compulsory.

Keeping records separates the best growers from the rest.

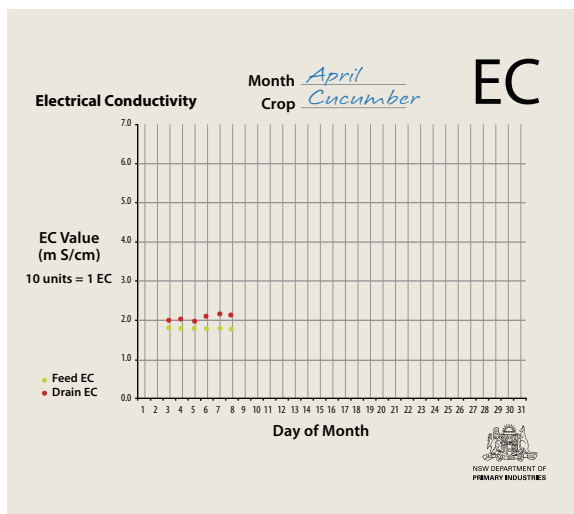
Keeping records

Daily record keeping is a very important and useful management tool in any business, including greenhouse cucumber production. Examples of records which should be kept include:

- Pesticide use or spray application records
- Pesticide storage/inventory records
- Quality Assurance (QA) documentation
- Financial and tax records
- Employee records
- Greenhouse temperature and humidity records
- Electrical conductivity and pH of feed and drain solutions
- Specific nutrient concentrations in solution
- Irrigation and run-off volumes
- Pest and disease occurrences and levels
- Crop yield
- Production inputs and costs.

Keeping records separates the best growers from the rest. Not only is it good business sense, but day-to-day crop records allow you to review practices when a problem occurs and evaluate the outcome of the corrective action taken. Without objective evidence or means to measure, there is no control of the business. Memory cannot be relied upon.

Read through records and notes from the previous year before the new crop gets put in and during the cropping period. Read through the corresponding records matching the same time of year. This will be a great help in foreseeing possible problems and avoiding ineffective or costly actions.



Charts are an effective way to keep records.

Benchmarking

Benchmarking is an essential practice if a commercial greenhouse cucumber enterprise is to be (and remain) profitable and sustainable. Benchmarking is an on-going process of measuring and recording your business' products and practices against past performance and against strong competitors. Strong competitors are not only other greenhouse cucumber producers, but may include any greenhouse producer and even businesses in other industries.

Benchmarking requires definition of key measurement points (or benchmarks). These are then used as a point of reference to continually measure performance. Basically, a benchmark is a point of reference. This allows you to see whether you are getting better, staying the same or falling behind.

Some possible benchmarks include:

Production efficiency

- How many cucumbers can you produce per hectare or square metre of greenhouse? (yield per unit area)
- How many cucumbers can you produce per megalitre of water used? (yield per unit of input)

Production quality

- What proportion of harvested product is unsaleable?
- What proportion of harvestable product meets your target specifications?

Sustainability

- How many applications of pesticides are used to produce a crop?
- What is the cost of pesticides per tonne of crop produced? (cost per weight of yield)
- Of the spray applications made, how many were low toxicity products used as alternatives to high toxicity products?
- What proportion of run-off water is reused?

Marketing

- What is the average price you get per kilogram of product? (dollars per kilogram)
- How many customers do you have?
- How many negative/positive reports have you received from customers?

Profitability

- How much money do you make for every dollar you spend? (return on investment)
- How much does it cost you to produce a kilogram of cucumbers? (cost per kilogram)

Social economics

- How many jobs does your business sustain per megalitre of water used?

Once you have defined a set of benchmarks, the information you collect and record can be used to identify not only problems or weaknesses but also opportunities for improvements. You can readily use this information to work out new strategies or ways of doing things which will improve your business. A lot of this information can also greatly benefit your product and business marketing programs with consumers and the community increasingly looking for businesses that benefit the local community and the environment.

Good agricultural practices

Good agricultural practices encompass all the options, actions and tasks that need to be carried out in a commercial greenhouse cucumber enterprise for it to be and remain profitable and sustainable.

Good agricultural practices include all the activities generally grouped together as integrated pest and disease management (IPM), but go even further to include all activities that impact on the economic, environmental and social aspects of an agricultural business, e.g. workplace health and safety (WHS) issues are part of good farming practice.

Good agricultural practices include all the activities that impact on the economic, environmental and social aspects of an agricultural business.

According to the Food and Agriculture Organization of the United Nations (FAO), good agricultural practices apply recommendations and available knowledge to addressing environmental, economic and social sustainability for on-farm production and post-production processes resulting in safe and healthy food and non-food agricultural products.

The following contribute to the concept of good agricultural practices:

Benchmarking – record key production, workplace and environmental parameters and use this information to gauge performance on a regular basis.

Biological controls and biorationals – implement sustainable and safe pest and disease management alternatives.

Cool chain management – maintain postharvest quality of cucumbers with suitable temperature and humidity management right from harvest to the consumer.

Crop training and pruning – manage crop growth to produce balanced, healthy plants.

Employee training – provide employees with ongoing, appropriate training to maintain productivity and workplace safety.

Farm layout – the farm should be designed for production efficiency, employee and visitor health and safety and environmental protection. Draw a farm plan and update it when needed.

Harvest – pick cucumbers at the optimal period to meet market specifications. Always comply with any relevant withholding period requirement.

Hygiene – maintain a clean and healthy production and work environment to ensure productivity, reduce the use of chemicals and meet safe food and workplace requirements.

Irrigation – provide an appropriate supply of water to maintain crop vigour, balanced growth and health.

Production system – apply nutrients and farm chemicals only as needed to avoid contamination of the substrate and nutrient solution resulting in an unhealthy production system with poor plant growth and yield.

Low toxicity pesticides – if chemical controls are needed, select the least toxic pesticide available. The toxicity of a pesticide is indicated by the signal heading on the label.

Marketing – integrate the marketing process at every stage of the planning and production cycle.

Monitoring – check and record pest and disease levels on a regular basis and use this information when making all pest management decisions.

Nutrition – provide a balanced and appropriate supply of nutrients to maintain crop vigour, balanced growth and health.

Workplace Health and Safety – provide employees with appropriate supervision, training and equipment to ensure a safe and healthy workplace.

Propagation and transplanting – only use strong, healthy, uniform seedlings to ensure crop is progressive and productive.

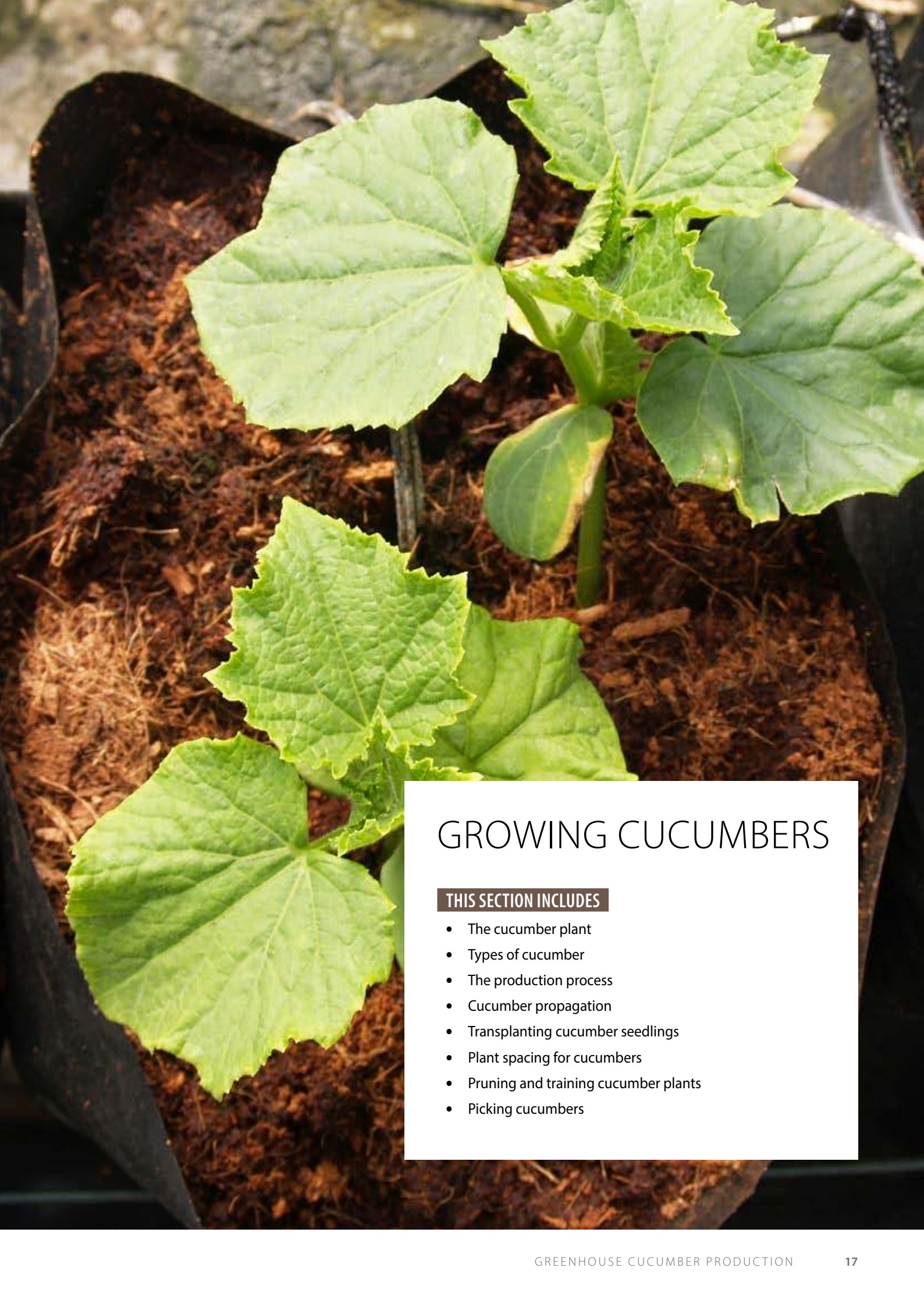
Quality assurance – implement management procedures to minimise and manage incidences of contamination and to maintain product quality.

Spray calibration – make sure spray application equipment is correctly calibrated on a regular basis. This ensures that the rate specified on the label, not under or over it, is accurately applied to the crop.

Transport – use the most efficient mode of transport available. Get produce to the consumer in as short a period as possible. When transporting chemicals, use an appropriate vehicle such as a utility or use a secure receptacle to prevent the load from movement and damage.

Variety selection – the most suitable varieties should be grown to improve productivity, reduce use of chemicals and meet market requirements.

Waste management, recycling and re-use – minimise production of waste, recycle and reuse materials wherever feasible.



GROWING CUCUMBERS

THIS SECTION INCLUDES

- The cucumber plant
- Types of cucumber
- The production process
- Cucumber propagation
- Transplanting cucumber seedlings
- Plant spacing for cucumbers
- Pruning and training cucumber plants
- Picking cucumbers

The cucumber plant

History

The cucumber is a semi-tropical plant considered to be native to southern Asia, specifically from the warm and humid foothills of the Himalayas in north west India, and possibly from northern Africa. Consequently, it responds and grows best when conditions of high temperature, humidity and light intensity are combined with a constant and plentiful supply of water and nutrients.

The cucumber has been cultivated in India for at least 3000 years and was introduced into China about 100 years B.C. Cucumbers are one of the few vegetables mentioned in the Bible – ‘garden of cucumbers’ in Isaiah 1:8. It has often been suggested that the cucumber was one of the fruits of Egypt that the Israelites recalled with regret during their desert trek. There is evidence that the Egyptians provided cucumbers to slaves as a source of water. Some of the very first greenhouses ever built, were constructed by the ancient Romans so that the Emperor Tiberius could eat cucumbers every day of the year. The crop spread through Arabia, South Western Asia, the Mediterranean, Europe and the British Isles. By the ninth century A.D. they were introduced in France and common in England by the early 14th century.

There have been many different names for the cucumber over the ages. The ancient Romans called the cucumber ‘*cucumis*’ which is used today as the name of the genus. The ancient Greeks cultivated cucumbers and called them *sikvos*, later in their history *sikva* was used. The present day Greek word for cucumber is *angouri*. The Arabic name *chiar* predates the Sanskrit for a type of cucumber, which supports the belief that this plant has been cultivated for some 3000 years. In late Middle English it was called *cucumer* which was later replaced by *cucumber* and *cocumber*, the latter often pronounced *cowcumber*. This pronunciation was eventually dropped but the pronunciation *coocumber* gained popularity.

Taxonomy/botany

All plants have at least three levels of botanical classification. Firstly, they belong to a **family**, then a **genus** within that family, and finally a **species** which identifies a specific type of plant that belongs to the genus. All cucumbers (*Cucumis sativus*) belong to the **Cucurbitaceae** or gourd family. This valuable

horticultural family contains some 90 genera and 750 species. Other important cultivated crops that belong to this botanical family include pumpkins, zucchini, squash, gourds, muskmelons, watermelons, rockmelons/cantaloupes and chokos.

The family **Cucurbitaceae** consists of five sub families; cucumbers are part of the **Cucurbiteae** sub family. The cucumber species belongs to the genus *Cucumis* which also contains rockmelons/ cantaloupes and the West Indian Gherkin. Up until recently there was confusion over the classification of species in the genus *Cucumis*, as many of the species were either incorrectly identified or were assigned out-dated botanical names. Modern botanical taxonomic and morphological identification techniques have resulted in two subgenera, 32 species and six subspecies classified in the genus *Cucumis*. There are also some 74 synonymous names as well as 19 dubious names listed for the cucumber, *Cucumis sativus*.

The fig leaf gourd (*Cucurbita ficifolia*) which belongs to the Cucurbiteae sub family is cultivated to some extent, but its greatest world-wide importance is its value as a disease resistant rootstock onto which greenhouse cucumber varieties are grafted.

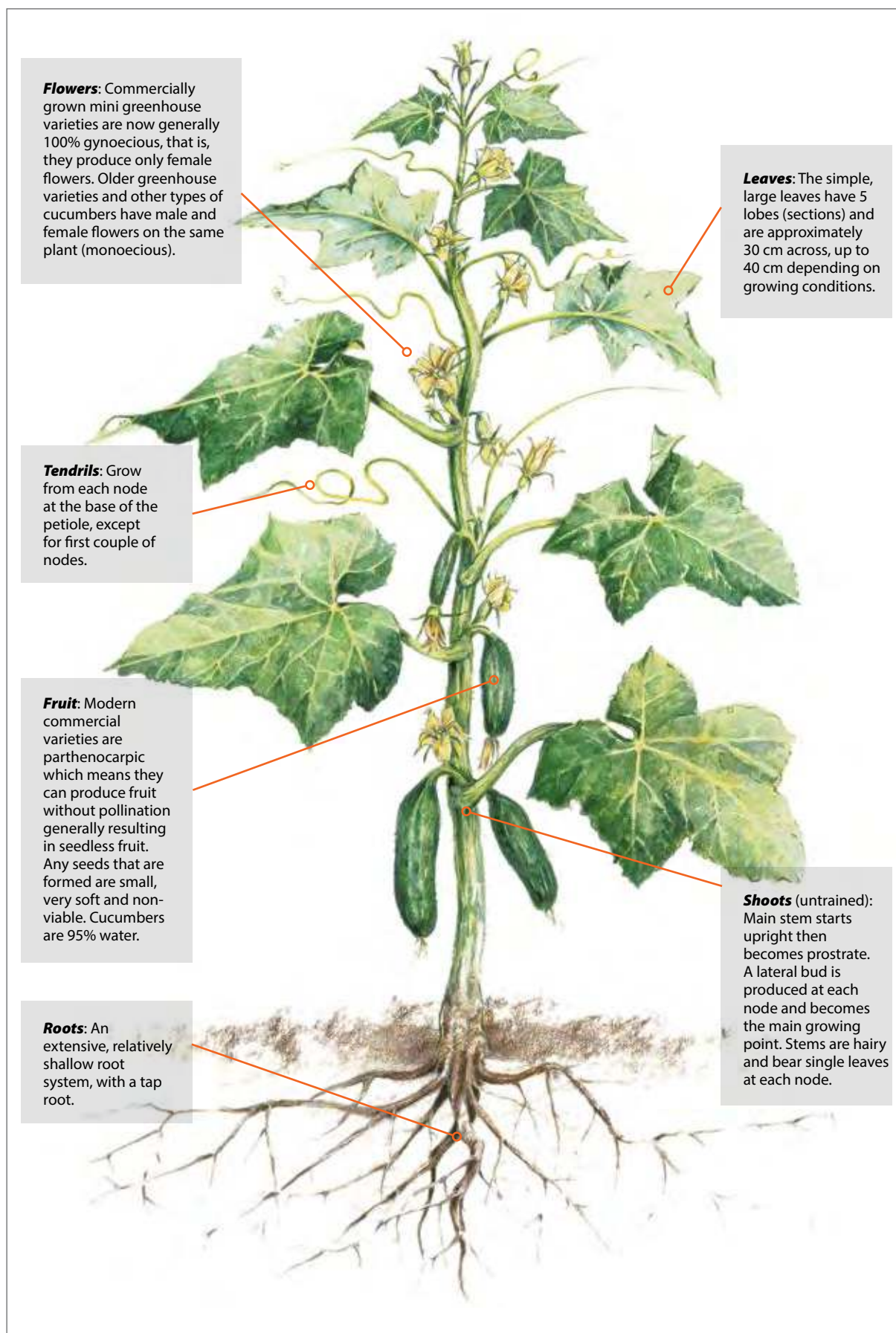
The cucumber plant is a typical semitropical plant, growing well under stable, warm and humid conditions with high levels of light. It requires a continuous supply of water and nutrients. It has a medium tolerance to salt levels. In the wild, the plant is extremely variable in both vegetative and fruit characteristics.

Growth habit

The cucumber plant is a tender, herbaceous, annual bristly vine. The main shoot starts with a climbing (erect) habit but soon adopts a prostrate trailing or running characteristic/manner.

When the plant begins to ‘run’ it assumes a branching growth pattern. The main shoot or growing point produces side shoots from the lateral buds at the base of its leaves. These primary laterals or side shoots can produce their own side shoots or secondary laterals and so on. This type of growth pattern in which the main direction or line of growth is formed by repeated forking of side shoots or laterals is known as a sympodial habit. It results in a branching effect with numerous growing points.

The stiff, prickly or spiky haired stems are angular in cross-section and can become hollow when the vine is mature.



The cucumber plant.

Some varieties require frequent pruning of side or lateral shoots to ensure a single stem that can be trained up vertical wires. Modern hybrids are generally less vigorous and thus need less pruning. Given ideal conditions, four or five fruit may develop from the axil at each leaf. Fruit thinning may be needed so that the full potential fruit size can be realised. If plants are left to carry too many fruit, they can become fatigued, resulting in aborted fruit and wide fluctuations in the consistency of the fruit cropping cycle.

Single leaves are promoted from the nodes (buds) on the main stem and laterals. The leaf is positioned between the main stem and primary laterals.

The large, simple, ovate-pointed leaves are attached to the stem by long (7 – 20 cm) petioles. The leaf margin or edge usually has five distinct angular lobes or tips, with the middle point being the largest. Depending upon the cultivar, the leaf margin can have either deep sinuses (gaps between the lobes) or indistinguishable sinuses and lobes. The leaf surface is covered in numerous, tiny spiky hairs called trichomes.

A simple unforked tendril grows from the base of each petiole after the first three to five nodes on the main stem. The tightly hugging grip of the tendrils gives the plant a natural capacity to grow vertically. Under commercial production, the plant is pruned and trained vertically.

The cucumber plant produces excessive fruit under optimal growing conditions. Left unchecked, plants become exhausted, leading to fluctuating productivity and lower overall yields. This characteristic means that the cucumber plant needs management to sustain an optimal balance between vegetative and generative growth.

Types of cucumber

There are several types of cucumber. As a general classification, there are slicing cucumbers and pickling cucumbers. Slicing cucumbers, such as the European, mini and green cucumbers are generally eaten raw in salads and sandwiches. They are dark green and modern varieties are seedless. Pickling cucumbers, on the other hand, as the name implies, are generally pickled. These types are generally smaller and lighter in colour.

Gherkins are small, spiny cucumbers used exclusively for pickling.

Most commercial cucumbers produced today are seedless. Since the seeds in cucumbers can generate gas in many people, seedless types are also referred to as 'burpless'.

Mini or Lebanese

The mini cucumber types were first bred and developed in The Netherlands in the early 1970s. A Dutch seed company crossed Continental cucumbers with the seedless pickling cucumber lines resulting in fruit that looked like a miniature version of the longer continental cucumber and the term mini cucumber came into use.

The mini cucumber is grown throughout Australia and dominates production in NSW. In Australia mini cucumbers are known as Lebanese cucumbers as they were introduced to the country by the Lebanese community. The Australian mini cucumber industry started at Glenorie in the Hills District of the Sydney Basin in the early to mid 1980's.

Mini cucumbers have thin, bitter-free skin and usually don't contain any seeds. The fruit of mini cucumbers is ribbed or dimpled and spineless with dark green skin, and overall, is generally considered to be more attractive or appealing than the Beit Alpha types.

One of the most significant developments in the Australian cucumber industry has been the introduction of 'all female' hybrid varieties in the early 1990s which do not require male flowers for pollination or fertilisation to produce high yields of seedless fruit. These varieties which are less vigorous and therefore need less pruning now dominate the industry and essentially superseded varieties that need to be pollinated. Variety performance is often related to season so correct variety selection is an important management consideration.

Gynoecious hybrid plants, being '100% female', do not need pollen from male flowers to produce fruit and only bear fruit-producing female flowers which set and produce seedless, or *parthenocarpic*, fruit.

Hybrids with a very high percentage of fruit-producing female flowers, that also carry a few male flowers unable to effectively pollinate fruit, are known as 'predominantly female' plants. Pollinator plants need to be grown alongside these hybrids to produce a good crop. The seed of pollinator plants may be supplied separately or blended with the hybrid seed.

The older, superseded *monoecious varieties* are known as 'mixed-flowering' or 'semi-female' types.

Although outdoor varieties exist, mini cucumbers are almost exclusively grown on trellises in greenhouses to maximise year-round fruit production, especially in cold areas and/or during winter. Plants grown in a protected environment and trellised so that the fruit form and mature off the ground, produce a higher yield of superior quality fruit compared to field grown cucumbers. Trellised plants and fruit are also easier to manage.

Mini cucumbers are harvested when about 12 – 18 cm long and about 2.75 – 3.5 cm thick (100 – 200 g). The plants are very prolific producers. Varieties are further sorted into single fruiting, semi-multi fruiting and multi-fruiting according to the number of fruit produced per node. Up to 14 kg (as many as 100 fruit) can be produced on a single plant depending on variety and growing conditions, though yields around 8 – 9 kg are more common.

Beit Alpha types

In Europe and the Middle East, short seedless cucumbers are known as either Beit Alpha or 'mini' and 'super mini' cucumbers. Beit Alpha cucumbers originated from breeding work which started about 45 years ago in Israel on a kibbutz called Beit Alpha. Prior to this selection process and breeding work, varieties used for commercial production were very heterogeneous, resulting in great variations in yield and fruit characteristics.

About 10 years later a plant breeder from the Hazera seed company in Israel back-crossed a female cucumber line with Beit Alpha and a hybrid which produced only female flowers (*gynoecious*) was developed. Such plants could only produce fruit by inter-planting with a small percentage of special pollinator plants. The pollen donor plants bore a sufficient number of male flowers to assure ideal pollination and fruit set. Seed of pollinator plants



Above: The mini cucumber dominates production in NSW. Note the longitudinal ridges of the Dutch types.



Note the smooth skin of Beit Alpha types.

was supplied in a separate packet or mixed in with the varietal seed at packaging. The pollinator seed was specially coloured to make it easily distinguishable.

The Beit Alpha type has also been crossed with cucumber lines sourced from Japan and India to develop hybrids with improved disease resistance particularly to downy mildew, powdery mildew and cucumber mosaic virus.

The traditional Beit Alpha types generally have a shiny, smoother and pale green skin, with very short black or white hairs. The cylindrical fruit has a firmer consistency and better taste than mini cucumbers. However, the mini cucumber hybrids have superior vigour and better yields than the Beit Alpha types. Beit Alpha types are now generally regarded as mini cucumbers and in Australia both the different types of miniature cucumber are called 'Lebanese' cucumbers. Both greenhouse and field varieties are available.

European/Continental

The European or Continental cucumber is a long narrow dark green fruit. These cucumbers are generally harvested when about 25 – 40 cm long and about 3 – 4 cm thick (250 – 450 g). The skin is edible. These cucumbers are seedless and do not require pollination. A good crop should produce 20 – 30 fruits per plant. The European cucumber has a very thin skin and loses water quickly after harvest. To reduce dehydration and improve shelf-life, these cucumbers are individually wrapped in plastic. This type may also be called the 'telegraph', 'Dutch' or 'English' cucumber.

Note: There are also continental cucumber varieties that produce 20 cm long fruit. These are commonly called 'midi' cucumbers. In the past, they were referred to as 'half' long types, forcing types or mini 'Dutch' cucumbers.



The European cucumber has a very thin skin and loses water quickly after harvest.

Snack

The cocktail, baby or snack cucumber has become a popular premium cucumber in Australia in recent years. This type is a smaller version of the Lebanese cucumber. It matures at a much smaller size and is harvested when about 6 – 8 cm long and 1.5 – 2.5 cm thick. Cocktail cucumbers are packed in punnets.



Cocktail cucumbers can be picked while still very small.

Green

The traditional or standard green slicing or 'Aussie' cucumber is an elongated fruit thicker than the mini and European cucumber. This type is harvested when about 20 – 25 cm long (about 350 – 550 g) and 5 – 6 cm thick. Both greenhouse and field varieties are available. They are also dark green and can have small bumps on skin or be smooth.



The green slicing cucumber is dark in colour and can have small bumps on its skin or be smooth.

Apple

The apple cucumber is a white to pale yellow colour. There is a high quality green variety called Richmond Green Apple. It is rounded and has a mild sweet flavour. It is also referred to as the lemon cucumber. These fruit are typically about 400 – 450 g at harvest.



The apple cucumber is generally pale but can be lemony and green in colour and is spherical or round.

Oriental

Oriental (or Asiatic) cucumbers are mostly long, up to 45 cm long, and thin, about 5 cm in diameter but other shaped and sized varieties exist. Japanese, Korean and Chinese types are the most common. The seed cavity is small and hence flesh thick. The skin is often prickly. These types are picked when they are immature and used for pickling and in salads.

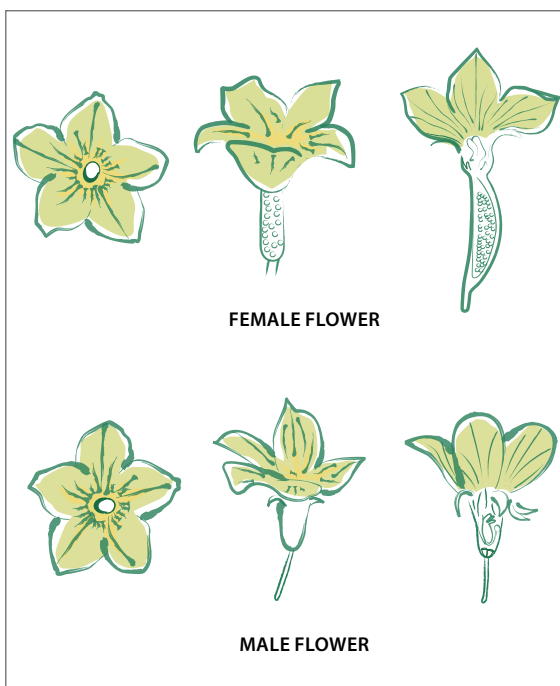


Oriental cucumbers vary in length and colour, are thin and can be prickly.

Pollination

The varieties of greenhouse cucumber grown commercially in Australia are gynoecious (all female), so their flowers develop into seedless fruit without pollination.

Some varieties, though rarely grown, are predominantly female types, but not totally gynoecious. This means that they can produce a few male flowers under certain conditions. Male flowers are usually encouraged by conditions that favour vegetative growth such as hot, sunny conditions with a plentiful supply of nitrogen and water. If male flowers are produced, they should be removed immediately. If pollen is transferred from a male flower to a female flower, such as by bees, seeds will develop. This distorts the fruit and they are not marketable. This distortion should not be confused with damage caused by thrips or cold growing conditions.



Modern commercially grown mini greenhouse cucumber varieties produce only female flowers and do not need pollination.

The production process

The process of growing cucumbers involves five key stages. These are repeated for each crop.

Stage 1: Set-up

The set-up stage is about getting the greenhouse and the hydroponic system ready for a new crop. Sanitation – keeping the production area clean and healthy – is one of the most important parts of intensive cucumber production. Keeping everything clean reduces problems, particularly diseases, and will save you money. A good, methodically clean and tidy greenhouse and surrounds can mean the difference between making a healthy profit and losing money.

Sanitation

Clean everything. You might need sanitisers, cleaning agents, water, a pressure cleaner, pumps, hoses etc.

Layout hydroponic system

Put out new or cleaned containers/bags/pots/boxes/channels. If you are using a substrate hydroponic system*, decide on type and supplier of substrate. Check the quality, uniformity and characteristics of the substrate. If reusing substrate, clean and pasteurise it.

Layout irrigation system

Clean pipes and emitters (acid, sanitiser). Check and clean pumps, filters and injectors/valves.

Check the irrigation uniformity – the DU% test#

Set environmental parameters

Check control systems for the greenhouse and hydroponic systems. Reset programs for the new crop and season. Calibrate sensors.

Set up footbaths

Keeping the greenhouse clean is critical. Set up and maintain footbaths and make sure everyone going into the greenhouse uses them.

Keeping the production area clean is one of the most important parts of intensive cucumber production.

Stage 2: Cucumber propagation

The propagation stage is about getting quality seedlings ready for planting out. This stage may be on farm (in-house) in your own propagation greenhouse or they may be sourced from a commercial seedling supplier. Whether you propagate your own plants or buy them in, it is essential that you only use high quality, robust seedlings free from pests and diseases. Clean and healthy seedlings can mean the difference between making a healthy profit and losing money.

Choose variety

Check your market. What variety(ies) is/are right for your business? Look at your production schedule. Discuss trends with seed suppliers, market and/or customer agents.



Only use high quality seedlings free from pests and diseases.

Order seed/seedlings

Work back from the date you want to plant into the greenhouse. Place your order well in advance. If buying seedlings make sure your supplier is clear about what you want, for example, do you want advanced seedlings? Are there any chemicals which you do not want used on your seedlings? What type of substrate do you want the seedlings produced in?

* For more information on hydroponic systems, refer to 'Hydroponic systems and technology' starting on page 87.

Information about irrigation distribution uniformity starts on page 95.

Propagating

You will need seed, substrate, pots, a water and irrigation system, and nutrient solution. Will you need heating and supplementary light to ensure quality seedlings? What are your pest and disease management strategies?

Stage 3: Cucumber production

The production stage is about growing the crop. This stage has four sections:

1. Planting out and establishment
2. Growth Stage 1 (Vegetative – plant establishment)
3. Growth Stage 2 (Generative – early fruiting)
4. Growth Stage 3 (Full crop)

Throughout production, as a grower your job is to provide the right conditions for the plants. This involves balancing the focus of the plants – are they vegetative (the juvenile growth phase of roots, leaves and stems) or generative (the phase in which fruit is produced)? Keeping a plant ‘in balance’ can mean the difference between making a healthy profit and losing money.

A grower's job is to provide the right conditions for the plants.

Planting and establishment

You will need healthy, clean, quality seedlings ready on the day you want to plant out. Your hydroponic system needs to be working. Your substrate should be wetted up. The greenhouse environment should be set for the new plants. It is important not to stress the plants. Do not damage the seedlings' roots. You will need sufficient staff to make sure the planting is finished quickly so seedlings are not left waiting in the sun or heat.

Avoid extreme temperatures especially over the first few days. Raise relative humidity to reduce plant stress if needed.

GROWTH STAGE 1

In this stage, focus on producing a vegetative plant. The aim is to build a robust plant via a healthy root system, shoot growth and leaf area that will support a high yield relative to the variety's genetic potential.

Training and pruning

You will need crop support strings. What training and pruning program will you use? Manage the green waste – do not leave prunings² in the greenhouse or nearby.

Feeding and irrigation

You will need a nutrient solution and irrigation schedule. Nutrient and irrigation decisions should be made on the basis of the root zone solution – always check the run-off (that is the DRAIN EC, pH and volume) but make adjustments to the FEED EC, volume and possibly pH. Make sure pH does not drift too far.

Pest and disease management

Regularly inspect your crop with a magnifying glass. Actively monitor pest and disease levels. Use sticky traps and a crop monitoring plan. Practice IPM. Prevent pests and diseases from establishing in the crop³. Use action or threshold levels to determine management decisions. Use physical and environmental controls to reduce pests and diseases. If using chemical controls, use the least toxic product wherever possible. Incorporate biological controls such as predators, parasitoids and beneficial pathogens into your management program.

GROWTH STAGE 2

In this stage focus on creating a shift towards a generative plant. The aim is to manipulate and support the growing plant to produce the best possible fruit quality and yield.

Training and pruning

Keep up with training and pruning. Use pruning as a management tool to keep the plant in balance. Manage the green waste – do not leave prunings in the greenhouse or nearby as they are a hygiene hazard.

Feeding and irrigation

Continue to make nutrient and irrigation decisions on the basis of the root zone solution – always check the run-off (that is the DRAIN EC, pH and volume) but make adjustments to the FEED EC, volume and possibly pH. A higher potassium level is beneficial.

² In some circumstances when biological control agents are being used, it may be necessary to leave prunings in the crop for a short period.

³ For more information on preventative pest and disease management, refer to Badgery-Parker, J. (2009), *Keep it Clean – reducing costs and losses in the management of pests and diseases in the greenhouse*, NSW Department of Primary Industries.

Pest and disease management

Regularly inspect your crop. Actively monitor pest and disease levels. Use sticky traps and a crop monitoring plan. Practise Integrated Pest Management (IPM). This means prevent pests and diseases establishing in the crop. Use action or threshold levels to determine management decisions. Use physical and environmental controls to reduce pests and diseases. If using chemical controls, use the least toxic product wherever possible. Incorporate biological controls such as predators, parasitoids and beneficial pathogens into your management program.

GROWTH STAGE 3

In this stage, keep the plant balanced – not too generative, not too vegetative.

Training and pruning

Keep up with training and pruning. Use pruning as a management tool to keep the plant in balance. Manage the green waste – do not leave prunings in the greenhouse or nearby.

Feeding and irrigation

Continue to make nutrient and irrigation decisions based on the root zone solution – always check the run-off (that is the DRAIN EC, pH and volume) but adjust the FEED EC, volume and possibly pH. A higher potassium level is beneficial.

Pest and disease management

Regularly inspect your crop. Actively monitor pest and disease levels. Use sticky traps and a crop monitoring plan. Practice IPM. This means prevent pests and diseases establishing in the crop. Use action or threshold levels to determine management decisions. Use physical and environmental controls to reduce pests and diseases. If using chemical controls, use the least toxic product wherever possible. Incorporate biological controls such as predators, parasitoids and beneficial pathogens into your management program.

Harvest

Use clean, sterilised secateurs or a knife to harvest fruit. This reduces damage and sites for potential disease infection. Use clean and convenient 'field containers' to pick into. Move fruit into the cool room or packing shed as quickly as possible. Do not leave product in the greenhouse or in the sun. Trolleys or small vehicles can greatly improve efficiency.



Harvesting trolleys that can run along the heating rails greatly improve efficiency.

Stage 4: Postharvest

The postharvest stage is about preserving quality and getting your product to the consumer. Remember you cannot improve quality once you have picked the cucumber. All you can do is try to preserve it.

Transport to pack house

Take care when you handle the crop. Knocks and bruises will show up later in poorer quality and shorter shelf-life.

Cooling

Effective cool chain management is critical to preserving the quality of your product. When cucumbers are harvested, they have 'field heat'. This needs to be removed as soon as possible.

Grading

Grade the product. You need to have clear specifications developed in conjunction with your agent and/or buyer. Never mix grades in a carton, tray or bag.

Packing

Handle the cucumbers with care. Pack to the agreed specification. Do not under pack cartons, trays or bags. Do not mix grades.

Weighing

Make sure you do not under pack your cartons, trays or bags. It is against the law.

Labelling

Check that boxes or trays are labelled correctly. Traceability is important for food safety as well as improving future management decisions.

Palletising

Stack cartons on pallets correctly. Damaged boxes or trays and over stacking can damage product, reduce value and even cause accidents. Tie-down or shrink wrap the cartons to secure the load.

Storage

If storing product, maintain your cool chain.

Load and dispatch

Check any documentation you, your agent or buyer requires.

Transport to buyer

Maintain your cool chain all the way from as soon as possible after harvest until your buyer takes delivery.

Once a cucumber is picked, you cannot improve its quality – you can only try to preserve it.

Stage 5: Clean out

The clean out stage is the end of the crop. Plants are removed from the greenhouse and the greenhouse and hydroponic systems are cleaned out – the use of disinfectants may be required.

Dry out crop

Turn off irrigation a day or two before you plan to remove crop. The plants will use up water in the substrate and make the containers lighter and easier to move. However, this can also make the plant material more brittle, making the plant debris harder to remove.

Cut twine

Cut or untie crop support strings at the bottom.

Cut stems

Cut stems of plants at the base.

Lay down crop

Untie or cut strings at tops and lay the plants down in the row. If using synthetic strings and planning to compost or bury crop residue, you will need to remove the strings. Biodegradable string is available.

Remove crop

Drag or carry plants from greenhouse for disposal.

Remove containers

If using a substrate system, remove bags/pots for disposal. If reusing substrate, clean and pasteurise to prevent diseases carrying over into the new crop.

Sweep/hose out greenhouse

Sweep out leaves, dirt and other debris from the greenhouse. You may also want to hose down the greenhouse floor and sides and disinfect.

Hose out hydroponic system

Depending on the hydroponic system used, hose out and disinfect channels, gutters and/or drains.

Flush lines

Flush irrigation lines and check for blockages. Disinfect if required.

Cucumber propagation

Good germination is important for a strong healthy crop. Plants which start off well typically have better yields and therefore better economic returns. The quality of germination also affects crop uniformity. Cucumbers have a large seed (about 1 cm) and while they can be sown directly, this rarely results in uniform germination. It is also more difficult and generally expensive to maintain the optimal conditions for germination in situ.

Slow germination increases the risk that plants will get infected with a disease. Cool propagation substrate results in weak and slow growing seedlings. Cucumbers have a minimum temperature for germination of about 15°C. Below 15°C, the seeds will not germinate.

The best temperature for growing seedlings is between 21 and 29°C. Good germination needs a temperature around 27 – 28°C. This should be maintained continuously until germination. At this temperature sprouting should begin within 48 hours. Once germinated, reduce the temperature by 3 – 4°C.

Night and day temperatures should be kept similar to promote strong even growth. When night temperatures fall below day temperatures, tall seedlings with small leaves will result. When night temperatures exceed day temperatures short and stocky seedlings are produced. A day temperature of 24 – 25°C and a night temperature of 22 – 24°C are suitable. In this temperature range, the first true leaf will appear in 7 – 10 days.

Under low light conditions, a further reduced day temperature of 22 – 23°C and night temperature of 20 – 21°C is ideal.

or rockwool cubes if producing advanced seedlings. This avoids the need for an extra transplanting task. Advanced seedlings enable a more efficient use of the greenhouse by reducing 'downtime' when no fruit is being picked.

When using plugs, loosely fill the plug tray with substrate then press the substrate into the cells (or use a premade cocopeat propagation product). Sow one seed per cell 10 mm below the top. Cover with more substrate to fill the plugs. Water the trays with plain water until the first couple of leaves appear. Keep propagation substrate moist but not wet.

Once the seedling has emerged, apply a weak nutrient solution. Dilute your standard nutrient solution to an electrical conductivity (EC) of about 1.2 mS/cm and a pH of 5.5 to 6.

When using rockwool blocks, lower the pH of the substrate before use. To do this, fully wet the rockwool in dilute nutrient solution with a pH of 5.0 – 5.5 and a low EC (about 1.2 mS/cm). About 4 – 5 litres are needed per square of substrate blocks.

Before sowing the cucumber seed, use a knife to cut down the long grooves between the individual blocks. This makes separating the blocks easier later.

Make a small hole in the top of the block and sow one seed per block. Do not press the rockwool around the seed. Instead, cover with vermiculite to help hold moisture around the seed. Keep the rockwool moist but not wet. When necessary, water with dilute nutrient solution with a pH of about 5.5. Check the drainage nutrient solution. Maintain a pH in the drainage water of about 6.0. Keep the EC of the drainage water below 2.2mS/cm. Make sure that excess water can drain away from the rockwool propagation blocks.

Propagation substrate

To avoid root damage, propagate cucumbers in plugs or propagation blocks (such as rockwool or cocopeat plugs) so that they can be transplanted with the full root system intact. Note, there are a range of propagation materials and options available. Cucumbers can also be sown directly into larger pots



Rockwool is a simple and easily used propagation material.

Table 3. Recommended temperatures for propagation of cucumbers

Propagation temperatures	Day Temperature °C	Night Temperature °C
Germination	27 – 28	27 – 28
Post emergence: high light conditions	24 – 25	22 – 24
Post emergence: low light conditions	22 – 23	20 – 21

Light

Adequate light is critical for a healthy cucumber seedling. Poor light levels result in a stretched or 'leggy' seedling which will produce a poor quality plant. Under low light conditions, reduce the temperature to slow growth, minimising the risk of stretching. Low light conditions will generally only be a problem during extended periods of cloudy dull weather or in situations where the propagation greenhouse is unsatisfactory, for example, dirty or old covering materials.

Cucumbers do not need light to germinate, but once the seeds have germinated, high light conditions are needed. When supplying supplementary light, provide a 12 – 16-hour day, though there is some evidence that continuous light may be beneficial.

Do not let seedlings become crowded. If using plug trays, the plants need to be transplanted or planted out by about 12 – 14 days after sowing. If using rockwool blocks or pots, space the seedlings to prevent crowding or transplant.

Buying in seedlings

Some growers prefer a hands-on approach and so propagate their own seedlings. Other growers propagate in-house to minimise the risk of bringing pests and diseases on to their property or because they are unable to get timely delivery of suitable quality plants in their area. However, buying ready to transplant seedlings is the preferred option for most commercial operations. Outsourcing propagation can provide significant savings in labour, infrastructure and energy and often better and consistent quality seedlings. A specialist propagator should deliver high quality, pest and disease free transplants on time to fit with your planting schedule.

Most seedling suppliers operate on a 'payment on planting' arrangement so payment needs to be organised in advance. Most specialist propagators take orders in lots of 1000 plants. Order approximately 5 – 10% more transplants than the number needed for planting out the greenhouse. This surplus means you can choose the strongest for planting out and have a ready supply of replacements of the same age and variety for any damaged during transport, transplanting or other mishaps that occur. It is essentially an insurance against having gaps in your crop, should something go wrong.

When organising a new order, check that the proposed propagating medium used is suitable with your production system.

You will also need to define what pesticides, if any, are used on the seedlings. This is critical if you intend to use biological control organisms, or your marketing program excludes the use of certain products.

Transplant seedlings as soon as possible after getting them.

Minimise the length of time transplants are stored before planting out by making sure that your greenhouse is ready by the delivery date. Although the seedlings may not appear to be aging, the longer they are kept before planting-out, the older the seedlings become physiologically so it's important to allow the roots to develop unimpeded in the substrate by planting-out quickly so that growth and yield are maximised. Have someone present when the transplants arrive. If seedlings are not going to be planted out straight away, store them in a cool place, with adequate water and ventilation, out of direct sunlight.

Always check the seedlings on delivery. Make sure the seedlings are delivered in good condition. Check that the plants are:

- uniform
- healthy
- free from pests
- free from diseases⁴
- at the right stage of development.

If everything is good, sign off any necessary paperwork and take delivery. If the plants are not suitable, for example, they are infested with pests or infected with disease, do not accept them and don't plant them into the greenhouse.

⁴In some situations, it is beneficial to have a system that enables seedlings to be held in quarantine for 10 - 14 days and planted out as advanced seedlings when they are shown to be disease free.

Grafted plants

Grafting is a useful strategy to manage particular disease problems. When a plant is grafted, the scion (stem) of a plant is joined to the rootstock (roots) of another plant. For example, you may wish to grow a high yielding variety but it is susceptible to root disease. The scion of this chosen variety is grafted onto the roots of a disease resistant variety, usually *Cucurbita ficifolia*.

There are several different grafting techniques. Grafting is a skilled job and can add significantly to the cost of plants. However, grafted plants can be a very effective part of an integrated disease management program.



Grafting is a useful strategy to manage some disease risks.

Transplanting cucumber seedlings

Seedlings are transplanted either directly to the greenhouse or for growing on as advanced seedlings. Avoid causing damage to the roots of seedlings during transplanting. Do not remove the growing medium from the root ball of the seedlings. Seedlings need transplanting or planting out before the roots protrude beyond the propagation block or plug.

Growing on

Cucumbers can be grown on to produce advanced seedlings about four weeks old. Using advanced seedlings reduces the time cucumbers are not being picked from the greenhouse.

Transplanting of advanced seedlings in pots is a more time-consuming task than planting out two-week-old seedlings in plugs and may negate any advantage of planting out older seedlings.

When growing on seedlings, transplanting can be done about 7 – 8 days after sowing. When using propagation plugs, transplant the seedlings to a larger pot (8 – 10 cm). Make sure the substrate is moist. The top of the plug should be level or a little above the top of the substrate.

Rockwool is a very convenient system for propagation and production of seedlings and makes the use of advanced seedlings much simpler and efficient. Propagation blocks are transplanted to rockwool cubes (pre-drilled with a hole to fit the block) for growing on. It is also possible to sow directly into rockwool cubes to avoid the extra step. This will require more space in the propagation house and may not be feasible if supplementary lighting is needed. There are also similar products developed for cocopeat that can streamline the propagation process.

Planting out

Cucumber seedlings can be transplanted directly into the greenhouse about 12 – 14 days after sowing, depending on growing conditions. Advanced seedlings are generally four weeks old when transplanted into the greenhouse.

When planting out standard seedlings (trays of 198 seedlings), the top of the plug or rockwool block should be level or a little above the top of the substrate.



Seedling plug ready for planting out.

If using rockwool cubes, these are placed onto the substrate.

During and after transplanting, it is critical to reduce stress on the young crop as much as possible. Young plants suffer stress more readily than older established plants. The two factors that must be managed are heat and humidity. It is important to avoid an excessively hot greenhouse and low humidity. Transplanting in the late afternoon gives the crop an opportunity to settle without undue heat or evaporative stress. Retractable horizontal screens and fogging or misting systems can also be used to reduce the heat stress and help build humidity in the greenhouse.

Plant spacing for cucumbers

The plant spacing in a greenhouse can be worked out from the desired plant density. The plant density is the number of plants grown in each area (a square metre). It is based upon the level of light, the relative humidity, how the plants will be trained, the variety and the type of growing system.

Plant density will affect crop growth, yield and particularly set up and growing costs. Increasing the density does not necessarily mean the yield will be increased. If light becomes limiting to the plants, growth and yield will decline. Set up and growing costs also increase with more plants. The optimal density is ultimately dependent on the available level of light. Under normal circumstances, it is generally better to have a lower plant density rather than risk having a crop density which is too high should the season turn out to have lower than average radiation levels. It is always possible to change the training and pruning* regime to optimise conditions if radiation levels are higher than average.

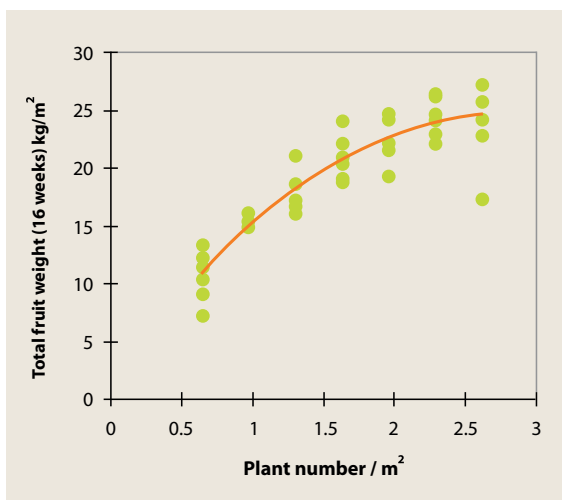
Cucumbers require a relatively high level of light. The proportion of light used by plants is called photosynthetically active radiation (PAR). Recommended optimal radiation levels (PAR) for cucumbers vary but typically range between 250 and 670 $\mu\text{mol}/\text{m}^2/\text{s}$ (unit is micro moles/ m^2/s) which corresponds to about 55 – 150 PAR Watts/ m^2 .

A single day of low light conditions (below 80 $\mu\text{mol}/\text{m}^2/\text{s}$ or a daily light interval of 0.8 MJ/ $\text{m}^2/12\text{-hour day}$) has been shown to reduce the photosynthetic rate of cucumbers by as much as 25%. Low light intensity will result in flower and fruit abortion and lower yields. Plants grown under low light conditions also have longer internodes. This is called 'stretching' and is a common problem when seedlings are grown without enough light. It is important to maximise light transmission into the greenhouse by maintaining covering materials and avoiding excessive shadowing by structural items and equipment above the crop.

Cucumber plant densities used in the industry tend to range between 1.4 – 2.5 plants/ m^2 depending on the location and planting season. In most Australian production areas, light levels are very good throughout the year. Training and pruning practices have an important effect on density and crop growth and production and so must be considered. A plant density of around 2.3/ m^2 is a good starting point. When a single stem is trained, the planting density

* Training and pruning is described starting on page 34 'Pruning and training cucumber plants'.

equals the 'head' density. It is important to note that head density can be adjusted as a season changes by training or removing additional laterals from a plant. More information on changing the density during cropping is provided on page 33.



Plant density also impacts air circulation and humidity levels in the crop. In very humid conditions, reduce the density by about 5% to improve air flow and therefore manage the humidity. Very humid conditions may be regional and/or seasonal but can also result from the greenhouse set up. It is important to know and manage your production area.

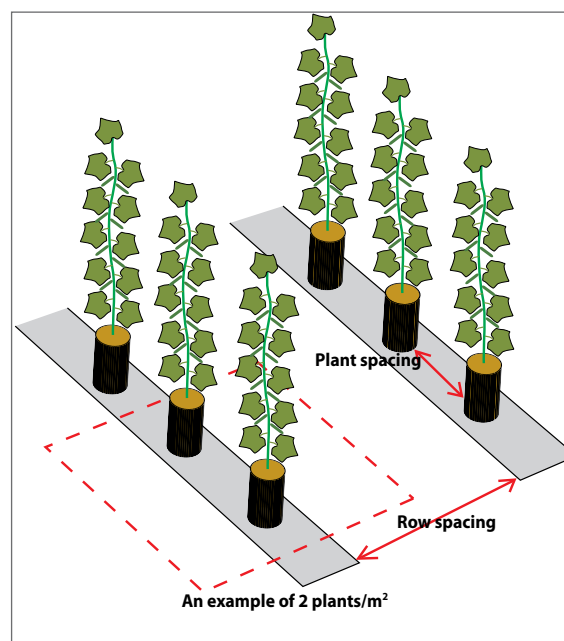
Seed companies undertake a lot of trial work for their variety lines and are generally the best source of information relating to planting densities for specific varieties, however, benchmarking your crops will give you superior information over time. See page 14 for information on benchmarking.

The spacing between plants (*plant spacing*) within a row can be readily altered (up to a point) to result in a specific plant density. Typical plant spacings range from around 350 to 600 mm.

The spacing between rows (*row spacing*) is generally fixed once a greenhouse is set up. It will vary with the training system and greenhouse dimensions as well as the type of equipment used in the crop. A key criterion in deciding the space between rows should be the type of equipment used, for example trolleys. Even if no trolleys or other equipment is used, sufficient space is needed for a person to walk between the rows without damaging the plants.

Frequently, the row width is based on a grower's preference or a standard determined by the greenhouse builder. The row space is often worked out within a general range based on the span of the greenhouse in order to have a certain number of rows fit evenly in the structure. The location of posts may also have to be considered. Row spacings usually range from around 900 – 1200 mm. A wider row spacing is used with a canopy training system.

The row width is dependent on the hydroponic system/substrate being used. Plastic wrapped



Plant density is determined by the row and plant spacing.

rockwool, cocopeat and perlite slabs are about 150 – 200 mm wide. Plastic bags and planter pots are usually 200 – 300 mm wide.

A channel to collect drainage water is needed for every row. A simple system is to make a collection channel with plastic sheeting attached to two parallel wires running the length of the row. The channel needs to be a little wider than the growing bags to enable the flow of drainage water down the channel. Typically, a row width, including the channel, is 300 – 500 mm.

A space between the substrate and the drainage channel is needed to prevent roots of the plants growing into the drainage channel. This also reduces the risk of disease spreading between plants via root to root contact.

A common practice is to place the containers of substrate on top of a low bench. Elevation of the crop in this way improves hygiene in the greenhouse, prevents roots from growing into the drainage channel and reduces physical damage to the bottom leaves. An added benefit is that the first fruit are at a convenient height. Air flow around the crop is also improved.

A drawback to this system is that root to root contact between adjacent plants is possible which can contribute to the spread of disease.

A low-cost alternative is to place the containers of substrate on a pair of high tension parallel wires, running above the channel. This prevents root to root contact and prevents roots from growing into the drainage channel while also improving air circulation and drainage.

Styrofoam boxes have, in the past, been used to elevate the growing bags. If using any material like this, place a sheet of plastic over the boxes and under the growing bags. When the growing bags are removed, the plastic sheet can be hosed down and/or decontaminated easily before bringing in the new growing bags. This makes it possible to properly clean the greenhouse – styrofoam boxes are nearly impossible to clean thoroughly. The readily cleaned sheet of plastic prevents any residual disease infecting the new substrate. A clean, hygienic greenhouse is the first and one of the most important steps to good agricultural practices and reduced pesticide use.

Make sure that the plastic sheet is positioned and secured so that drainage water from the growing bags drains into the channel and not on to the floor of the greenhouse.

Hanging gutters are a prefabricated system to improve drainage and airflow whilst enabling good greenhouse hygiene and are commonplace in newer and higher technology systems.

Changing the density during cropping

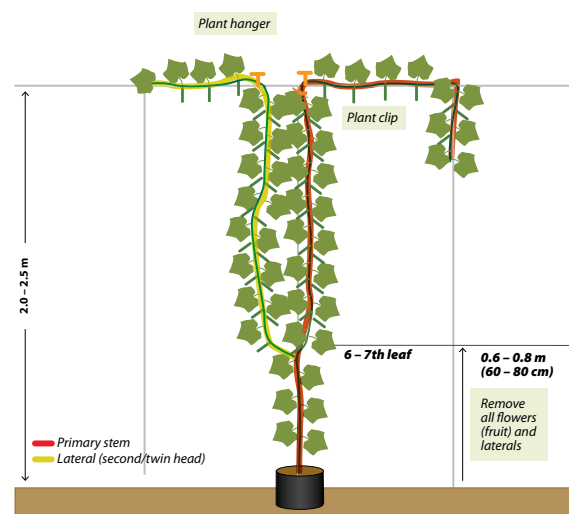
The density of a crop can be altered during the growing cycle. A higher density can be attained across spring and summer (higher light levels) by multi-heading the crop, though it is less successful with cucumbers than some other greenhouse crops.

Multi-heading is an advanced pruning and training technique that takes one or sometimes two extra laterals and trains them alongside the main stem to produce 2 (twin heading) or 3 (triple heading) stems from the same plant. The 'head density' of a crop is more important than the plant density as it directly relates to light interception by the crop. In a crop without multi-heading, the head density is the same as the plant density.

Multi-heading can be a useful technique to capitalise on high light conditions, reduce hyphenate set-up costs and correct plant balance, but multi-heading needs to be used with caution. Only relatively small cost savings are realised but there is an increased risk of larger yield losses should disease, pest or nutritional problems affect the crop. Problems with irrigation uniformity, plant stress and management of plant balance can result, costing more money than what may be gained.

Multi-heading also places an additional workload on a plant's root system. Good management of the growing substrate is critical and quality substrates must be used.

A multi-headed crop is generally more difficult to prune which can make it more difficult to maintain plant balance. Labour costs are greater in multi-headed crops.



Good management of the growing substrate is critical when multi-heading a crop. Quality substrates must be used.

Pruning and training cucumber plants

The aim of training and pruning is to grow the largest possible crop of the best quality by making optimal use of available light and space with the least labour. Pruning is also about managing the balance between vegetative and generative growth. While a crop is pruned and trained to a general plan, specific pruning decisions are ultimately an individual consideration.

What is pruning?

Pruning is the selective removal of parts of the plant. Pruning can refer to removal of leaves, laterals, the tip of the main stem, flowers and fruit. It is one method used to regulate growth and direct plant balance. Pruning also improves the uniformity of the crop. Pruning is a way to regulate fruit per square metre to meet seasonal variations.

Why should you prune?

Pruning is a fundamental part of cucumber crop management. It is an important tool used to manage plant balance and ensure that the plant produces good quality fruit. An unpruned plant produces more total dry matter (leaves, stems, roots and fruit) than a pruned plant, as well as many unmarketable fruit – fruit that are too small or misshapen. Pruning is used to control the plant and encourage it to do what we want.

If there is too much vegetative growth, excess leaves grow at the expense of fruit. A dense canopy of leaves can cause several problems. Lower levels of sunlight and heavy shading in the crop can result in pale fruit and reduce fruit quality, especially in terms of shelf-life. The amount of bent fruit has also been associated with very dense canopies. Excessive leaf growth slows down air flow through the crop resulting in a build-up of humidity within the canopy. Conditions of high humidity encourage the development of several diseases. Spray applications are also less effective and more expensive when the canopy is dense because it is more difficult to get good coverage of the plant.

If leaf growth is excessive, while reducing the plant density in the greenhouse for subsequent crops is the preferred long term approach, plant balance should be adjusted to reduce vegetative growth in

the existing crop. Remove leaves (not more than one leaf per plant per week) to address specific problems, e.g. leaf removal is useful when plant density is too high for light conditions and fruit colour is poor. Take off excessively damaged leaves on a plant to reduce infection sites for disease. Avoid heavy de-leafing. Do not take off more than 1 – 2 leaves in a week.

Reducing plant density in the greenhouse for subsequent crops is the preferred long term approach if excessive leaf growth is common.

Routine leaf pruning is not generally done. It is relatively high cost and when cucumbers are produced in heated greenhouses there are few benefits.

Regular maintenance is required to produce a uniform crop of high-quality fruit. Prune laterals at least weekly, but often 2 – 3 times per week. This is especially important given the speed at which greenhouse cucumbers grow and develop. A cucumber plant can grow more than 10 cm in 24 hours.

An open canopy pruned regularly is easier to maintain and harvest. This reduces overall costs of production.

While in general, all the plants in a crop are treated the same, pruning is a plant specific tool. Removing or not removing a leaf or fruit from a plant has an impact on that plant. To this end, pruning is used to steer plants on an individual basis to correct plant balance. For example, if a plant is more vegetative than the rest of the crop, you may decide to leave an extra piece of fruit on the vine to slow the plant down, or, if a plant has become too generative, you may decide to remove some of the new fruit instead.

Avoid removing leaves at the top of the canopy during the summer months and periods of high light intensities. These leaves act like shade umbrellas and protect developing fruit. In winter and autumn, when light is less intense, they can be removed if necessary.

What is training?

Training is the method of guiding plant growth so that plants make the best use of the available light and space.

Training has two basic parts. The first part of training is the overall shape of the vines. There are several training systems. The second part of training is the general day-to-day management of the crop.

General plant management

Training and pruning operate together. The usual pruning system used for cucumbers is the umbrella system. This has several variations.

Plants are trained upwards around a length of string (a cordon) so that the main stem climbs to an overhead wire – the crop support wire. The height of the crop support wire impacts on the cropping cycle as well as management of the plants.

Crop support wires are suspended from the roof and walls of the greenhouse at 2 to 4 metres above the floor depending on the greenhouse used, the chosen training system and a grower's preference. The type of equipment available should also be considered in determining the wire height.

The string used is a length of polypropylene or sisal. Sisal is preferred because it can later be composted with the plant residues after the crop is finished.

The support string is tied to a crop support wire above each plant. The lower end of the string is attached to the growing medium or container to secure it. Depending on the set-up used, the string can also be attached to a horizontal wire strung just above the top of the containers. It is better not to tie the string to the base of the plant because if it is knocked, it can damage the plant. If sisal is used, it cannot be anchored under the container because it will rot.

Support strings are usually installed at transplanting or shortly afterwards. The string may be loosely twisted onto the main leader of the plant to help start the plant climbing, or simply clipped onto the plant or its supporting stake.

In the past, the process continued as the plant grew by loosely twisting the main stem around the string, with one complete revolution every 15-20cm. However, this risks damaging the growing tip of the plant. Moreover, cucumber stems are brittle so can easily break when handled.

Attaching the plants to the string using metal or plastic clips is faster and ensures the plant is not damaged. Metal clips rust, disintegrating once the crop is removed and composted, so are more biodegradable than plastic clips. Clips can be put on manually or using powered devices.

The lower fruit are removed in all systems to prevent them from touching the ground or the substrate. If a developing cucumber touches the ground or growing substrate, it may curve and is also more prone to yellowing or disease. For food safety issues,



Plants may be twisted onto strings or attached using plastic or metal clips. Using clips is quicker and avoids potentially damaging the growing tip of the plant. Metal clips naturally rust and degrade once the crop has finished.



Above and top right: Stems are brittle and can break if not supported over the wire.



Note: White plastic top hangers in place on crop support wires will guide stem and side shoot growth over the crop support wires. They prevent snapping of brittle growth as fruit and plant weight increases.

preventing fruit from touching the ground is also important.

When a vine is trained over the crop support wire before growing back down, it should be looped around the wire rather than just hung over it. If the stem is only hung over the wire, it is prone to breaking under the fruit load. An alternative is a plastic mould hooked onto the wire. These simple devices provide a curved support for the vine and prevent breakage. Some growers have found difficulties with these as they can get in the way when removing crop debris.

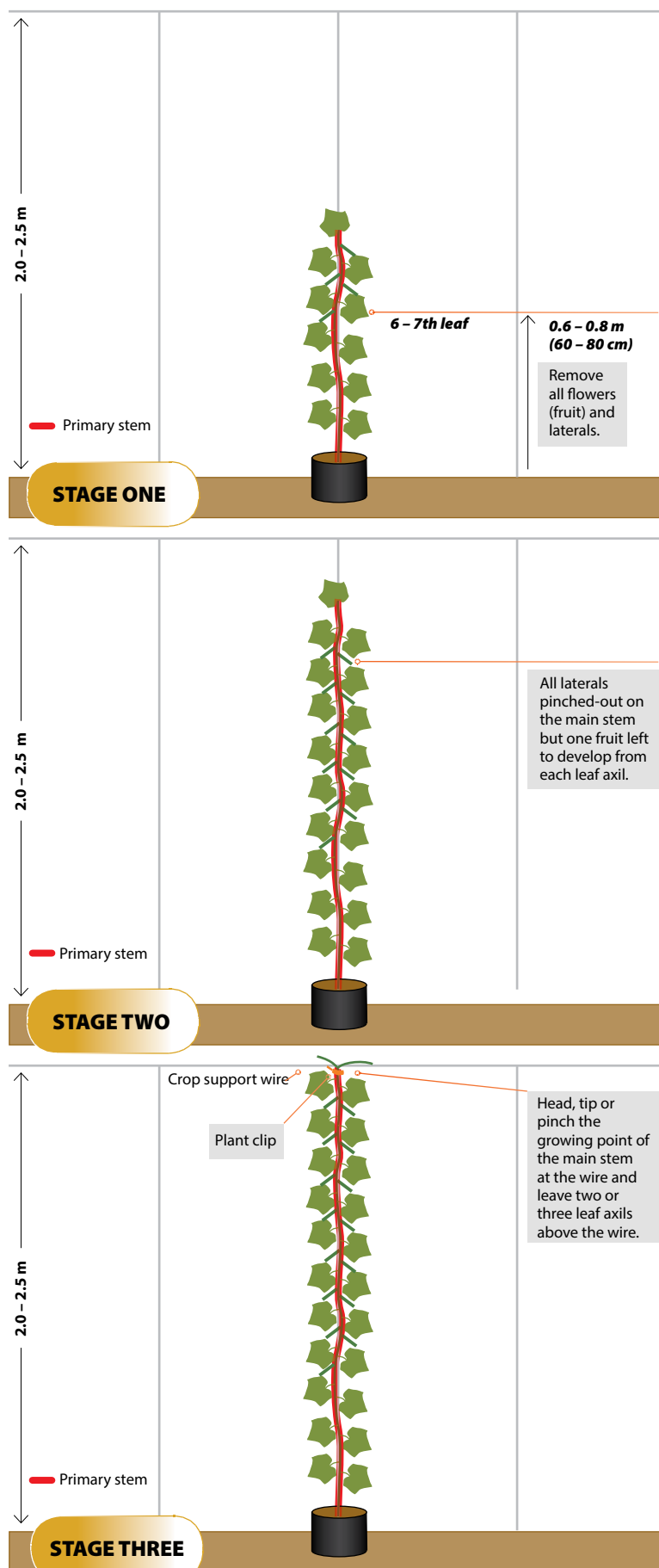
Plant layering

There is increasing interest in the layering of cucumbers and producing a crop over a longer period. This practice is common in greenhouse tomato production where advantages include higher

productivity per square metre per year and lower costs in crop establishment and biological controls. However, the cost of labour and the fast rate at which cucumbers grow make this practice unlikely to be cost effective in cucumbers. Cucumber stems are also easily broken. Two to four short, non-layered crops each year simplifies plant management and pest and disease control and can optimise quality and yield. It is possible that varieties may be developed in the future that make layering a feasible practice in cucumbers.

Pruning systems

The main two pruning systems used for greenhouse cucumber plants are the modified umbrella system (system 1) and its variations and the original umbrella system (system 2) and its variations. The modified umbrella differs from the original umbrella system in that the laterals are removed all the way up the vine.



System 1: Modified umbrella

The modified umbrella pruning system allows fruit to develop on the main stem.

System 1.1 Determinate system (standard modified umbrella system – stem only fruit)

Stage 1

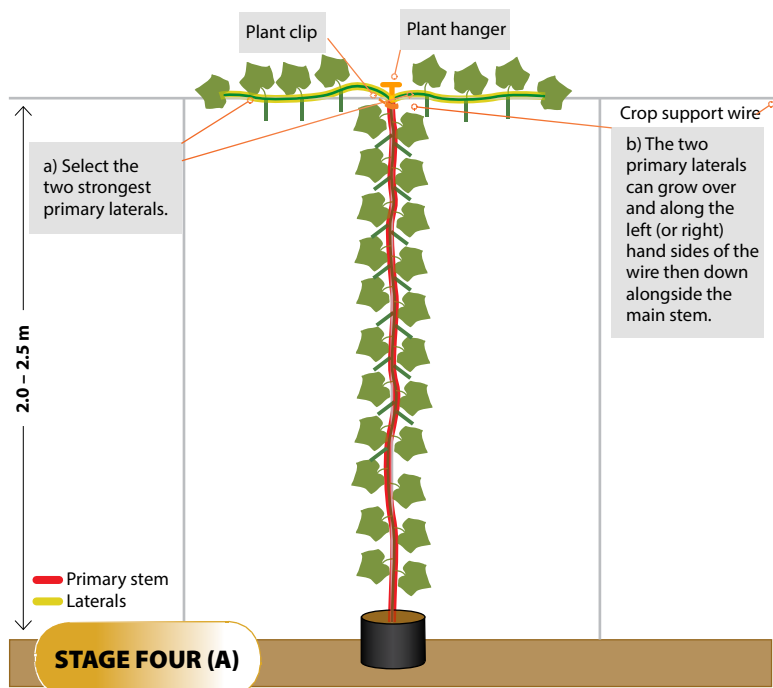
Remove all the flowers (and fruit) and laterals from about the bottom 60 – 80 cm of the stem, to establish a strong healthy vine. The actual height is adjusted on the basis of plant vigour. For a very vigorous vine, prune fruit to about 60 cm but for a less vigorous vine, pruning may continue up to about 80 cm.

Stage 2

Continue removing laterals up to the support wire. Let a fruit develop at each leaf axil. Some growers remove tendrils as well, though this is not cost effective. Just selectively remove tendrils if they start to twist around fruit or leaves.

Stage 3

When the main stem is two leaves above the crop support wire, prune the growing tip. Clip the vine to the support wire to prevent it slipping down when it becomes heavy with fruit.

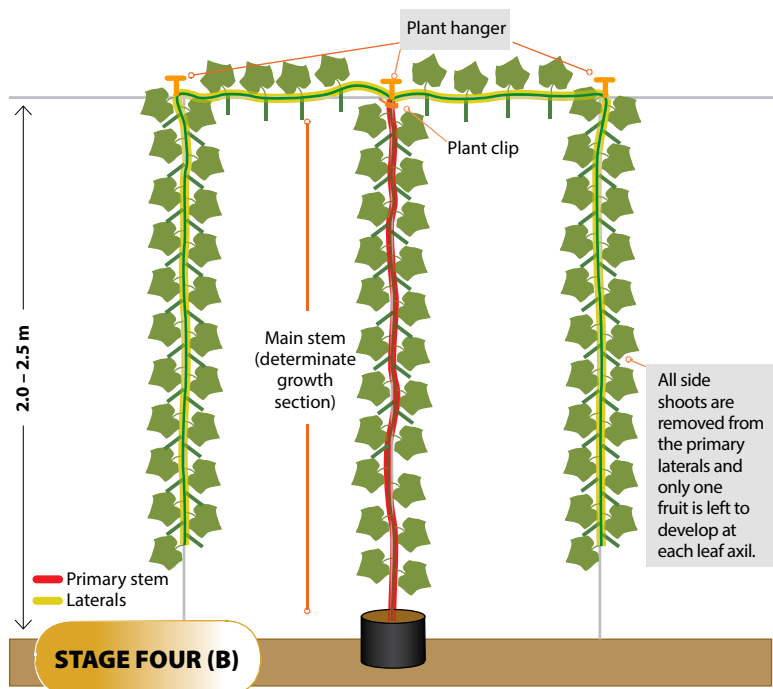


Stage 4

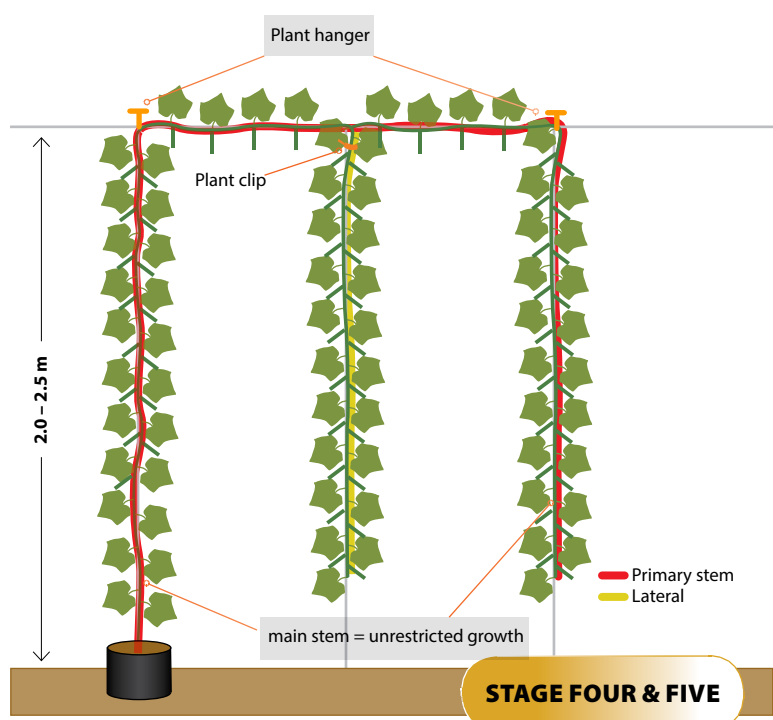
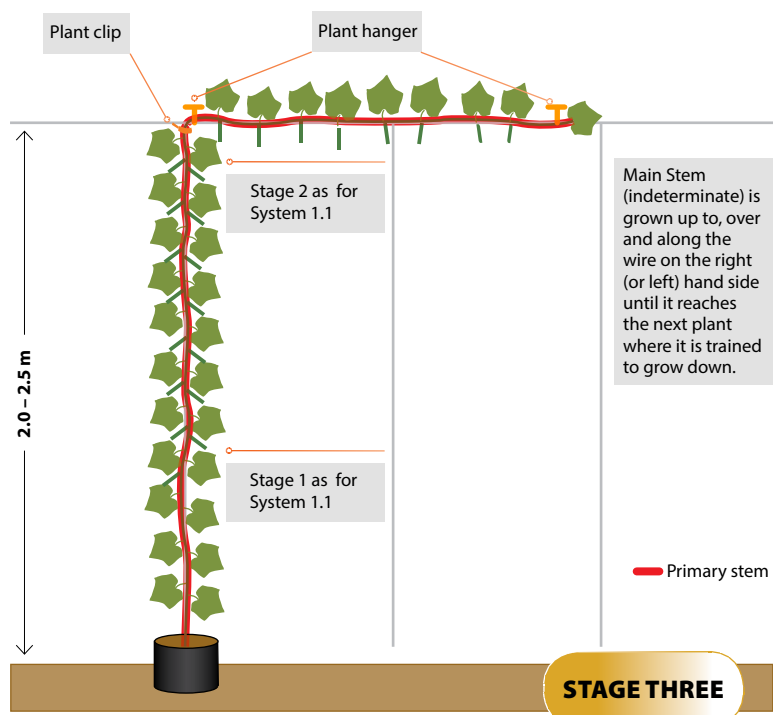
Let two laterals from the top of the plant grow over the wire and hang down beside the main stem – one on each side. These are the primary laterals. Let these primary laterals grow almost to the ground before pruning out the growing tip so that no fruit can touch the ground. Note that determinate growth means that the plant is limited or restricted.

Stage 5

When the two primary laterals are old and production falls off, let two new ('secondary') laterals grow from the top of the plant, over the wire and hang down beside the main stem. Remove the primary laterals once all the fruit has been harvested from them. Repeat the process with the next two laterals.



1.1 Fully developed determinate system: standard modified umbrella pruning method (stem only fruits). Note: Determinate Growth = limited or restricted growth.



1.2 Fully developed indeterminate unidirectional variation:
Alternative modified umbrella pruning method (stem only fruits).
Note: Indeterminate growth = unrestricted growth.

System 1.2 Indeterminate unidirectional variation (Alternative modified umbrella method)

Stages 1 and 2

Stages 1 and 2 are the same as for system 1.1.

Stage 3

When the main stem reaches the crop support wire, train it left or right along the support wire until it reaches the next plant then allow it to grow downwards.

Stage 4

Let a primary lateral from the section of the vine trained along the support wire grow and hang down between the main stems. Let this lateral grow almost to the ground before pruning out the growing tip so that no fruit can touch the ground.

Stage 5

When both the hanging main stem and lateral are old and production falls off, let two new ('secondary') laterals grow from the top of the vine, over the wire and hang down between the main stems. Remove the primary laterals once all the fruit has been harvested from them. Repeat the process with the next two laterals.

Note: An alternative method is to train the main stem down where the primary lateral is in the diagram. Then train a primary lateral from a side shoot (left or right) towards the next plant then downwards – as is depicted by the main stem in the diagram.

System 1.3 Indeterminate bidirectional variation (Alternative modified umbrella method)

Stages 1 and 2

Stages 1 and 2 are the same as for system 1.1.

Stage 3

When the main stem reaches the crop support wire, train it around the support wire to one side (left or right) and then let it hang and grow downwards.

Stage 4

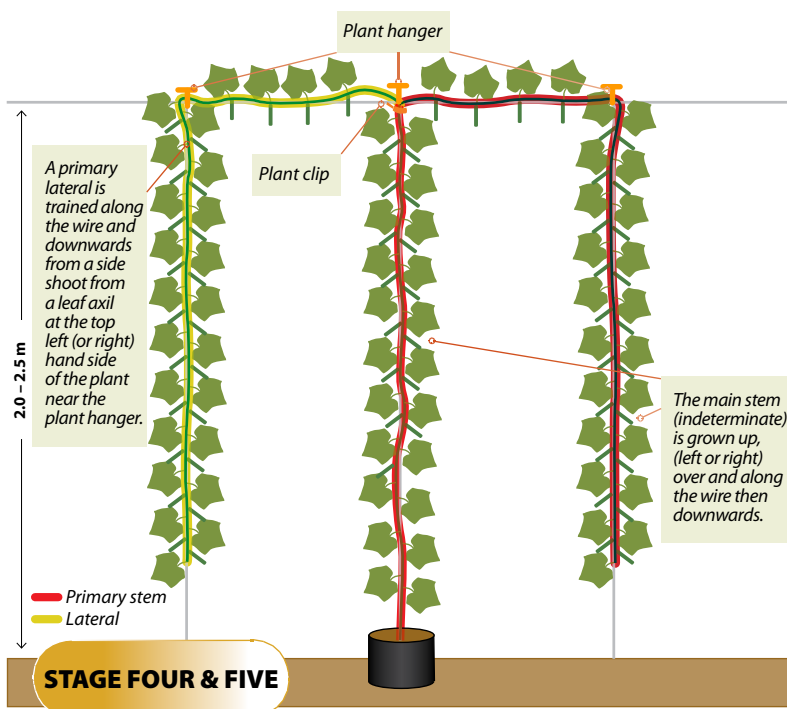
Let a single lateral from the section of the vine at the support wire grow and hang down on the opposite side from the main stem. Let both the hanging stem and lateral grow almost to the ground before pruning out the growing tips so that no fruit can touch the ground.

Stage 5

When the hanging main stem and lateral are old and production falls off, let two new laterals grow from the top of the plant, over the wire and hang down beside the main stem. Remove the original stem and lateral once all the fruit has been harvested. Repeat the process.

System 1.4 Short lateral variation (of 1.1, 1.2 and 1.3)

In each of the modified umbrella variations, each lateral (hanging stem) is left to grow almost to the ground before pruning out the growing tip. These laterals can become twisted and tangled making canopy management of the crop more difficult and time consuming. To avoid this, a short lateral variation can be used. From stage 4, prune out the growing tips of the hanging stems when they are hanging down about 1 – 1.5 m from the support wire. Let the two new ('secondary') laterals grow from the top to repeat the process.



1.3 Fully developed Indeterminate bidirectional variation: Alternative modified umbrella pruning method (stem fruits only). Note: Indeterminate growth = unrestricted growth.

System 2: Original or traditional umbrella

The original umbrella pruning system allows fruit to develop on short laterals.

System 2.1

Determinate system (standard or original umbrella system – stem and lateral borne fruits).

Stage 1

Remove all the flowers (and fruit) and laterals from the bottom part of the stem to establish a strong healthy vine. The actual height is adjusted based on plant vigour. However, because this system produces more vegetative growth than the modified umbrella systems, fruit and laterals are typically only removed for about the first 60 cm.

Stage 2

For the next 60 cm or so, remove all flowers (and fruit) from the main stem, but let a lateral grow from each leaf axil. Prune out the tip of each lateral after the first leaf. Let one fruit develop on each of these laterals.

Stage 3

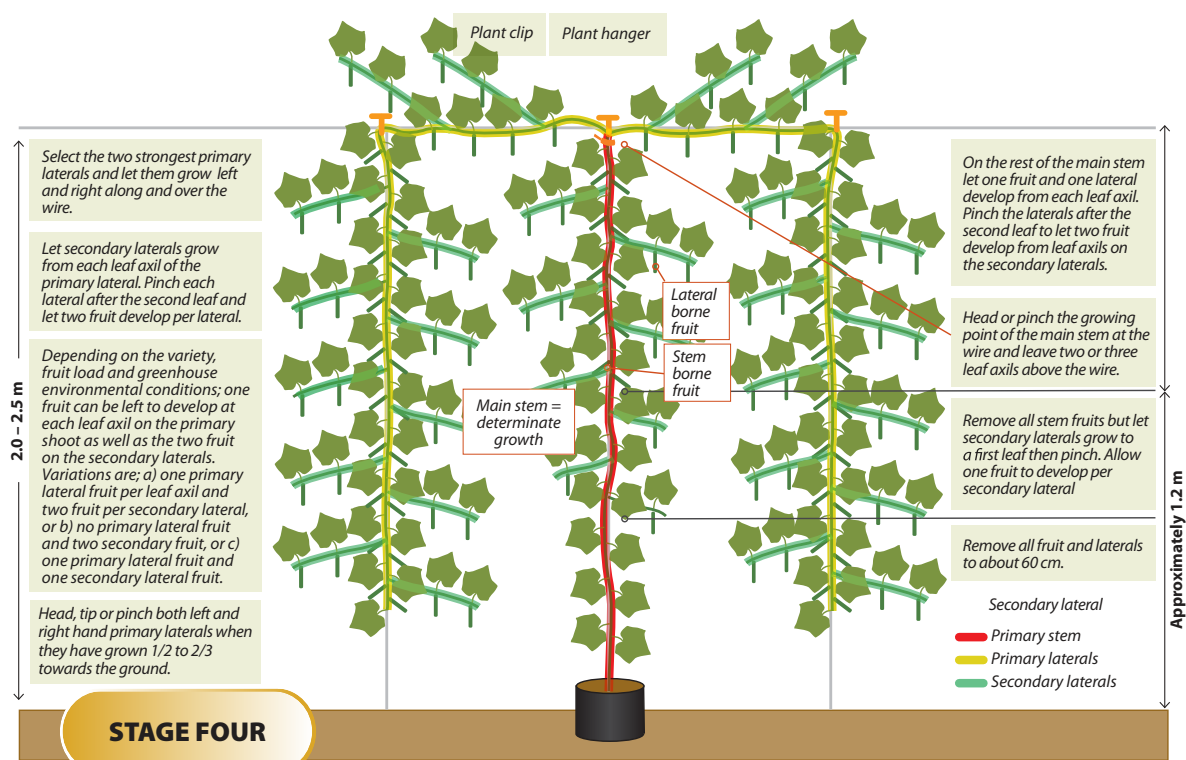
For the rest of the vine up to the support wire, let one fruit and one lateral grow from each leaf axil. Prune out the tip of each lateral after the second leaf. Let two fruit develop on each of these laterals.

Stage 4

When the main stem is two leaves above the crop support wire, prune the growing tip. Note that determinate growth is limited or restricted. Clip the vine to the support wire to prevent it slipping down when it becomes heavy with fruit.

Let two laterals from the top of the plant grow over the wire and hang down beside the main stem – one on each side. These are the primary laterals. Let these primary laterals grow one-half to two-thirds of the way to the ground before pruning out the growing tip.

Let one fruit and one secondary lateral grow from each leaf axil. Prune out the tip of each secondary lateral after the second leaf. Let two fruit develop on each of these laterals.

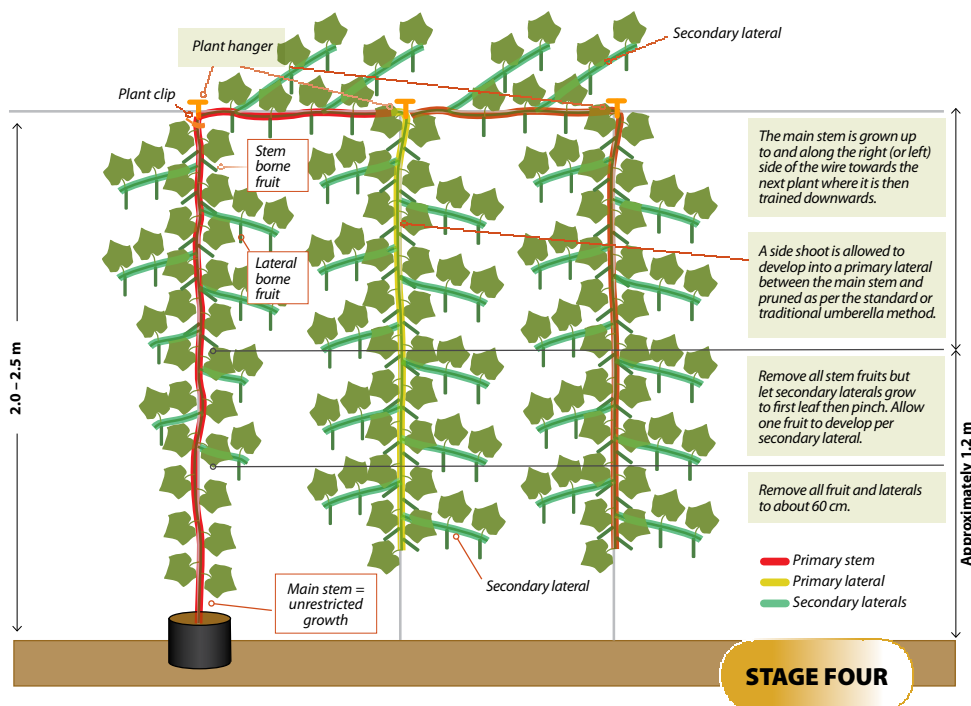


2.1 Fully developed Standard original umbrella pruning method (stem and lateral borne fruit).

Note: Determinate growth = limited or restricted growth.

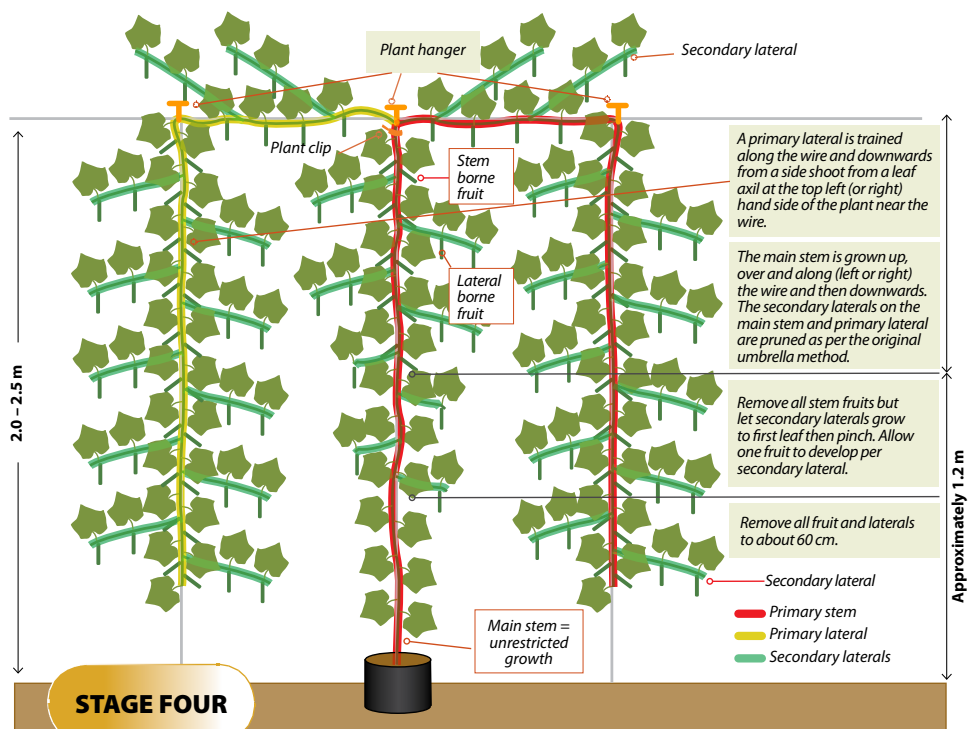
System 2.2
Alternative original umbrella – method 1
and
System 2.3
Alternative original umbrella – method 2

The same type of variations as for the modified umbrella system (systems 1.2 and 1.3) can be made on the original umbrella system. That is, indeterminate unidirectional and an indeterminate bidirectional variations can be used.



Note: An alternative method is to train the main stem down where the primary lateral is in the diagram. Then train a primary lateral from a side shoot (left or right) towards the next plant then downwards (as is depicted by the main stem in the diagram).

2.2 Fully developed Alternate original umbrella pruning method – variation one (Indeterminate unidirectional system).
 Note: Indeterminate growth = unrestricted growth.



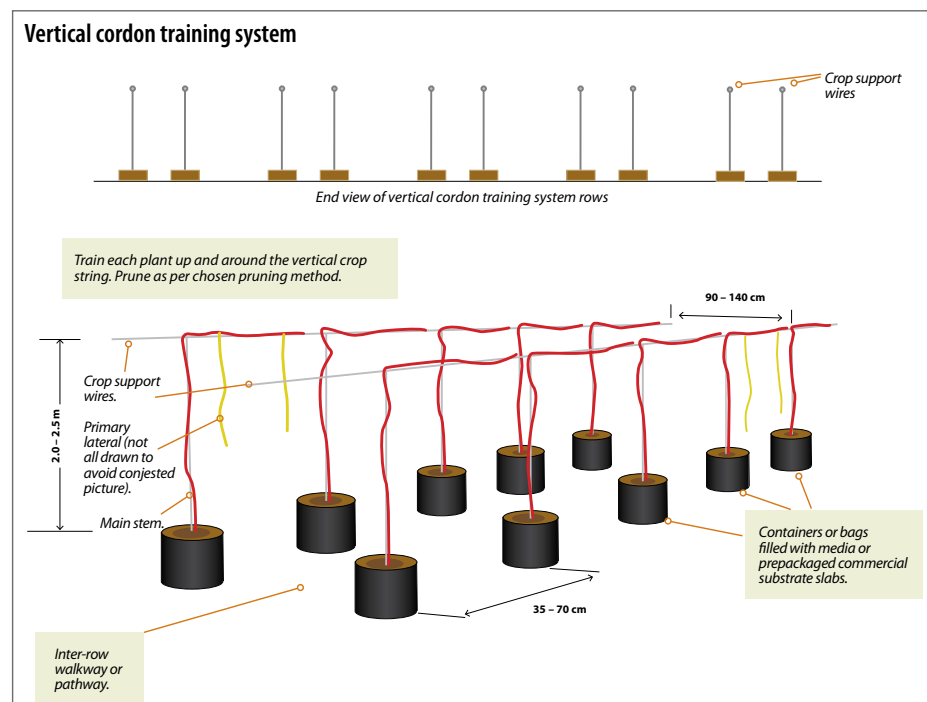
2.3 Fully developed Alternate original umbrella pruning method – variation two (Indeterminate bidirectional system).
 Note: Indeterminate growth = unrestricted growth.

Training systems

There are three main training systems in use in Australia: vertical, inclined and canopy systems.

1. The vertical cordon

A single crop support wire is strung directly above the middle of a single row of plants. The vines are trained vertically up the support string (called the cordon) to the support wire.

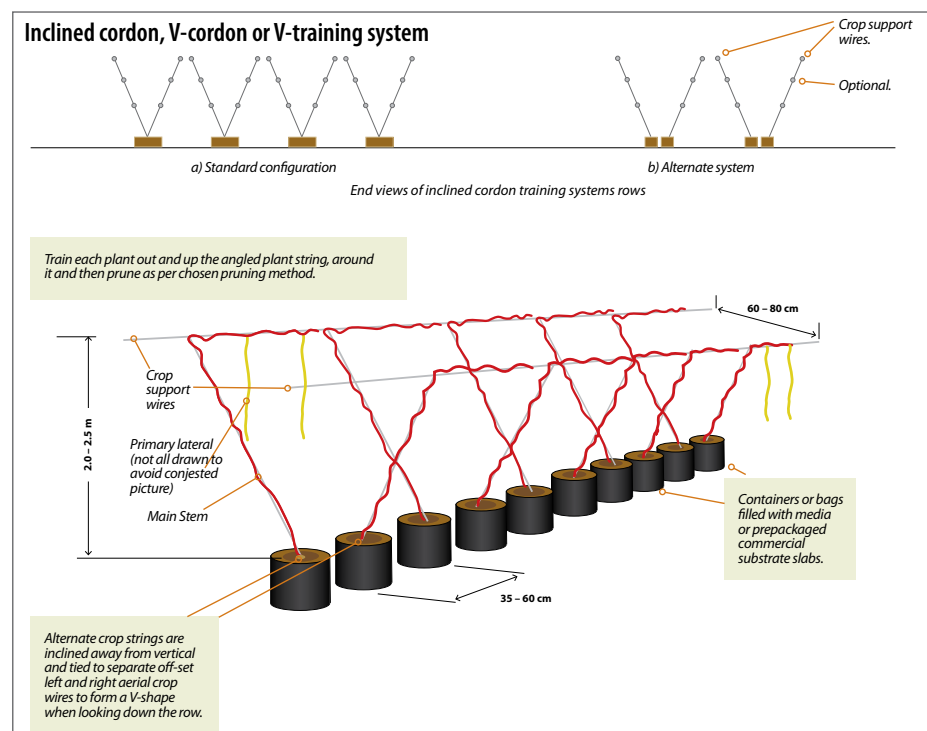


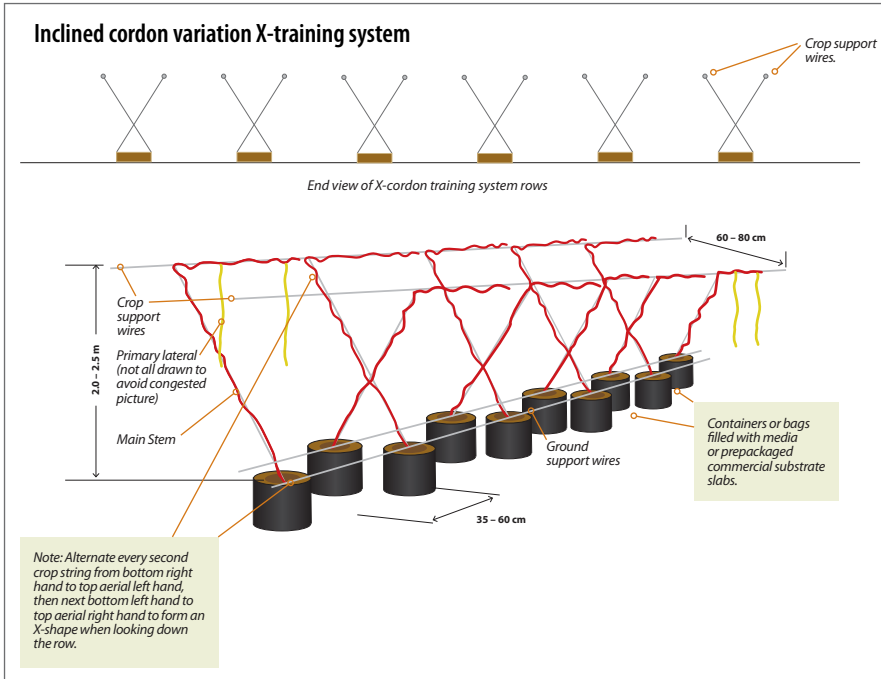
2. The inclined cordon

This system is also called the V-cordon due to the shape of the row when looked at from the end. Two wires (60 to 80 cm apart) are strung above every row of plants – equally offset from the centre of the row. The support strings (cordons) are strung from the middle of the row at the base at an angle alternately to each support wire forming a V-shaped double row. This system improves light interception and the fruit hang away from the stems which reduces the risk of

fruit being marked and damaged. Pruning and picking in the crop is generally easier and more efficient than when plants are trained on a vertical cordon.

If the row set up in the greenhouse has wires or other structures to which the base of the support strings are tied, the support strings can be angled across the row to create a top-heavy X-shape rather than a V-shape.





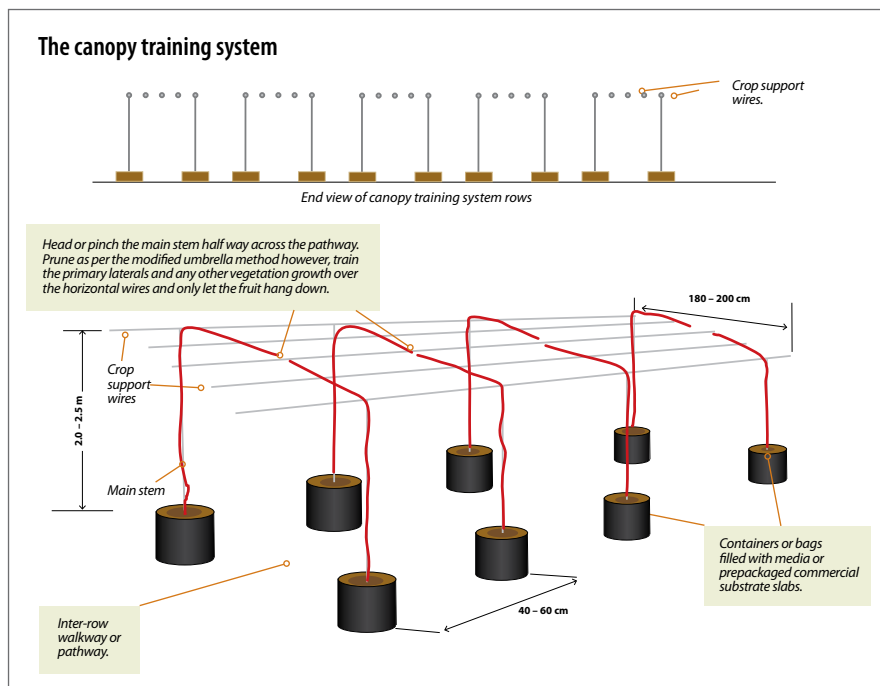
3. The canopy system

The canopy training system is not commonly used except in hotter climates in northern regions of Australia. It provides a better working environment (under the canopy) and the fruit are better protected from direct, intense sunlight.

In the canopy system, a crop support wire is strung above each row. Another 2 – 3 wires are evenly spaced and strung parallel to the rows above the

inter-row. This creates a series of parallel wires evenly spaced across the production area. The inter-row is wider in the canopy system, usually around 2 metres. Double or single rows can be used.

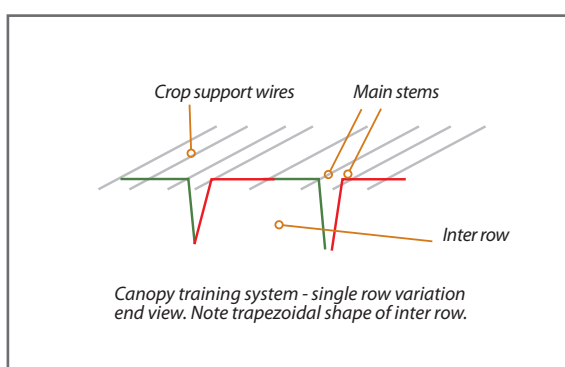
The canopy system is easy to harvest as the fruit hang down away from the stems and leaves. However, there is more labour required to maintain the canopy structure.



Single row variation

In the single row variation of the canopy system, the plants are grown up a string or wire like the inclined or V-cordon system with the plants trained alternately to the left (green in diagram below), and right (red in diagram below), of the row. When they reach the first crop support wire, they are then trained horizontally across the extra wires running above the inter-rows. Vines are tip pruned when they reach the centre of the inter-row and meet up with the vine from the adjacent row.

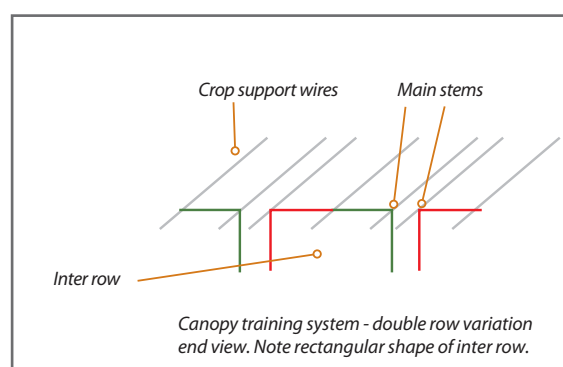
This system forms a series of linked trapezoidal tunnels all running parallel.



Double row variation

The plants are grown up a string or wire like the vertical cordon system. They are then trained horizontally across the extra wires running above the inter-rows. Vines are tip pruned when they reach the centre of the inter-row and meet up with the vine from the adjacent row.

The rows are spaced 1 – 1.5 metres apart. The vines in each row are all trained in the same direction – across the inter-row. This system forms a series of separate parallel rectangular tunnels.



Picking cucumbers

Cucumbers are picked to market specifications. The specifications may vary depending on the requirements of the purchaser. A key part of your marketing needs to be defining, with your customer(s), exactly what they want and what you can produce. You should aim to have as much of your crop within set specifications as possible. This can be used as a benchmark for how well you are going. You may define the specifications for your product with your buyer or agent, develop your own for your brand or even use major retailers' or co-operatives' specifications as a guide.

A crop is generally harvested 3 – 4 times per week in warmer seasons and 2 – 3 times per week during

winter. This is not a hard and fast rule as the market is the main factor. More frequent harvesting may be needed. Some types such as the cocktail cucumber may be harvested daily.

It is important to be aware that picking fruit has an impact on plant balance. Removing fruit encourages a vegetative bias while leaving fruit on the vine encourages the plant to be generative. Keeping fruit on a vine also places stress on the plant.

Consequently, picking is not only based on the market, but also on the production schedule and crop vigour.

When picking cucumbers, use a sharp knife, secateurs, scissors or shears. Tools ensure a clean wound on the plant and a neat stalk on the fruit which contributes to marketability.

PRODUCT : TYPE : VARIETY : GRADE :	CUCUMBER Telegraph Various One
COLOUR	Uniform mid green to dark green, lighter green at blossom end permitted provided < 20% of surface area
VISUAL APPEARANCE	With bright bloom, cuticle
SENSORY	With uniformly firm, crisp texture
SHAPE	With uniform, straight, cylindrical shape
SIZE	45 – 70 mm (blossom end to stem end)
MATURITY	Firm bodied, not softening
INSECTS	With evidence of live insects
DISEASES	With fungal or bacterial rots (e.g. <i>Bacterial spot</i> , <i>Alternaria</i> , <i>Fusarium</i> , <i>Rhizoctonia</i> soft rot)
PHYSICAL / PEST DAMAGE	With cuts, splits, holes, bruising or wounds that break the skin
TEMPERATURE INJURY	With obvious bruising or soft damaged areas
PHYSIOLOGICAL DISORDER	With chomped / stained areas > 2 mm deep (inward damage)
FOREIGN MATTER	With puffed or discoloured skin, water-soaked lesions or flesh (cutting injury)
	With bleached, dry areas (sunburn)
	With yellowed skin (ethylene damage / senescence)
	With growth cracks, splits or hollow centres
	With cracked, softened or abraded skin, or 'pinching' at blossom end (distortion)
	With foreign matter (e.g. glass, metal, hard plastic)
PHYSICAL / PEST DAMAGE	With shallow (< 2 mm) pest damage, e.g. chomped, stained areas affecting > 0.5 sq cm
SKIN MARKS / BLEMISHES	With dark coloured rub or weather marks affecting > 0.5 sq cm
TOLERANCE PER CONSIGNMENT	Total minor defects (within allowance limit) to be < 2 defects per item. Total minor defects (outside allowance limit) must not exceed 10% of consignment. Total major defects must not exceed 2% of consignment. Combined Total not to exceed 10%.
PACKAGING & LABELLING	Packaging as per Progressive requirements. Bulk Loose Product to identify. Packed On date (e.g. Packed DATE/YY) on outer grade/size, size and minimum net weight. On your retail fresh fruit and vegetables a "Packed On" date is required, unless it is in a package that obscures the nature or quality of the food. If the nature or quality of the food is obscured then a "Best Before" date is still required. If a Packed On Date is to be used the POQ should not exceed 5 days at the time of receiving product into the DC.
TRANSPORT & RECEIVAL CONDITIONS	Stacked to T1 re specifications into a stabilised pallet that has been strapped or strapped as per policy. Refrigerated van or truck with air bag suspension, unless otherwise approved. Pulp Temperature 7 – 12°C during transport from the farm to the orchard and at receipt into Distribution Produce DC.
CHEMICAL & CONTAMINANT RESIDUES	Imported and domestically produced food sold in New Zealand must comply with the New Zealand (NZ) Food Standard Code standard for imported foods in general. Complies with FSANZ Standard 1.4.1 and Schedule 19 – Maximum levels of contaminants and natural toxicants.
Specifications reviewable: e.g. to account for specific regional effects or adverse seasonal impacts on quality or early or late seasonal variances as agreed with the Category Manager for each region and communicated formally in writing by Progressive.	

Product specifications may vary depending upon your chosen market.



OPTIMISING PRODUCTION

To be profitable and sustainable, the cucumber crop needs to be monitored, and its growth directed and controlled. Your challenge as a grower is to keep the plants balanced maintaining an optimal mix of vegetative growth and fruit development. A plant that is out of balance has fluctuating yields and fruit quality may decline.

Successfully managing a crop requires monitoring and recording the plants' growth and health, the level of pests and diseases, as well as the results of any corrective actions taken and then using this information make decisions about how the crop is managed in the future. It is not possible to make effective and profitable decisions about the crop if you do not undertake continual and robust assessments.

Due to the nature of the greenhouse cucumber business, crops are always pushed to the limit however, overstepping the limit will cause a rapid, negative response from the plant. Even small deviations from a proven blueprint can cause significant damage or loss. Growers must become skilled at advancing or reducing cropping to get the best yields. Manipulating temperature, light, irrigation, nutrients (particularly nitrogen and phosphorous), pruning, electrical conductivity (EC) and day length are ways of achieving the best yields.

THIS SECTION INCLUDES

- Crop observation and monitoring
- Vegetative growth
- Generative growth
- Managing the cucumber plant
- Temperature, humidity and Vapour Pressure Deficit
- Directing the plant
- Quick guide to growing conditions

Crop observation and monitoring

Crop observation is one of the most important practices in sustainable and profitable greenhouse cucumber production. It is essential for making decisions about cultural management, nutrient management, pest and disease management and even marketing and labour.

There are basically two components. Firstly, crop observation undertaken daily to check on the general health of the plants and gauge the vegetative versus generative balance of the crop. Secondly, regular crop monitoring as the basis of integrated pest and disease management, essential for early detection and effective management of pests and pathogens.

Crop observation

A cucumber crop, if it is to produce at its optimum, cannot be left unchecked. The balance of the plant needs assessing every day and adjustment if necessary. It is important not to let the cucumber plant get out of balance. Being either too vegetative or too generative reduces yield.

Managing plant balance is one of the most important aspects of controlled environment horticulture and has a significant impact on profitability. A range of growing conditions influence whether a plant has a generative or vegetative bias. To optimise production, you need to determine the bias of the

plant (and the crop). This is often called 'reading the plant'. You then need to use different 'tools' or strategies to steer the plant.

Observation is necessary on two levels. Firstly, assessing the crop as a whole. Macro management of the crop is based on this assessment and involves the adjustment of the temperature, humidity (and vapour pressure deficit), irrigation, nutrient balance and concentration, light intensity, spray application and carbon dioxide concentration. All these management tools are used on the whole crop.

Secondly, observation is on an individual plant basis, or sometimes groups of plants in certain sections of the greenhouse. This assessment is used for micro management decisions such as pruning, training and even removal of whole plants (rogueing).

Crop observation should be done every day to assess whether the crop is generative or vegetative and whether specific plants are generative or vegetative.

Monitoring

Monitoring means looking for pests and diseases on a regular basis. It involves trained people regularly inspecting the crop, using a magnifying glass and sticky traps to collect samples and recording this information so that it is easy to see trends in pest and disease occurrences and objectively assess how well any treatments worked.

Monitoring is important because it helps you to find pest and disease problems early. These are then controlled more easily before they become 'full blown'. e.g. taking out a single diseased plant, pruning affected areas and spot spraying can all be used to control a problem when it is small and in its infancy. This saves money and time. There are two main types of monitoring: random (pattern and zone) and selected.

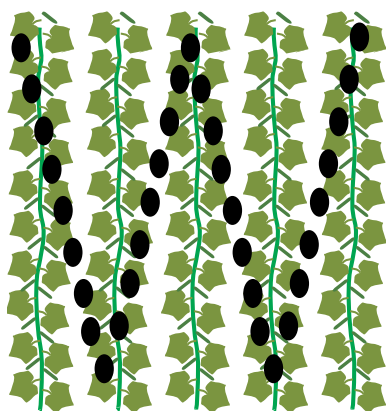
Pattern monitoring

Pattern monitoring is essential when you are trying to catch a problem early. A pre-planned pattern is used to decide which plants to check. You do not need to look at every plant. Walk through your crop and select plants in a 'W', 'X', 'Z' or '8' pattern over the whole greenhouse. Stop and check these plants for pests and diseases. You should check at least 12 plants in a greenhouse every day.

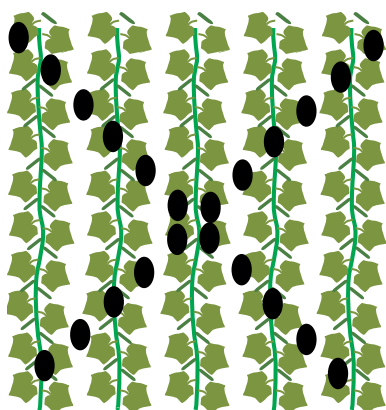
CROP RECORD SHEET		WEATHER	
CROP	cucumber	Day Avg	25
PLANTING DATE	2 / 10 / 05	Night Avg	16
WEEK #	3	24 hr Avg	21
DAY #	23	Wind speed	0.2
DATE	25 / 10 / 05	Relative humidity	85%
GREENHOUSE CONDITIONS			
Day Avg	24	Day max	27
Night Avg	17	Night min	16
24 hr Avg	22	CO2 Avg	
24 hr Avg	21	24 hr CO2 max	21
HYDROPONIC SYSTEM			
Feed EC	3.8	Drain EC	3
Feed pH	5.8	Drain pH	5.8
Feed volume	200L	Drain volume	150
24 hr Drain %	75.5		
PLANT GROWTH			
Stem thickness	11	Stem node length	15
Leaf length	14	Leaf width	18
Fruit length		Fruit width	
Fruit weight		Fruit size	
Plant growth bias		COMMENTS	
Vegetative	<input checked="" type="checkbox"/>	new galling on fruit seen	
Generative	<input type="checkbox"/>	then solved by	

Crop observation needs to be done daily. Keep a record.

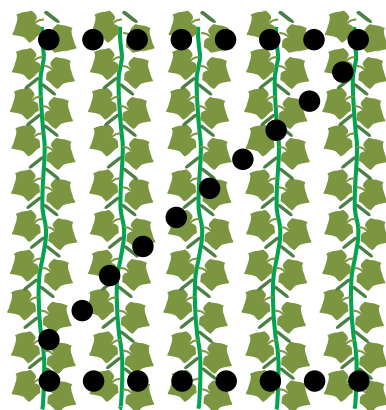
Pattern monitoring



Aerial view



Aerial view



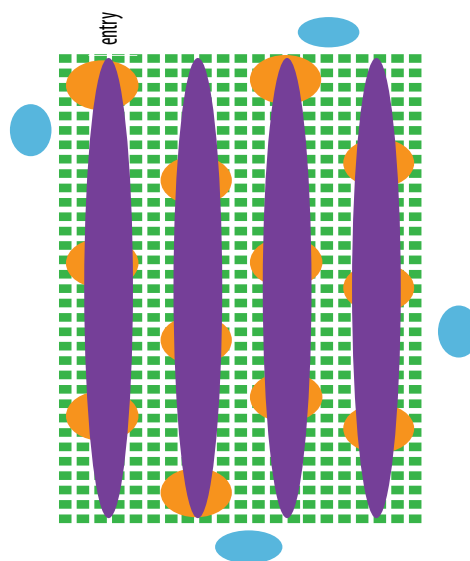
Aerial view

Walk through the crop and select random plants in a 'W', 'X', 'Z' or '8' pattern. Select at least 12 plants in each greenhouse every time you monitor.

Zone monitoring

Zone monitoring is an alternative to following a pattern method. Key zones are determined in the greenhouse and when monitoring is undertaken, a plant is randomly selected from each zone and thoroughly checked for pests and some rows are assessed for disease levels.

Zone monitoring



Zone monitoring is an alternative, simplified monitoring method. Key zones are determined in the greenhouse. These are shown in the diagram above. Inside the greenhouse, there are four long zones (purple) and 12 orange zones. Outside the greenhouse there are four blue zones.

Purple zones

When checking a purple zone, walk down one of the rows in the zone. Look at the plants and make a record of the number and type of diseases found. Walk back along a row in the next purple zone and so on.

Each time you monitor, select a different row in each zone to the one which you checked last time.

Orange zones

When walking down a row, each time you come to an orange zone, stop and select 1 plant. Look closely at the plant and make a record of the number and type of pests found. There are 12 orange zones.

Sticky traps should also be used. Use at least three traps per greenhouse. Place one in the orange zone near the entry and the other traps in other orange zones in the greenhouse.

Blue zones

After checking the greenhouse, walk around the greenhouse and look for weeds and other places where pests and diseases can live. This gives you some early warning information about which pests are near and could get into the greenhouse. Weeds need to be removed from around the greenhouse.

Selected monitoring

Selected monitoring is used when you suspect a problem. Stand back and look for signs of ill-health in the crop. This might look like an area of smallish plants, yellow plants or plants with holes in leaves or any other symptom. Look closely at these plants for signs of the pest or disease. You can also pick key parts of the crop to monitor such as the base of the stem and under the leaves. These might be places that have had problems before or are in high risk areas.

When monitoring be aware that different pests and diseases are found on different parts of the plant. Look under the leaf and on top of the leaf, on the stems, in the flowers and around the plants on the surface of the substrate and in it.

Many of the pests in your crop will be very small, move very fast or hide in the leaves, substrate or roots. You will need some simple tools to help you find them.

Put a kit together of the following:

- Yellow sticky traps
- Hand lens or magnifying glass, 10X and 20X
- Head band magnifier
- Colour pest, disease and nutrient disorder field identification guides for cucumbers
- Recording sheets and a clipboard
- Apron with pockets
- Coloured ribbon or tape to mark infestations
- Permanent pen for writing on sticky traps
- Pencil for writing on sheets
- Plastic jars or bags for collecting samples
- White plastic ice-cream container
- Camera (useful but not essential)

Sticky traps

Sticky traps are a useful tool to use as part of a monitoring program. A sticky trap is a card covered in glue. The glue does not dry out or run. Sticky traps are either yellow or blue. The colour attracts flying insects such as aphids, whiteflies and thrips which get stuck in the glue. Yellow traps attract most of the flying pest insects so yellow traps are normally used on farms.

Sticky traps can give you an early warning of pests. They can show you where there are problem areas in the greenhouse or farm. You can also use sticky traps to check that your control program is working. Sticky traps are not designed to control pests – only to

make it easier for you to find them and indicate their numbers and life stages.

Remember, insects which are not pests are also attracted to the traps so you the ability able to identify both pest and beneficial insects as well as their different life stages.

When using sticky traps:

1. Attach the traps to strings, wires or stakes.
2. Place the traps just above crop height.
3. Write the date and trap number on the back of the trap.
4. Use 1 trap per 200 m² or if this is too many to manage, use less.
5. Check and count insects on traps every time you monitor. Replace traps every week in summer, every two weeks in winter.

For more information on monitoring, refer to Goodwin, S. (2002) *Integrated Pest Management in Greenhouse Vegetables* and Badgery-Parker, J. (2009), *Keep it Clean – Reducing costs and losses in the management of pests and diseases in the greenhouse*, NSW Department of Primary Industries, 2009.

Vegetative growth

Vegetative growth in a cucumber crop refers to the growth and development of leaves and stems. The production of flowers is also a vegetative process.

There are several features that indicate a plant is vegetative:

- Rapid growth
- Large leaves
- Soft lush growth
- Thick brittle stems
- Thick growing heads
- Large, deep yellow flowers
- Long, vigorous tendrils
- Long internodes
- Short fruit
- Leaves growing out of the fruit

What makes a plant vegetative?

There are several conditions which steer a plant to be more vegetative. These conditions are also the 'tools' a greenhouse manager has available to manipulate and control plant balance:

- A lower 24-hour average temperature
- Cool night temperatures
- Higher relative humidity
- A small gap between day and night temperatures (An increasing gap between day and night induces flowering)
- A slow change from day to night temperatures
- Reduce ventilation to reduce plant stimulation/activity
- Reduce air circulation around crop
- Removal of fruit
- Less leaf pruning
- Increased volume of run-off
- Excess nitrogen
- No water stress – frequent but small irrigations
- Start irrigation early in the day
- Finish irrigation later in the day
- Low to moderate electrical conductivity (EC) in the root zone
- Reduce carbon dioxide
- Higher root pressure

- A higher 24 hour average temperature
- Higher night temperatures
- A larger difference between day and night temperatures
- A fast change from day to night temperatures
- Lower relative humidity
- More ventilation to stimulate plants
- Increase air circulation around crop
- Leaving fruit on plant
- Reduce volume of run-off
- Increase water stress
- Larger, less frequent irrigations
- Start irrigation later in the day
- Finish irrigation earlier in the day
- High electrical conductivity (EC) in the root zone to increase water stress
- Very low EC in root zone creating nutrient stress
- Increase carbon dioxide
- Reduce root pressure
- Wet the leaves (includes application of pesticides and foliar fertilisers)

Generative growth

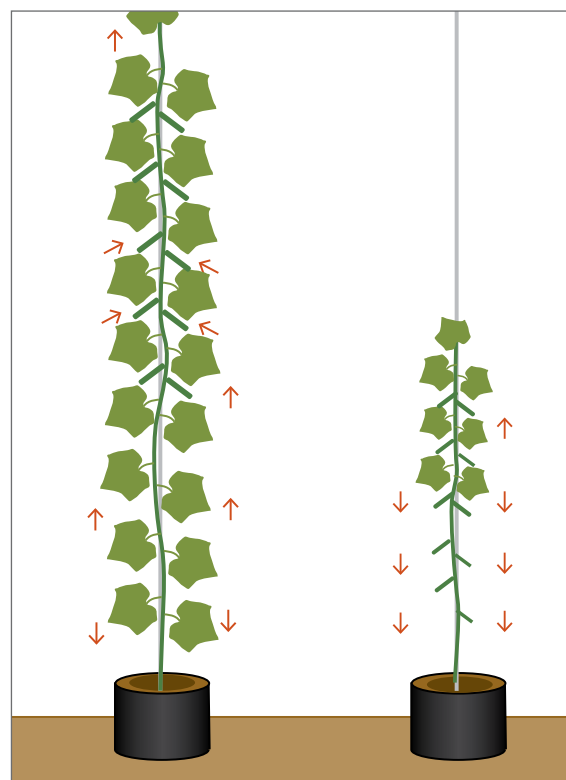
Generative or reproductive growth in a cucumber crop refers to the growth and development of fruit (the actual production of flowers is a vegetative process).

There are some features that indicate a plant is generative:

- Thin growing point
- Small leaves
- Poor flower development
- Poor tendril growth
- Short internodes
- Small flowers and small underdeveloped fruit
- Very dark green colour
- Weak laterals

What makes a plant generative?

In general terms, any stress on a plant will direct it towards being generative. As with vegetative growth, there are several conditions which steer a plant to be more generative. These conditions are the 'tools' a greenhouse manager has available to manipulate and control plant balance.



In a balanced crop (left), plant food made in the leaves goes mostly to developing fruit and ensures root replacement, good stem growth and good development of the growing tip.

Right: Carrying too many fruits and not enough leaves robs the roots, stem and growing point of plant food which greatly inhibits productive growth and leads to root death. Plant parts that are deprived of food like this are more prone to diseases.

Managing the cucumber plant

The wide range of factors which direct a plant to being either generative or vegetative provide the greenhouse manager with a selection of 'tools' to direct the crop.

The aim in balancing a plant is to make sure that neither vegetative nor generative growth dominates. Management of the growing environment and the



A plant needs to be kept in balance (1). If it becomes too vegetative (2) or too generative (3), total yield will be reduced.

growth habit of each plant is the basis for all crop production recommendations. Optimal management is a balancing act.

At different stages of the crop, the management objective will change. From sowing to transplanting, the focus is on uniformity and vigour of seedlings. After transplanting the seedlings into the greenhouse, the aim is to have a healthy, vegetative plant. The focus is on building a strong healthy root system to support the plant when it is producing fruit later.

At about 4 – 5 weeks, as the cucumber plant begins to flower, the focus changes. Now the aim is to support the generative bias of the plant. As harvest starts, a balance between a generative and vegetative bias is maintained so that the plant produces plenty of fruit but not so much that it runs out of energy or gets stressed. From this stage on, if the plant becomes too vegetative or too generative, total yield is reduced.

The way in which a cucumber plant looks can indicate its growth bias. As a grower, you need the ability to 'read' the plant. Variations between cucumber varieties will occur, affecting their features.

Effective plant management resulting in optimal production requires control of the 24-hour average growing temperature, the volume and frequency of irrigation and vapour pressure deficit. Leaf and fruit numbers – managed by plant balance and pruning – are also important.

Temperature

The cucumber plant grows satisfactorily over a wide ambient (air) temperature range, from 20 – 30°C. The optimum ambient temperature is about 22°C. Some varieties of Lebanese cucumber tolerate cooler temperatures – down to about 16°C reasonably well. Continental cucumbers are less tolerant of cold conditions. Below about 16 – 17°C, the cucumber plant shuts down. This reduces yield and makes the plant more susceptible to pests and diseases.

Above 30°C, plants commonly suffer water stress. High root zone temperatures damage roots leading to a lower production capacity and greater risk of root disease.

In general, a minimum night temperature of 18°C should be maintained. The maximum day temperature should be about 24°C. A general day/night temperature program of 22/19°C might be

used. However, this is also dependent on the amount of light and the vapour pressure deficit.

The 24-hour average temperature is an important piece of information and is used to manage the cucumber crop. It can be used to reduce energy costs and even to work out the speed at which pests and diseases will mature and start to breed or develop in your greenhouse. The optimum average 24-hour temperature for cucumbers is 20 – 21°C.

Target a minimum night temperature of 18°C and a maximum day temperature of about 24°C.

A 24-hour average of 20.5°C is often used as a benchmark for lower light conditions, such as late autumn and into winter. Under bright light conditions, a 24-hour average of up to 24°C may be targeted. When day temperatures are very high and light is moderate to low, the 24-hour average temperature can be adjusted by using a lower pre-night temperature. Ultimately, the target temperature is varied according to plant balance and light conditions to direct the plant appropriately.

What is the 24-hour average temperature?

The 24-hour average temperature is a measure that considers both the period of time and the temperature over a whole day and its principle is to govern the manufacture and use of sugars in the plant. To calculate the 24-hour average, the total hours at each temperature are multiplied to produce a unit called 'hour degrees'. The hour degrees are then summed and divided by 24, to get a 24-hour average temperature.

Table 4. Example calculations 24-hour temperature			
Day period	Hours	Temperature °C	Hour degrees
5am – 9am	4	22	88
9am – 5pm	8	25	200
5pm – 11pm	6	16	96
11pm – 5am	6	18	108
TOTAL			491.5
24 hr Average		20.5°C	

A simplified 24-hour average that some growers use is calculated as the average of the maximum temperature (day) and the minimum temperature (night) over a 24-hour period. For example:

Maximum temperature (day) = 25°C

Minimum temperature (night) = 16°C

Average 24 hr temperature = $(25 + 16) \div 2$
= 20.5°C

Under high light conditions, higher temperatures are tolerated. Similarly, when light levels are low, cucumbers can tolerate slightly lower temperatures. It is important to note that cucumber production is directly related to average temperature and so over a 24-hour period, temperatures can be allowed to deviate as much as 4 – 5°C above or below the target temperature, provided the desired average is attained.

Temperature and Light

While maintaining specific temperatures is necessary to optimise production in cucumbers, there is a relationship between temperature and light. The optimal growing temperature increases as the Daily Light Integral (DLI) increases. The DLI is the total amount of photosynthetically active radiation (PAR) received in a 24 hour period.

Under high light conditions, cucumbers perform well under higher temperatures, while under cold growing conditions, excessive light levels can cause damage to the plant. Temperature settings can be adapted to light levels to optimise productivity of the crop. Approximately 450 $\mu\text{mol}/\text{m}^2/\text{s}$ (100 PAR Watts/ m^2) is thought to be close to the optimum at 25°C.

Maintaining night temperatures above set minimums is also important. A single cold night can impact on the plant process of photosynthesis (converting sunlight to useable plant energy) in the plant. For several days following a cold stress, photosynthesis is suboptimal, reducing plant growth and productivity.

Humidity

Careful management of humidity in the greenhouse is an important part of maintaining both crop production and health. Humidity can influence everything from plant growth rates to disease problems. Cucumbers perform well under relatively high humidity. The target should be 75 – 85%.

Target a relative humidity of 75 – 85%.

All greenhouses should have a hygrometer (measures humidity) located in the crop canopy to measure and monitor relative humidity. Humidity is a measure of the level of moisture in the air. Relative humidity (RH%) refers to the amount of water vapour held in the air, compared to how much can be held in the air at a particular temperature. This is a ratio and is usually stated as a percentage.

The actual amount of water that can be held in a particular volume of air is dependent on temperature. One cubic metre of air, at 25°C, can hold approximately 23 grams of water. As temperature increases, for example to 35°C, the amount of water that can be held increases to almost 40 grams. At 100% RH, the air is saturated and no more water can be evaporated.

There are a few potential crop problems which are associated with relative humidity.

Guttation

At 100% relative humidity, when the air is saturated and ventilation is reduced, plants stop transpiring, however water can still be pumped through the plant due to root pressure. If the water cannot be evaporated from the leaf, it forms droplets on the edges and tips of the leaf and even on pruning wounds. This is called 'guttation' and it often occurs at night.

It is important to prevent guttation in your crop. Wet leaves provide an ideal environment for fungal and bacterial diseases to take hold. Spores and bacteria can even be sucked into the leaf with the droplet exudate when transpiration starts up again during the next day. The build-up of salts on the leaf surface when water droplets are evaporated is associated

with guttation. If guttation occurs regularly, the salts build to toxic levels and kill the plant cells causing scorched areas prone to disease infection.

Condensation

If humidity is very high, condensation is likely to occur. Condensation can result in leaf surfaces becoming wet, predisposing the crop to disease. Condensation on structures can:

- lead to droplets of water falling onto plants, causing damage to fruit and leading to disease
- reduce the amount of light entering the greenhouse
- increase heat loss from the greenhouse.

Air circulation in the greenhouse reduces incidences of condensation by ensuring water vapour is evenly distributed through the air – but it does not reduce overall humidity.

Since air can only hold a specific maximum volume of water at a given temperature, if the temperature is reduced and the volume of water stays the same, the relative humidity rises. If it rises above the maximum (saturation point), water condenses out of the air (the dew point). At very high levels of humidity, a small drop in temperature can result in saturation point. At lower humidity, a larger temperature change is needed to cause condensation.

For example, if the air temperature in your greenhouse is 25°C and the relative humidity is 90%, a drop of less than 2°C would cause condensation to form. Such a small drop in temperature could occur when a cloud passes in front of the sun. If the relative humidity was 75%, a drop of around 5°C would be needed before condensation occurred.

Nutrient uptake

The growth of a plant is driven by the level of transpiration. Transpiration is the process of water evaporating from the plant. As relative humidity rises, the amount of water a plant can pump through itself falls and with it, the rate of growth and supply of nutrients. For example, the movement of calcium can be restricted. For calcium to reach the plant's growing points such as leaf margins and developing fruit, a constant flow of water is required. As transpiration is reduced, deficiencies can result causing blossom-end rot, aborted fruit, cupped young leaves with scorched edges or other disorders.

Pests and diseases

Relative humidity also impacts upon the incidences of pests and diseases. If leaf surfaces become wet, from guttation, condensation or misting, the risk of infection increases.

Many disease pathogens only need a couple of hours to germinate and infect plants. Extremely high humidity (> 90%) favours many fungal (such as downy mildew) and bacterial pathogens while low humidity encourages powdery mildew and some pests like spider mites.

Water supply

Low humidity makes the supply of water critical. At lower relative humidity, plants become fairly free with water and transpire readily. Under these conditions, it is important to keep up supply. This introduces a new challenge in that large volumes of water need to be supplied without restricting the supply of oxygen, that is, without 'drowning' the roots. Very low humidity can result in plant stress and can also result in nutrient deficiencies.

Managing relative humidity

Reducing relative humidity

1. Temperature can be used to manage relative humidity in a greenhouse. By raising the air temperature, the relative humidity is reduced and vice versa. For example, if the air temperature is 20°C and the relative humidity is 90%, increasing the temperature to 25°C will reduce relative humidity to less than 70%.
2. Venting hot moist air is another method of reducing humidity in the greenhouse. This is particularly important during the night or early morning when the greenhouse is closed up and humidity levels rise. As relative humidity increases, the excess moisture can be released by releasing the moist air. This moisture venting is assisted by heating the greenhouse at the same time.
3. Humidity is generated when water evaporates becoming water vapour. Ensuring excess irrigation water is removed from the greenhouse and wet surfaces (such as substrate) are not exposed, limits the amount of water available to evaporate in the greenhouse.

4. For the most part, humidity in the greenhouse is a result of the normal growth processes of the crop. Through transpiration, water vapour is released into the greenhouse atmosphere. When a greenhouse is closed, the crop transpires and the volume of water in the air increases. If the air temperature remains constant, the relative humidity will increase. The number and age of plants influences the level of transpiration. Reducing the density of plants and/or foliage can slow the rate that moisture in the greenhouse builds up as well as improving air circulation.

Increasing relative humidity

1. Reducing air temperature increases relative humidity. This is achieved through shading and venting. Venting to reduce temperature releases the hot air carrying the most moisture so even though the temperature drops, because moisture is removed, the relative humidity may decrease. Closing the greenhouse up to contain the water vapour leads to a rise in humidity, but if there is an accompanying rise in temperature, relative humidity may not actually increase.
2. When air is very dry (low humidity), providing moisture for evaporation increases humidity. This is often used as a way of cooling greenhouses in hot dry conditions. Misting or fogging releases fine moisture droplets into the air which evaporate increasing humidity and lowering temperature.
3. The more vegetation in the greenhouse, the more moisture is transpired. Mature crops release more water into the atmosphere than young plants. Very dense planting increases humidity because there is more leaf area in the greenhouse. Reduced air circulation results in very humid air around the crop (even if the overall relative humidity in the greenhouse is lower!).

Vapour Pressure Deficit

The vapour pressure deficit (VPD) is a measure of the amount of water lost from the plant. Water vapour (moisture in the air) always moves in the direction from high to low levels. Inside the leaf and close to the leaf surface, the air is almost fully saturated with water, that is the relative humidity is 100%. Away from the leaf, the air surrounding the plant generally has less water vapour and therefore a lower relative humidity. This difference or deficit is what drives water movement through the plant. The movement of water from the leaf to the air is called transpiration. Transpiration is a key process by which plants cool themselves and move nutrients.

Vapour pressure deficit is measured in grams per cubic metre (g/m³). If the deficit is large, the transpiration rate is very high and plants lose a lot of water. When this happens, plants might wilt because they cannot move water from their roots up to their leaves fast enough. If the deficit is small, very

little water is lost. This means the plant is not able to draw up much water and may not get enough nutrients.

The optimum range of VPD is between 3 and 7 g/m³ and is a more valuable management tool than relative humidity. Growers can use VPD to produce an optimum growing environment.

In Table 5, the light and dark blue figures indicate acceptable VPD. However, it is important to note that dark blue figures show the desirable growing range.

The leaf tissue temperature (used in the table) on hot sunny days, especially in summer, can be as much as 12°C higher than the air temperature. During cloudy, dull weather, leaf and air temperatures are similar. It is important to remember that light is energy. When light hits a surface, such as a plant leaf or the greenhouse floor, some of the energy becomes heat.

Table 5. Target vapour pressure deficits (g/m ³)*										
Leaf tissue temperature	Relative Humidity									
	95%	90%	85%	80%	75%	70%	65%	60%	55%	50%
15°C	0.5	1.1	1.7	2.2	2.8	3.3	3.9	4.4	5.5	5.5
16°C	0.6	1.2	1.8	2.3	2.9	3.5	4.1	4.7	5.3	5.8
17°C	0.6	1.3	1.9	2.5	3.1	3.7	4.3	5.0	5.6	6.2
18°C	0.7	1.3	2.0	2.7	3.3	4.0	4.6	5.3	5.9	6.6
19°C	0.7	1.4	2.1	2.9	3.6	4.3	5.0	5.7	6.4	7.1
20°C	0.8	1.5	2.2	3.0	3.8	4.5	5.3	6.1	6.8	7.5
21°C	0.8	1.6	2.4	3.3	4.1	4.9	5.7	6.5	7.3	8.1
22°C	0.9	1.7	2.6	3.5	4.3	5.2	6.0	6.8	7.7	8.6
23°C	0.9	1.8	2.7	3.7	4.6	5.5	6.4	7.4	8.3	9.2
24°C	1.0	2.0	3.0	3.9	4.9	5.8	6.8	7.8	8.8	9.7
25°C	1.0	2.0	3.0	4.1	5.2	6.2	7.2	8.2	9.2	10.3
26°C	1.1	2.2	3.3	4.4	5.5	6.6	7.7	8.8	9.9	11.0
27°C	1.2	2.4	3.6	4.7	5.9	7.1	8.3	9.4	10.6	11.7
28°C	1.3	2.5	3.7	5.0	6.3	7.5	8.7	9.9	11.2	12.4
29°C	1.4	2.7	4.1	5.3	6.7	8.0	9.3	10.8	11.9	13.2
30°C	1.4	2.8	4.2	5.7	7.1	8.5	9.9	11.3	12.7	14.0
* Table adapted from 1996/97 Greenhouse Vegetable Production Guide										

Table 6. Example of air and leaf surface temperature differences – Central Coast NSW

Measured air temperature in greenhouse		Measured leaf surface temperature			Average leaf surface temperature	Difference in temperature between air and leaf surface
Bright sun (summer)	15°C	16°C	17°C	21°C	18°C	+ 3°C
	24°C	29°C	26°C	31°C	28.7°C	+ 4.7°C
	28°C	35°C	41°C	39°C	38.3°C	+ 10.3°C
Dull weather	12°C	13°C	12°C	12°C	12.3°C	+ 0.3°C
	17°C	19°C	17°C	20°C	18.6°C	+ 1.6°C
	24°C	24°C	24°C	25°C	24.3°C	+ 0.3°C

Directing the plant

The wide range of variables influencing plant growth cannot be defined as exact conditions. They are instead a continuum stretching from vegetative to generative. Change in the plant takes a couple of days and may not be evident for a further few days. Because of this, it is important not to overdo any change. Only ever make small, incremental adjustments.

An experienced grower develops an understanding of how to 'read' the bias of the plant and make small adjustments. Growers with different greenhouse and hydroponic systems might use different strategies to adjust for the same situation.

Some example management decisions illustrate this.

If the crop is too vegetative:

- Increase the electrical conductivity (EC) of the feed solution to raise the EC in the root zone by up to 0.5 mS/cm. This has an osmotic effect creating a mild water stress and telling the plant to be more generative.
- Make the 24-hour average temperature up to 2°C higher for 3 – 4 days by raising the venting temperature for a few hours in the middle of the day.
- Delay the first irrigation in the morning by up to 2 hours after sunrise and/or bring forward the last irrigation in the afternoon by up to 2 hours before sunset.
- Reduce the period of time taken to change from the day temperature to the night temperature.

If the crop is too generative:

- Bring day and night temperatures closer together.
- Remove an extra piece of fruit.
- Increase volume of run-off.
- Lengthen the period of time taken to change from the day temperature to the night temperature.

When making pruning decisions, the growth bias of the plant (vegetative or generative) also needs consideration. While the growing environment, irrigation and nutrition decisions are based on the need to manage the whole crop, pruning can be used to make small adjustments for individual plants to keep them properly balanced. The amount of fruit on the plant as well as the level of leaf pruning will affect the plant growth bias.

VEGETATIVE BIAS  **GENERATIVE BIAS**

Lower	24-hour average temperature (+/- 2°C)	Higher
Lower	Night temperature	Higher
Smaller	Difference between day and night temperatures	Larger
Slower	Speed of change from day to night temperature	Faster
Higher	Relative humidity	Lower
Less	Amount of ventilation/air movement	More
More	Amount of run-off	Less
Lower	Water stress	Higher
Higher	Frequency of irrigations	Lower
Earlier	Time of first irrigation of the day (up to 2 hours after sunrise)	Later
Later	Time of last irrigation of the day (up to 2 hours before sunset)	Earlier
Lower	Level of electrical conductivity (EC) in root zone (+/- 0.5 mS/cm; normal range is 2.0 – 3.0 mS/cm)	Higher
Higher	Level of root pressure	Lower
Less	Nutrient stress (very low EC in root zone)	More
Excess	Amount of nitrogen	Lower
Lower	Fruit load	Higher
Lower	Level of carbon dioxide in greenhouse	Higher
Less	Wet leaves (e.g. spray application)	More often
Less	Amount of leaf pruning	More

Quick guide to growing conditions

Temperature:	Minimum 17°C Maximum 30°C Optimum day 22°C 24-hour average 20.5 – 24°C	
Relative Humidity:	75 – 80%	
Vapour Pressure Deficit (VPD):	Optimum range between 3 and 7 g/m ³	
Irrigation:	up to 5.0 litres per day (peak demand)	
Daily run-off volume: (for flow-through substrate culture)	10 – 30%	
Electrical conductivity (EC):	Drain (Root zone)	2.0 – 3.0 mS/cm
	Feed	1.5 – 2.5 mS/cm
Power of hydrogen (pH):	Drain (Root zone)	5.5 – 6.5
	Feed	5.0 – 6.2
Plant density:	1.5 – 2.5 plants per square metre	
Light:	PAR	250 to 670 µmol/m ² /s ~ 55 to 150 PAR Watts/m ² (~ 130 to 360 total Watts/m ²)
Light – Temperature:	Approx 450 µmol/m ² /s @ 25°C (~100 PAR Watts/m ²)	

GREENHOUSE DESIGN AND TECHNOLOGY

Good greenhouse design is essential to produce high quality cucumbers in a sustainable and efficient way. The greenhouse is the basis for providing an optimal growing environment for the crop: a function of light, temperature, carbon dioxide and humidity. All of these affect how productive your cucumber crop is. Greenhouse design and technology influence these factors.

Effective plant management resulting in optimal production requires control of the 24 hour average growing temperature, the volume and frequency of irrigation and vapour pressure deficit.

A brief overview of the different items of greenhouse technology used in controlled environment cucumber production is provided in this section. It is intended as a starting point and general guide to greenhouse design and technology.

THIS SECTION INCLUDES

- The greenhouse
- Types of greenhouses
- Classifying greenhouses
- Covering materials
- Orientation and siting
- Ventilation
- Height of structures
- Control systems
- Heating
- Evaporative cooling
- Screens
- Light
- Uniformity in the greenhouse



The greenhouse

A greenhouse is a generic term referring to a transparent or partially transparent covering material supported by a structure enclosing an area for propagating or growing plants.

Specifically, where the covering material is glass, the structure may be referred to as a 'glasshouse'. A 'greenhouse' or 'polyhouse' refers to the use of plastic films or sheeting. When the enclosing material is woven or otherwise constructed to allow sunlight, moisture and air to pass through the gaps, the structure is known as a 'shade house' or 'screen house'.

When looking to develop or expand a greenhouse enterprise, it is important to make sure that the structures you invest in are suitable and meet your needs.

The shape and design of the structure influences:

- amount of light transmitted
- amount of natural ventilation
- useable internal space
- efficient use of structural materials
- condensation run-off
- heating requirements, and
- cost.

When deciding on a greenhouse design for commercial production, key factors of the greenhouse need to be considered. It is not possible to provide a definitive priority list to suit everyone, but generally, the height of the structure is critical and will have significant bearing on managing the growing environment in a range of conditions. Ventilation is also at the top of the list and because hot air rises, roof ventilation is superior to side wall ventilation. Twin vents enable ventilation to be optimised under a wide range of climatic conditions. Active ventilation systems can also be considered.

Heating is essential for controlled environment horticulture and naturally the computer control systems are critical. Covering materials, screens (thermal and insect) and evaporative cooling systems, as well as air circulation fans, should also be carefully assessed.

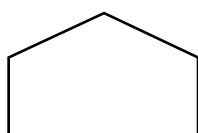


From bottom to top inside; low, medium and hi-tech greenhouses.

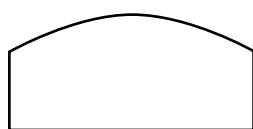
Types of greenhouses

The classification of a greenhouse is according to its basic shape. Types include Gable, Flat arch, Raised dome, Gothic arch (Chapel), Sawtooth, Skillion, Tunnel.

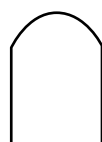
Gable



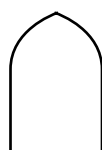
Flat arch



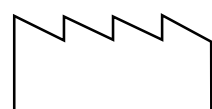
Raised dome



Gothic arch



Sawtooth



Skillion



Tunnel (Igloo)

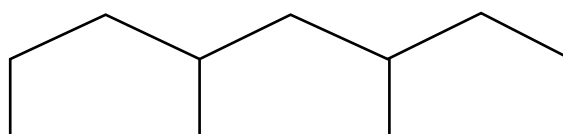


Multi-span structures

Multi-span greenhouses have a surface area (SA) smaller than the combined SA of a number of single span greenhouses of equivalent production capacity. This results in less heat loss and significant energy savings. Substantial economies of scale and production efficiencies are attainable using multi-span designs.

Multi-spans are typically more robust in design. As a result, they tend to suffer less damage during storms and gale force winds.

Gable multi-span



Flat arch multi-span



Other types of structures

Shade houses

Shade houses are structures covered in woven or otherwise constructed materials, allowing sunlight, moisture and air to pass through the material. The covering material provides a particular environmental modification, such as reduced light or protection from severe weather conditions. The height of the structure varies according to the type of crop being produced and may be as high as 8 metres.

Shade houses are used over outdoor hydroponic systems, particularly in warmer regions.

Screen houses

Screen houses are structures covered in insect screening material instead of plastic or glass. They provide environmental modification and protection from severe weather conditions as well as the exclusion of pests. They are often used to get some of the benefits of greenhouses in hot or tropical climates.

Crop top structures

A crop top is a structure with a roof which does not have walls. The roof covering may be a greenhouse covering material. These structures provide some modification of the growing environment such as protection of the crop from rain or reduction of light levels.

Classifying greenhouses

Greenhouses are a technology based investment. The higher the level of technology used, the greater potential for achieving tightly controlled growing conditions. This capacity to tightly control the conditions in which the crop is grown is strongly related to the health and productivity of the crop. The following three categories of greenhouse are defined to assist people in selecting the most appropriate investment for their needs and budget.

Low technology greenhouses

A significant proportion of the industry in Australia currently uses low technology structures. These greenhouses, known as tunnel houses, are less than 3 metres in total height. They are typically 9 metres wide and 50 metres long. Tunnel houses do not have vertical walls. They have poor ventilation. This type of structure is relatively inexpensive and easy to erect. Little or no automation is used.

While this sort of structure provides basic advantages over field production, crop potential is still limited by the growing environment and crop management is relatively difficult. Low technology greenhouses generally result in a suboptimal growing environment, restricting yields and doing little to reduce the incidence of pests and diseases. Pest and disease control, as a result, is normally structured around a chemical pesticide spray program.

Low technology greenhouses have significant production and environmental limitations, but they offer a cost effective entry to the industry.



Low technology greenhouses have significant production and environmental limitations.

Medium technology greenhouses

Medium technology greenhouses are typically characterised by vertical walls less than 4 metres tall and a total height usually less than 5.5 metres. They may have roof and/or side wall ventilation. They are usually clad with either single or double skin plastic film or glass and use varying degrees of automation.

Medium technology greenhouses offer a compromise between cost and productivity and represent a reasonable economic and environmental basis for the industry. Production of cucumbers in medium technology greenhouses is more efficient than field production. Hydroponic systems increase the efficiency of water use. There is greater opportunity for non-chemical pest and disease management strategies but overall the full potential of greenhouse horticulture is difficult to attain.



Medium technology greenhouses offer a compromise between cost and productivity.

High technology greenhouses

High technology greenhouses have a wall height of at least 4 metres, with the roof peak up to 8 metres above ground level. These structures offer superior crop and environmental performance. High technology structures have roof ventilation and may also have side wall vents. Cladding may be plastic film (single or double), polycarbonate sheeting or glass. Environmental controls are almost always automated. These structures offer enormous opportunities for economic and environmental sustainability. Use of pesticides can be significantly reduced. High technology structures are increasingly involved in agritourism opportunities internationally.

Although these greenhouses are expensive, they offer a highly productive, environmentally sustainable opportunity for an advanced fresh produce industry. Investment decisions should, wherever possible, look to install high technology greenhouses.



High technology greenhouses offer a highly productive, sustainable environment.

Greenhouse covering materials

The covering material used on a greenhouse influences productivity and performance. Covering materials impact on the level and quality of light available to the crop. Diffused light is better than direct light. Fluorescent and pigmented films can increase the proportion of good red light. Dust, attracted to plastic films, reduces the transmission of radiation. Water droplets, from condensation for example, on the inside of coverings have been shown to reduce light transmission by 8% and also block thermal radiation.

Greenhouse coverings all reduce light to some extent. As coverings become dirty and age less light enters the greenhouse. Light coloured materials in the greenhouse, such as white weed matting, increase the light available to the crop.

Key characteristics considered in selecting a covering material are cost, durability, weight, ease of repair or replacement, how much light is transmitted and how much heat energy moves through the material.

Diffusing materials are designed to scatter incoming light, resulting in better light conditions for crops – for example, a cloudy white plastic film diffuses light better than a clear plastic film.

Glass

Glass has long been the traditional covering. Its favourable properties include:

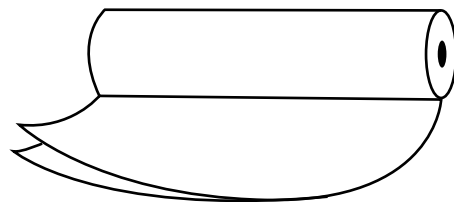
- high transmission in the photosynthetically active radiation (PAR) bandwidth
- good heat retention at night
- low transmission of UV light
- durability
- low maintenance costs.

Plastic sheeting

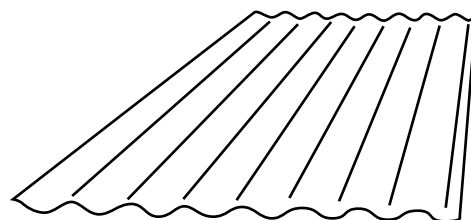
Essentially there are three materials in this category – polycarbonate, acrylic (polymethyl methacrylate) and fibreglass. Plastic sheeting is not used extensively in Australia but its use is increasing. Sheeting products are more durable than plastic films and have fairly good heat retention, good transmission in the PAR range and low UV light transmission.

Plastic films

Films are the most common and lowest cost type of covering material. The types of film available are polythene (polyethylene), EVA (ethyl vinyl acetate) and PVC (poly vinyl chloride). ETFE (ethylene tetrafluoroethylene) is an exceptional plastic and is likely to become a common greenhouse cladding material. With the constant improvements in plastics, these covering materials offer a lot of flexibility and performance options. Plastic film technology is progressing rapidly and commercially available materials is tailored to suit almost any requirement, can be superior to other cladding options. A variety of additives give plastic films useful properties. For example, films may exclude ultra violet (UV) light to enhance chemical free pest control or reflect



Films are the most common and lowest cost type of covering material.



Sheeting products are more durable than plastic films.

long wave infra red (IR) radiation to improve heat retention at night. As a result, some plastic covering materials are coloured or tinted.

Additives to plastic film determine:

- durability
- capacity to reduce heat loss
- capacity to reduce droplet formation
- transmission of particular wavelengths of light
- capacity to reduce the amount of dust sticking to the film.

Types of additives

- UV (290 – 400 nm) absorbers and stabilisers increase durability, reducing the potential damage to biological systems in the greenhouse, and may control some plant pathogens.
- Infrared (700 – 2,500 nm) absorbers reduce long wave radiation and minimise heat loss.
- Long wave radiation (2,500 – 40,000 nm) absorbers reduce the loss of heat radiated from materials and objects (including plants) inside the greenhouse.
- Light diffusers scatter light entering the greenhouse, reducing the risk of plants getting burnt and improving the amount of light available to the lower parts of the plant.
- Surfactants reduce the surface tension of water, dispersing condensation.
- Antistatic agents reduce dust accumulation on plastic films.

In addition:

- Colour pigments may improve plant growth by altering the proportion of selected wavelength ranges.
- Fluorescence increases the emission of red light.
- Glossy surfaces may repel insects.

The process of making multilayer films enables thin layers of materials with different properties to be joined, producing superior composite films. Properties such as durability, creep (deformation over time) and long wave radiation absorption can be improved.

Maintenance

A poorly maintained covering material can lose a lot of energy and significantly increase production costs.

Glass coverings should be kept clean and broken panes replaced. Plastic coverings need routine replacement. The performance of plastic coverings declines over time. Old coverings reduce light transmission which can restrict yield. The useful life of plastic films depends on the specifications of the plastic purchased. All plastic covering materials need to be replaced before they visibly start to break down; discolouration, for instance, is an early indication of wear.

Orientation and siting of a greenhouse

Emphasis internationally is placed on orientation to maximise light interception in the greenhouse. This is not such an issue in much of Australia because our light levels are higher than most overseas production areas.

Shadows cast by gutters, trusses and equipment in the roof of the greenhouse can lead to uneven light conditions in the crop. As the sun moves from the east to the west during the day, the shadows of the greenhouse structure will also move. An east-west alignment creates structural shadows in the same part of the crop through the day which can affect crop productivity and plant health in this area. Subsequently, to minimise shading effects, greenhouses are generally oriented north-south.

In southern areas of Australia, an east-west orientation may result in slightly more light transmission, but the need for cooling and ventilation is a more important factor under Australian conditions. Further north, there is even less difference in light transmission whichever

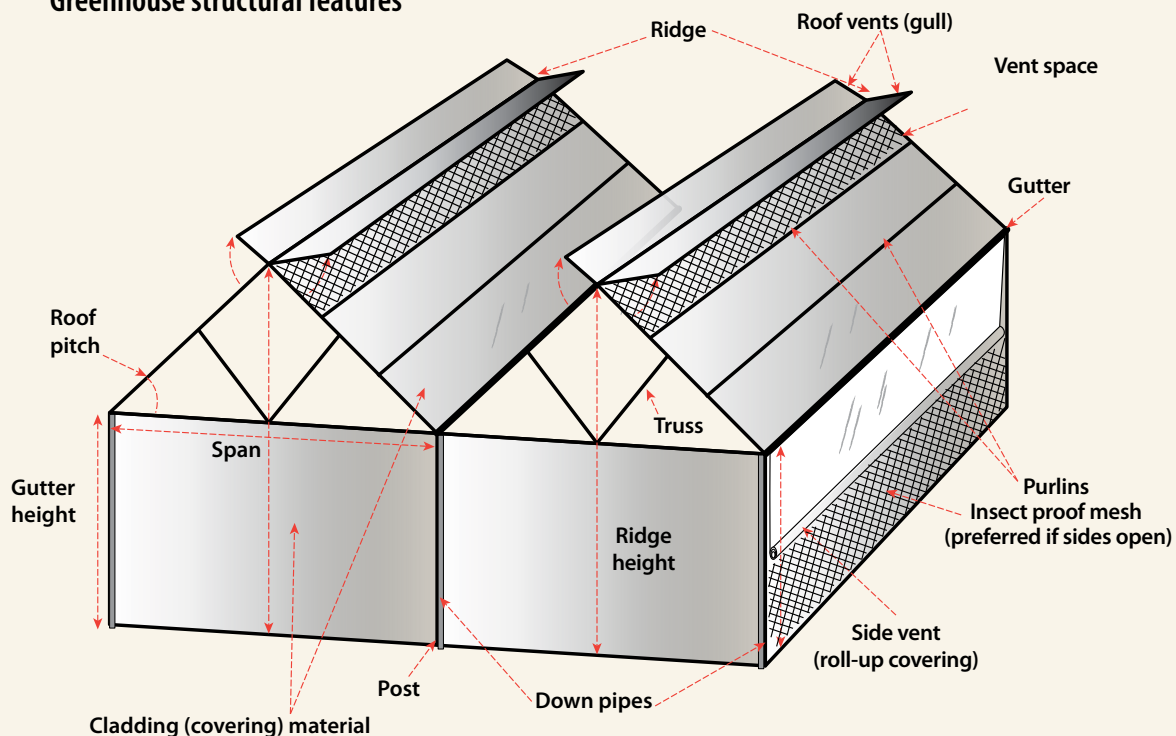
way a greenhouse is oriented. Again, cooling and ventilation should be the primary consideration in orienting a structure.

Crop rows are typically aligned north-south to minimise shading within the crop. In most areas, vents are on the east and west. The direction of prevailing winds should be considered, with structures oriented to take advantage of cooling summer breezes.

Where fans are used for forced ventilation, they should be positioned to minimise any likely noise impacts on neighbours.

When siting a greenhouse, consider the shading effect of vegetative screens and windbreaks. Locating greenhouses against a tree line will result in lower yields because of reduced light levels. Greenhouse covering materials near trees will also become quite dirty, further reducing light transmission.

Greenhouse structural features



When siting a greenhouse:

- Favour a property with natural visual screening.
- Consider proximity to key markets.
- Prevent a direct line of sight between the development and adjoining dwellings or roadways.
- Locate new developments, such as additional greenhouses, behind existing structures.
- Locate structures with sufficient setbacks from roadsides and boundaries.
- Use landscaping, mounding and vegetation to soften the impact of the development.
- Keep existing vegetation and landforms wherever practical.
- Consider transport routes and the availability of labour and services.
- Avoid development in areas that are visually prominent or highly exposed, such as ridgelines.
- Locate structures so that they follow the contours of the land.
- Avoid locating structures on steep slopes (greater than 1 in 5).
- Check potential impacts of adjacent land uses in terms of pests, diseases and weeds.
- Take note of adjacent sensitive areas (e.g. wetlands, waterways, native vegetation) and site greenhouses appropriately.

Ventilation in greenhouses

Good ventilation is critical in maintaining an optimal growing environment and improves the overall efficiency of a greenhouse. It is essential for both temperature and humidity management. Cooling is critical in the Australian environment and is most commonly achieved using passive roof ventilation. The movement of hot air up and out of the roof vents, pulls in cooler air.

Ventilation is also important for air circulation and replenishing carbon dioxide. Poor air circulation reduces plant activity and can lead to problems with humidity and disease management. Air movement in the greenhouse should be between 0.2 and 0.7 metres per second. If carbon dioxide levels are not maintained, plant growth is affected.

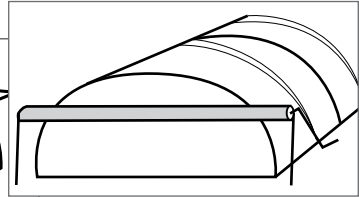
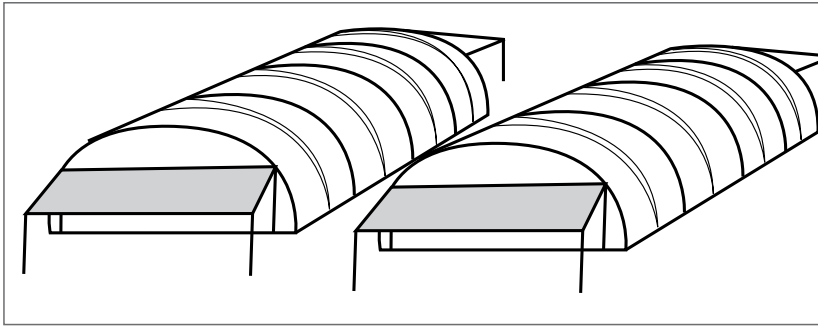
Ventilation is about air exchange. Large volumes of air need to be moved during hot conditions. A greenhouse must achieve at least 30 air changes per hour. Ideally 60 air changes per hour – that's one air exchange every minute – are needed to make sure the greenhouse environment can be managed in hot, sunny Australian conditions.

Ventilation is achieved passively or actively. The venting capacity of greenhouses is usually described as a percentage of floor area. For example, a greenhouse with 30% roof ventilation has 0.3 m² of open vent area for every 1 m² of floor area. A greenhouse in all but the coolest areas of Australia should have a venting capacity of at least 25%, but up to 40% is desirable. It is better to have more venting capacity than you need.

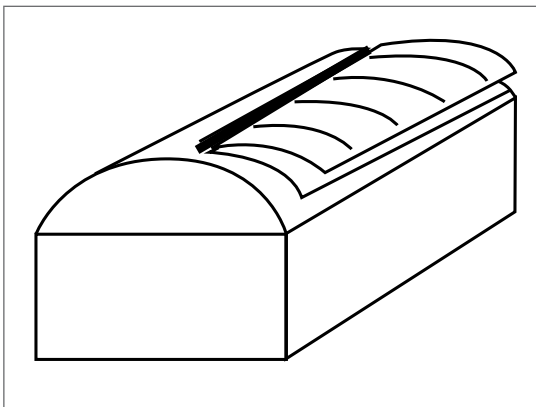
Vents

Passive ventilation uses openings (vents) which naturally draw air through the greenhouse. Vents are the most common ventilation method used in greenhouse cucumber production. Though different designs vary in their effectiveness, in general terms, roof vents are up to five times more effective than side wall vents. Opposing roof vents, that is vents on both sides of the peak, offer greater flexibility and capacity to optimise the growing environment under a wider range of climatic conditions.

The Dutch venlo design features twin peaks within every 8-metre span which more effectively spreads the ventilation over the floor area.

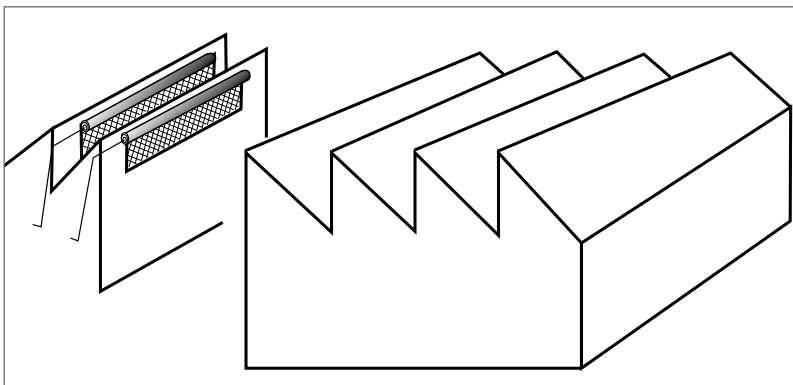


Tunnel houses have very poor venting capacity.

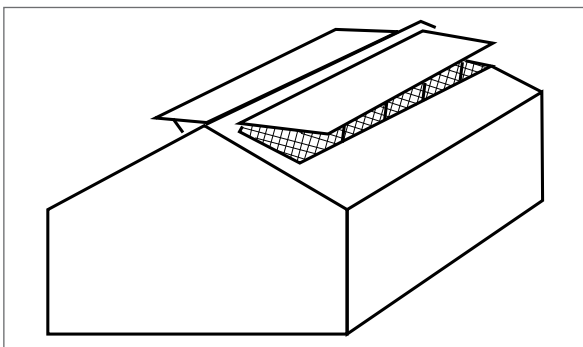


Unmeshed single roof vents on open-ended multispans.

Roof vents are more effective than wall vents.



Venting (preferably insect proof meshed), of sawtooth designs can be limited by wind direction and must be sited correctly.



Twin roof vents, preferably with insect proof mesh, offer excellent venting capacity under most conditions.

Single roof vents on enclosed higher tech greenhouse.

The natural 'chimney effect' of rising hot air and falling cooler air which is the basis for passive ventilation becomes truly effective above approximately 3.5 metres. Beyond this, the movement of air over the greenhouse provides the main venting action which is why roof vents are superior.

A low profile walled greenhouse therefore, will require forced cooling to produce similar conditions to a taller structure.

Fans

Active ventilation is the use of equipment to force air into or out of the structure. Fans are the key method of actively venting a greenhouse. Fans can also be fitted in greenhouses to move or circulate air within the greenhouse. Circulating fans (horizontal air flow or HAF fans) are used inside passively ventilated structures to assist air movement and air mixing when venting is minimal. They improve heating and management of humidity. Vertical air flow fans (VAF) can also be used to circulate air and manage uniformity in a greenhouse, however, vertical air flows can interrupt horizontal airflows and both

the design and benefit to cost need to be carefully considered.

When using fans for air exchange, the most effective approach is to pull the air through the full length of the structure from multiple points to avoid hot air pockets remaining. Fans placed to extract air from higher in the greenhouse are more effective for cooling than fans placed lower.

Active ventilation systems are limited in their capacity to quickly exchange large volumes of air. If the design specifications for your greenhouse are inadequate, poor air circulation through the crop can result. Under-ventilated structures often have overheating problems in the crop in the middle of the greenhouse. To ensure correct capacity and installation, select fans in consultation with the manufacturer and an independent expert. Ventilation fans generally need sufficient capacity to completely replace the air in the greenhouse every minute.

Fans have an on-going operational cost and noise generation may pose problems in some areas. Fan efficiencies influence running costs and should be considered when purchasing. It is important to clean and maintain fans to ensure that they are functioning properly.



Horizontal Air Flow (HAF) fans are used to circulate air within the greenhouse.

Height of structures

Height is one of the most important aspects of a greenhouse. The height of a structure directly impacts on natural ventilation, the stability of the internal environment and crop management. Greenhouse structures with wall heights of at least 4 metres should be constructed wherever feasible, in preference to designs of lower height.

A tall walled, roof ventilated greenhouse can achieve a more uniform, stable and ultimately superior growing environment for the crop. During hot weather, a taller structure avoids trapping hot, humid air around the cucumber plants.

Many of the problems encountered in greenhouse crops can be directly attributed to the capacity to manage the growing environment. Better control of the growing environment directly impacts how well other problems in the greenhouse are managed. A significant proportion of yield loss in Australian greenhouse crops are attributed to poor management of heat. The capacity for a grower to manage heat in summer is greatly improved with increasing greenhouse height.

Effective management of pests and diseases using non-chemical management strategies is also dependent on good control of the growing environment and the value of height in the structure can not be overstated.

Although cucumbers can be grown relatively well in lower profile greenhouses, taller structures are more versatile, are suitable for a wider range of crops and therefore a better long term investment.

Computer control systems, sensors and monitoring equipment

Good crop management depends on having the right information to make necessary decisions. In the past, the grower has been the greenhouse sensor and control system – checking conditions and adjusting equipment settings as needed to optimise crop growth.

To improve crop management, a number of sensors and instruments can (and should) be used to gather information. A computer control system can then use this information to make regular adjustments to equipment settings, optimising growing conditions.

Monitoring growing conditions is essential. Even without automated control of the production system, it is not possible to make the right decisions about the crop without having accurate information. Temperature and relative humidity (and/or vapour pressure deficit) need monitoring in every greenhouse. Light levels should be checked at least periodically to make sure covering materials are performing adequately. Ideally light levels need regular checking in order to know the optimal temperature regime for the crop. The electrical conductivity and pH of both the feed and drain solutions should be monitored in every hydroponic system.

Temperature and relative humidity sensors should be placed level with the growing tip of the crop. Placing a thermometer near the door of a greenhouse might be convenient but will not give you accurate information needed for producing a good cucumber crop.

Medium and high technology* greenhouses make use of a range of sensors linked to automated control systems. These systems can monitor temperature, relative humidity, vapour pressure deficit, light intensity, electrical conductivity (feed and drain), pH (feed and drain) and carbon dioxide concentrations as well as wind speed and direction and even whether or not it is raining. The information is used to control heating, venting, fans, screens, nutrient dosing, irrigation, carbon dioxide supplementation and fogging systems.

Correct operation and maintenance of the automatic controllers is essential to management of an optimal growing environment for cucumbers. Emergency alarms and backup generators may be used in case of problems or power failure due to the large investments made in producing a crop.

Closer monitoring of the greenhouse environment with sensors and advanced software can greatly improve

* Refer to the 'Classifying greenhouses' section starting on page 64.



yields and economic performance by optimising plant growth. The cost of automated equipment and computer control systems can generally be recovered within a couple of seasons through savings in labour and better crop production.

Increasingly sophisticated sensors are being developed and adopted in commercial greenhouse operations to monitor the plants directly. Today's growers have access to continuous measurement of a wide range of aspects of plant growth including stem diameters, sap flow rates, expansion of fruit and leaf temperatures. The integration of this information into production decisions is still new, but is rapidly providing better data about growing conditions and even assisting in the early detection of plant stresses.

Good control in the greenhouse is the ultimate aim of controlled environment horticulture. The most important benefit of control in the greenhouse is the efficiency and effectiveness of your management decisions. There are a lot of other practices that can be adopted to save money and result in a better crop.



Monitoring temperature, humidity and water use by the plants is essential to maximise productivity.

These include greater energy and labour efficiency, more efficient use of water and fertilisers and fewer pesticides. Better control also gives you a more uniform crop so it costs you less to sell.



Ducted gas heating with portable gas units is not ideal but is the first step to providing effective temperature management.

Heating

Heating is used to provide optimal temperatures for crop growth and management of humidity in the greenhouse. Heating may be needed throughout the year, not just in winter. Heat should ideally be applied as low as possible in the greenhouse (with the exception of 'grow pipes'). Distributing heat evenly is essential for optimal crop production.

There are essentially two methods of heating – hot air and hot water. Hydronic heating refers to the use of a boiler to heat water which is then piped through the greenhouse. The pipes, located around the walls of the structure and/or between plant rows, radiate heat. The major costs are in the boiler and piping. A centralised hydronic heating system is a more efficient form of heating in greenhouses greater than 1000 m² and especially where there are several separate greenhouses. When hot water heating is



Top and above: Hydronic heating pipes can double as trolley rails to improve efficiency.

used, the boilers may be situated away from the greenhouse. This flexibility provides the opportunity to locate potentially noisy boilers away from farm boundaries, minimizing disturbance to neighbours.

Hydronic pipe heating offers greater management options through the use of minimum pipe temperatures to aid ventilation, air movement and transpiration. Heating pipes can double as rails



Bulk storage for gas heaters are popular in Australian greenhouses.

for trolleys resulting in more efficient crop and labour management. Adjustable 'grow pipes' are an additional tool that can be used to influence plant balance.

Heated air may be directly generated in the greenhouse or the internal air can be warmed through heat exchange with an external heat source. Where combustion is used as the source of the heat, such as in a gas fired heater, locating the heater outside the greenhouse and using a heat exchange pad to warm the internal air is recommended. This is because the combustion process can result in ethylene production and water vapour. Ethylene can cause leaf drop and premature ripening of fruit. Increased moisture levels in the air may result in excessive humidity and condensation problems.

Fuel

Gas remains the primary source of energy for greenhouse heating in Australia. Oil, diesel and coal are also used. Natural gas costs less and burns cleanly. It does not require on-farm storage tanks and is typically low maintenance. Unfortunately, natural gas is not available in all areas. Bottled gas (LPG) costs can be volatile and storage tanks are needed.

Oil and diesel are more expensive than natural gas and because these fuels do not burn as cleanly, more boiler maintenance is needed. On-farm storage is also required.

Coal is relatively low cost if it is locally available. It is typically more polluting than other fuel sources. Large storage areas are needed on farm as well as loading equipment. As coal does not burn as cleanly, significant boiler maintenance is needed.

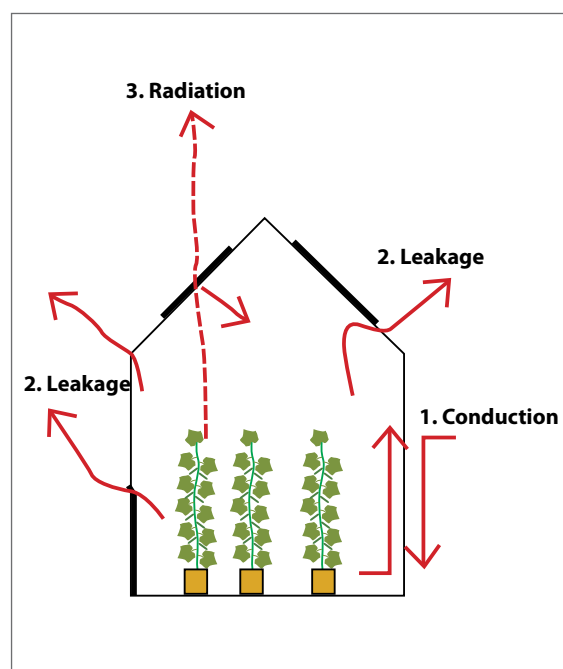
Ground source heat

Ground source heat using heat pumps is an underutilised greenhouse energy option and offers substantial economic and environmental opportunities for Australian growers. This technology can be readily integrated with other heating and energy options.

Greenhouse heating requirements

The main basis for heating in a greenhouse is the replacement of lost heat. Heat can be lost through conduction, leakage and radiation. Most heat is lost through conduction, where heat energy is transferred directly through covering materials and the structure to the outside atmosphere.

Leakage of air accounts for the next greatest amount of lost heat. In a well constructed and maintained structure as much as 10% of heat loss can still be due to leakage. In greenhouses with poorly fitting doors, partially opened vents, other gaps or broken covering materials, significantly more heat can be lost this way.



Three ways heat is lost from the greenhouse:

1. Conduction – direct movement through structural materials.
2. Leakage – hot air escaping through gaps and doorways.
3. Radiation – radiant energy moving directly through covering materials.

Radiation is the third way heat is lost from the greenhouse. The heat load through radiation depends on the covering material. Glass does not permit much heat to escape through radiation, but basic polythene covering materials can. There are, however, a number of plastic films on the market today that restrict thermal radiation. These are known as thermic films.

Working out how much heating is needed

Heat losses are worked out for the coldest expected night temperatures, giving the maximum heating capacity needed. Heater capacity is calculated from the heat load (Q) of the greenhouse and the heater efficiency.

Calculating the total heat load (Q_T)

The total heat load is the sum of the amount of heat loss through all three different processes:

Conduction (Q_C) + Leakage (Q_L) + Radiation (Q_R);

$$Q_T = Q_C + Q_L + Q_R$$

The loss due to radiation is generally ignored, so the total heat load is;

$$Q_T = Q_C + Q_L$$

Heat load due to conduction (Q_C)

Conduction – the transfer of heat through the structural materials – is the main way that heat is lost. Different materials have different conduction values. These are referred to as 'U' values or heat transfer values. They are measured in Watts per square metre per degree Kelvin or you may find them in Btu (British thermal units) per hour per square foot per degree Fahrenheit.

You also need to know the surface area of the greenhouse and the difference between the temperature set point for your crop and the coldest outside temperature.

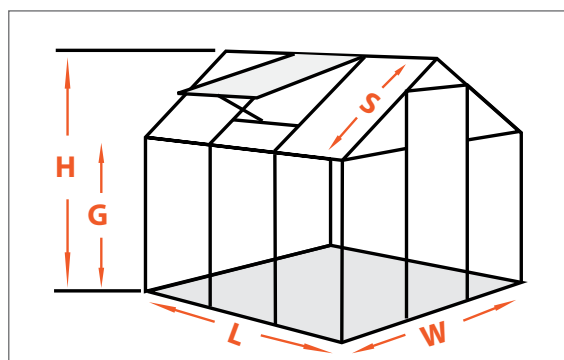
Table 7. Heat transfer values

Covering Material	U Value	
	Watts / m ² °K	Btu / hr sq.ft °F
Single polythene plastic film	7.5 – 8.5	1.2 – 1.5
Double polythene plastic film	4.0 – 5.0	0.7 – 0.9
Polycarbonate	6.8	1.2
Polycarbonate double walled	3.5	0.6
Glass 3 mm	7.0 – 8.0	1.2 – 1.4
Glass 6 mm	6.5	1.15
Thermal screen	2.8	0.5

Surface area (SA) of the greenhouse

The amount of heat transferred out of the greenhouse is dependent on the surface area of the structure. A large surface area can lose more heat than a smaller surface area over the same period of time. The surface area of the greenhouse is referred to as 'SA' and is measured in square metres or square feet. The SA includes the roof and all the walls of the greenhouse.

For a gable type greenhouse, you need to measure the total height to the roof peak (H), the height of the gutter or eave (G), the width (W), the length (L) and the width of the roof slope (S).



The surface area is the sum of the following:

$$\text{Area of side walls} = 2 \times (L \times G)$$

$$\text{Area of sloping roof} = 2 \times (L \times S)$$

$$\text{Area of end walls} = 2 \times [(G \times W) + (0.5 \times (H - G)) \times W]$$

$$\text{Total surface area} = \text{Area of side walls} + \text{area of roof} + \text{area of end walls}$$

Note that a multi-span greenhouse only has two side walls, but every bay has roof area and end walls.

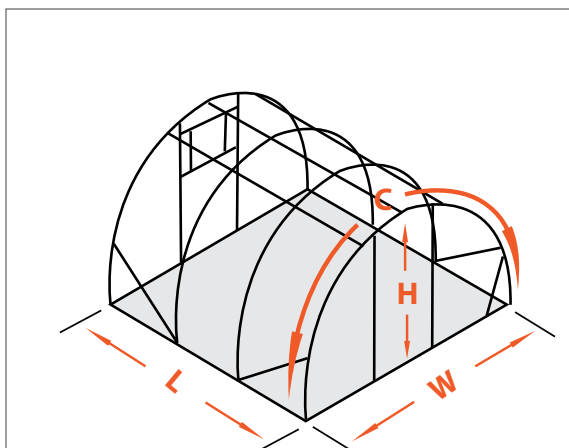
For a tunnel house, you need to measure the height (H), the width (W), the length (L) and the length of the curved frame (C).

The surface area is the sum of the following:

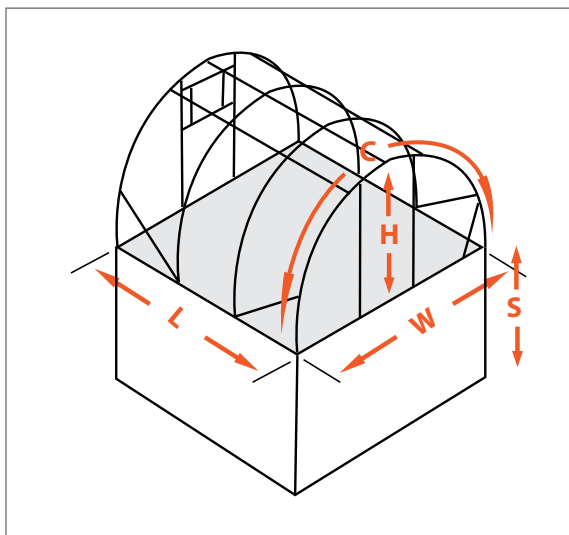
Area of curved roof and walls
 $= L \times C$

Area of end walls $= 2 \times \pi \times (h \times w)$ where $\pi = 3.14$

Total surface area = Area of curved roof and walls
 + area of end walls



For a straight walled curved roof greenhouse, you need to measure the height of the curved section (H), the width (W), the length (L) and the length of the curved frame (C). You also need the height of the vertical section of the side (S).



The surface area is the sum of the following:

Area of curved roof and walls $= L \times C$

Area of curved part of end walls
 $= 2 \times \pi \times (h \times w)$ where $\pi = 3.14$

Area of rectangular side walls
 $= 2 \times L \times S$

Area of rectangular part of end walls
 $= 2 \times W \times S$

Total surface area = Area of curved roof and walls
 + area of curved part of end walls + area of rectangular side walls + area of rectangular part of end walls

Note that a multi-span greenhouse only has 2 side walls, but every bay has roof areas and end walls.

Temperature difference (ΔT)

The temperature difference (ΔT), called 'delta T', is the difference between two temperature points. In this case, it refers to the difference between the minimum required temperature in the greenhouse and the lowest outside temperature. The required temperature in the greenhouse is the set point that you want to achieve. This may be a compromise temperature to reduce heating costs. For example, while you may want a minimum night temperature of 19°C, to reduce your heating costs, you might decide to use a set point of 17°C instead.

If the lowest outside temperature is 1°C and your set point is 19°C, the ΔT is 18 degrees.

Calculating heat load due to conduction

The heat load due to conduction (Q_c) of your greenhouse equals the heat loss (U) multiplied by surface area (SA) multiplied by the temperature difference, divided by 1000. This will give you a heat load in kilowatts (kW):

$$Q_c = \frac{U \times SA \times \Delta T}{1000} \quad \text{kW}$$

Additional accuracy in calculating the heat load can be achieved by including the effect of wind and heat loss through the floor.

a) Effect of wind

Wind increases the removal of heat from the outside of the greenhouse so heat transfers faster. If you are in a particularly windy area, especially during winter, it is a good idea to include it. The stronger the wind

is, the greater the heat loss.

A wind factor (W) is used in the heat loss calculation.

$$Q_c = \frac{U \times SA \times \Delta T \times W}{1000} \quad \text{kW}$$

Table 8. Wind factors

Wind speed (km/hr)	Wind factor (W)
< 25	1.0
30	1.025
35	1.05
40	1.075

b) Amount of heat loss through the floor

The greenhouse floor is another surface where some heat can be lost. To include the loss of heat through the floor, you will need a U value for the floor (e.g. poured concrete is about 1.1, black plastic is about 2.7) and the surface area of the floor.

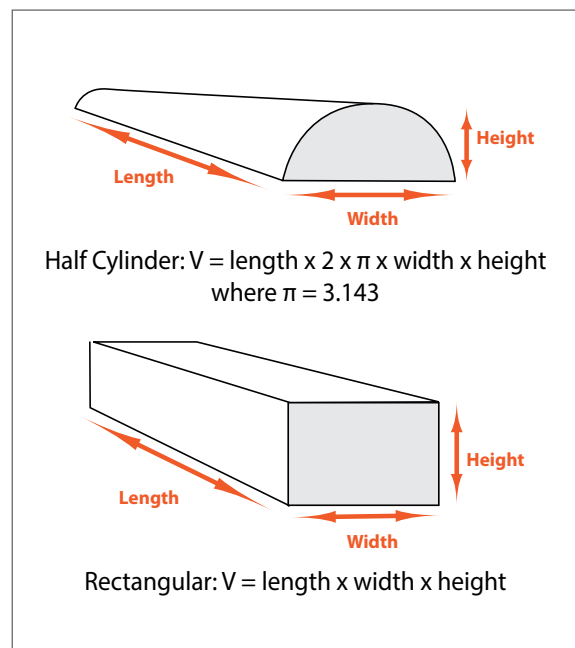
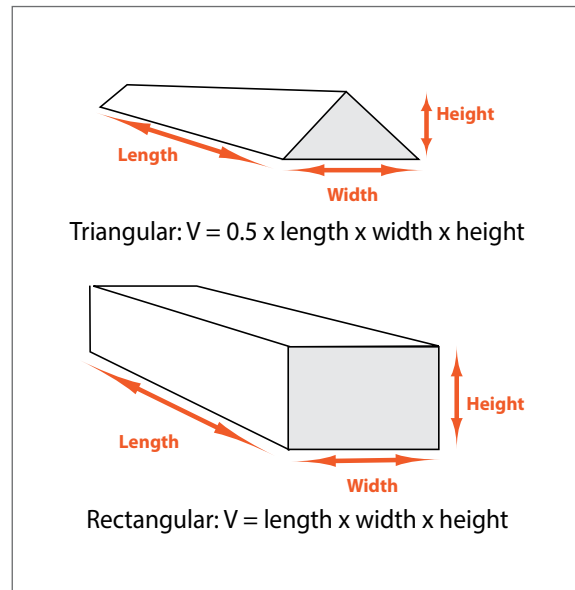
Heat load due to leakage (Q_L)

Air leakage is usually the second biggest source of heat loss from a greenhouse. To include the heat load due to air leakage (Q_L), you will need to know the air volume of the greenhouse in cubic metres (V), the number of air changes occurring (E), the wind factor (W) and the difference between your temperature set point and the outside minimum temperatures (ΔT).

$$\text{Leakage } (Q_L) = \frac{0.373 \times \Delta T \times V \times E \times W}{1000} \quad \text{kW}$$

For the wind factor (W), refer to wind factor table above.

To calculate greenhouse air volume (V), imagine the structure as different shapes (rectangular, triangular or half cylindrical) and use the following formulae. If the greenhouse is made up of more than one shape, work out the volume for each and add them together. All dimensions should be in metres to give you a volume in cubic metres.



Heater capacity

Once you know what the maximum heat load of your greenhouse is, you can work out what capacity of heating system you need. This is dependent on how efficient the heater is. In general, using bottled or natural gas, the heating efficiency is about 80%.

$$\text{Heater capacity} = \frac{\text{Heat load of your greenhouse } (Q)}{\text{Heater efficiency}}$$

Reducing heating requirements

Several strategies can be used to reduce heating costs:

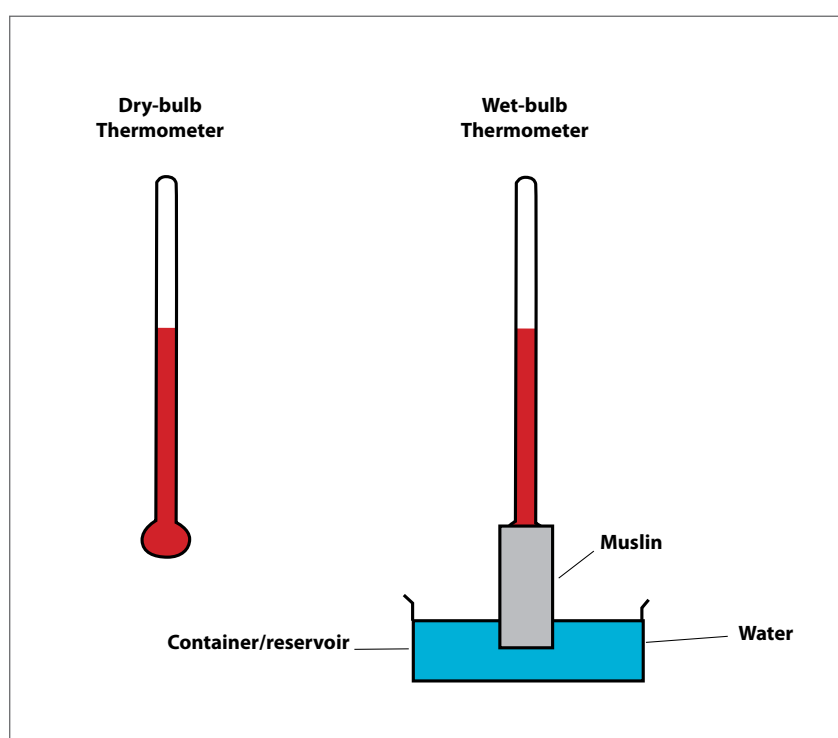
- Use a greenhouse design that minimises surface area relative to production area, for example, a gutter connected multi-span greenhouse has a smaller surface area than several separate greenhouses of the same total production area.
- Use cladding materials with a low U value, for example, a double skin polythene clad greenhouse loses less heat than a single skin polythene covered greenhouse.
- Use thermal screens with a lower U value than the cladding material.
- Close air leaks and repair any damage in the cladding materials. Make sure doors and vents close tightly.
- Use windbreaks to reduce the speed of wind passing over the greenhouse.
- Use the most efficient heater possible.
- Use an automated control system.
- Use cooler set points when possible, for example when controlling to a 24 hour average temperature regime, increase the day temperature and lower the night temperature (subject to managing plant balance).

Evaporative cooling

Evaporative cooling uses the natural relationship between relative humidity, water and air temperature. When water evaporates it has a cooling effect. Humidity is also increased and the vapour pressure deficit is reduced. Evaporative cooling is most effective in southern coastal areas and most inland areas of Australia where humidity is low.

Air temperature is measured as either a dry bulb or wet bulb temperature. The wet bulb temperature gives an indication of what temperature air can be cooled to with evaporative cooling. Wet bulb temperature is measured using a thermometer with a wet sleeve or wick around it. Air passes over the thermometer and the water on the sleeve evaporates and cools the thermometer, so that it will read less than the temperature read by a normal (dry) thermometer.

The amount of cooling achieved from evaporative cooling systems is dependent on how much water can be evaporated so it is related to the amount of water already in the air. This is relative humidity. The following Table 9 shows the temperature to which air can be potentially cooled. Evaporative cooling is most effective when the relative humidity is below 60%.



The difference between the temperatures shown by a dry bulb and a wet bulb thermometer indicate how much the temperature inside the house can potentially be reduced by evaporative cooling.

Table 9. Potential cooling effect

Air temp. °C (dry bulb)	Potential cooling effect (difference between dry and wet bulb temperature) in degrees (°C) at different levels of relative humidity (%)																			
	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10
10	94%	88%	82%	77%	71%	65%	60%	54%	49%	44%	39%	34%	29%	24%	19%	14%	9%	5%		
15	95%	85%	85%	80%	75%	71%	66%	61%	57%	52%	48%	44%	40%	36%	31%	27%	24%	20%	16%	12%
20	96%	87%	87%	83%	78%	74%	70%	66%	62%	59%	55%	51%	48%	44%	41%	37%	34%	30%	27%	24%
25	96%	88%	88%	84%	81%	77%	74%	70%	67%	63%	60%	57%	54%	50%	47%	44%	41%	38%	36%	33%
30	96%	89%	89%	86%	83%	79%	76%	73%	70%	67%	64%	61%	58%	55%	52%	50%	47%	44%	42%	39%
35	97%	90%	90%	87%	84%	81%	78%	75%	72%	70%	67%	64%	61%	59%	56%	54%	51%	49%	47%	44%
40	97%	91%	91%	88%	85%	82%	80%	77%	74%	72%	69%	67%	64%	62%	60%	57%	55%	53%	51%	48%

Fan and pad systems

Fan and pad systems combine two pieces of equipment. An exhaust fan is located at one end of the greenhouse and a porous pad is built into the wall of the structure at the opposite end. A pump circulates water over and through the pad. When the fan is in operation, it pulls air from outside the structure, through the evaporative pad, into the greenhouse. The air, passing through and over the wet pad evaporates some of the water and is cooled. As a result, cool air is drawn into the greenhouse to replace the hot air expelled by the fan.

These systems are quite effective for cooling but are relatively expensive to install and maintain. A disadvantage of the fan and pad system is that it tends to create a significant temperature gradient from one end of the greenhouse to the other (warmest at the fan end and coolest at the pad end) which can affect crop uniformity and make management more difficult. Under extreme conditions which demand a lot of cooling, the air movement through the greenhouse generated by exhaust fans may damage cucumber plants.

Fogging systems

Fogging systems are a fairly effective and uniform method of greenhouse cooling and provide a reasonable increase in relative humidity in a greenhouse. On a hot day, a cooling effect of up to 10°C can be achieved. Fogging systems produce very small droplets of water in the range of 10 – 20 microns which are suspended in the air and evaporate before they have time to fall on to the crop canopy.

Fogging line pressure and fogging nozzles must be properly maintained. A poorly maintained system may not provide sufficient cooling or could result in wetting of leaves and fruit. This can lead to reduced product quality and an increased incidence of pests and particularly diseases.

Misting systems

Misting systems deliver a fine spray of water into the greenhouse air space, providing some relief during very hot and/or dry conditions. Most misting systems operate at a pressure of between around 250 kPa and 300 kPa. The water droplets are typically in the range of 100 to 200 microns. This sized droplet is too large to be completely evaporated and so falls quickly, wetting the crop and the greenhouse floor.

While misting systems can have a cooling benefit, a wet canopy can lead to an increase in diseases and fruit damage. A wet floor can pose a safety risk to people in the greenhouse. A misting system outside (above) the greenhouse can achieve a reasonable cooling benefit without wetting the crop or the greenhouse floor.

Screens

There are several different materials in this category, broadly thermal screens, insect screens and shade screens.

Thermal screens

Thermal screens offer a flexible and efficient way of improving the management of the greenhouse environment. These horizontally mounted, retractable screens are designed to keep heat and radiation in a greenhouse during cold periods such as night time and prevent radiation and associated heat entering the greenhouse during hot periods, such as in the middle of a summer day.

This dual capacity makes these materials useful under a range of conditions throughout the year. Because they are retractable, greenhouse conditions can be adjusted and optimised. Thermal screens can



Thermal screens offer a flexible and efficient way of managing the greenhouse environment.

reduce temperatures during the day by as much as 10°C and maintain temperatures during the night by as much as 5°C.

When heating, thermal screens trap warm air nearer the crop, reduce the volume of air space to be heated and reflect radiation back to the crop. This can reduce heating costs significantly – possibly by up to half.

Under extreme, heat conditions, thermal screens are valuable in reducing incoming radiation during the day. This reduces the heat load in the greenhouse and assists in maintaining humidity around the plants and reducing plant stress.

The use of screens needs to be carefully managed to make sure that plants remain actively growing.

Shade screens

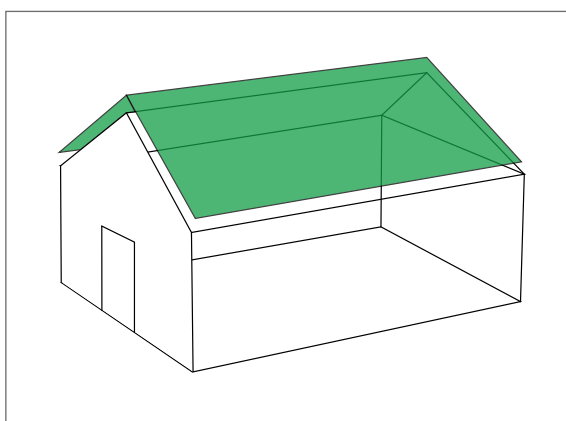
Shade cloth provides some of the functions of thermal screens. Under extreme heat conditions, shading reduces the amount of incoming radiation. This in turn reduces the heat load in the greenhouse and assists in maintaining humidity around the plants and reducing plant stress. The use of shade cloth for cooling is most effective when the material is used outside (above) the greenhouse.

If shade screens are used, pale coloured materials should be selected as these uniformly reflect solar radiation and do not absorb as much heat themselves as darker materials. A range of products offer shading from 30% up to almost total blackout.

Whitewash paints are another shading option that can be applied to reduce the amount of radiation entering the greenhouse. Whitewash is a lime wash or diluted paint applied to the outside of the greenhouse covering. It reduces the amount of solar radiation entering the greenhouse and therefore reduces temperature. The main disadvantage of this type of screen is that it is applied seasonally, such as late winter or early summer and consequently can not be readily adjusted for changing conditions from day to day or during a day. This results in reduced light levels even when temperature reduction is not needed. The end effect can be quite significant reductions in light levels and consequently yield. There are whitewash products available which become transparent when wet to allow more light in during rain periods. During warm overcast conditions, these products can be hosed down to increase light transmission.



Use of both thermal and shade screens.



Shade cloth provides some of the functions of thermal screens.

Insect screens

Insect screens or meshes are used to exclude flying and wind-borne pests from the greenhouse.

The main disadvantage of insect screens is that they restrict airflow. This can have a significant impact on venting capacity of a structure. The size of the mesh hole is the key characteristic that determines whether it can prevent a pest from getting into the structure. However, the finer the screen, the smaller the mesh hole size, the less air flows through it.

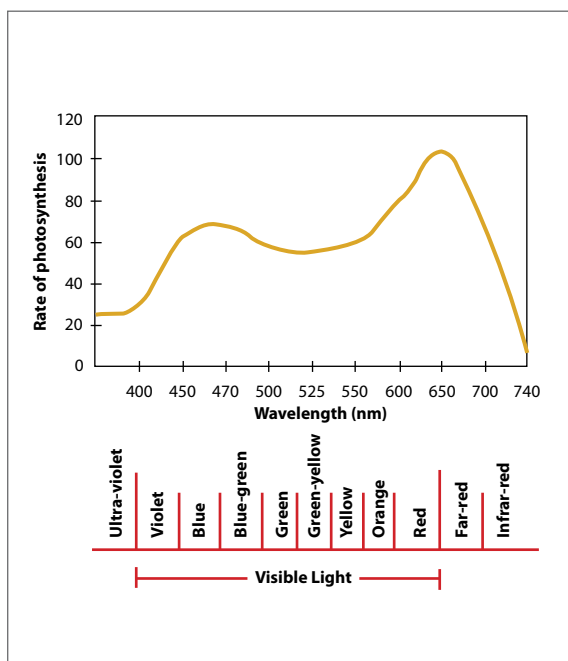
Insect screens, also have an impact on light transmission, particularly when they become dirty over time.

Light

Light may be measured in terms of its intensity (lux) or the number of photons reaching a surface (photon flux density).

In horticulture, the number of photons reaching a surface is more important. Photons are basically packets of energy making up a stream of light. The number of photons trapped by a leaf determines the effectiveness of photosynthesis and therefore the amount of plant growth.

The part of the spectrum that plants use is called photosynthetically active radiation (PAR) and relates to light in the 400 to 700 nanometer wavelength which is almost the same as visible light but not quite. It is measured in units of $\mu\text{mol}/\text{m}^2/\text{s}$ and describes the photon flux density, that is, the number of packets of energy which reach a (leaf) surface. PAR is approximately 42% of total light.



The rate of photosynthesis peaks in most plants around 450 nm (blue light) and 650 nm (red light).

Light transmission

The amount of light entering a greenhouse is influenced by:

- orientation of the structure
- materials used in construction and covers
- shape of the roof.

The greenhouse should be positioned north-south to provide more uniform light and reduce the shading effect of the support structure. The support structure must also be minimised to avoid shading. Metals make good structural material because of their strength which means narrower trusses and purlins can be used. A typical greenhouse frame can reduce light transmission by more than 10%. The type of covering material also influences the level of light in the greenhouse.

Finally, the shape of the roof will impact on how much light enters the greenhouse. For example, a flat roof will limit the amount of light because of reflection while a curved roof provides the greatest annual light transmission.

Quality of light

A balance of light across the PAR range is considered preferable. However there is increasing research being conducted in the area of light spectrum modification for improved plant growth, facilitated by the rapid growth and promotion of LEDs in recent years that enable almost infinite fine tuning of the light spectrum reaching a crop.

Diffuse light is better than direct light because it reaches the lower parts of the canopy (less shadowing) and does not cause sunburn. Irrespective of whether the light is direct or diffuse, it must be of sufficient intensity (lux).

The selected covering material may also increase the amount of diffuse light. A textured surface on glass, for example, can increase the proportion of diffuse light without significantly reducing the total level of light transmitted.

Coloured films

The colour of plastic films affects the total level of light entering the greenhouse.

A clear film transmits the most amount of light. Blue and green coloured plastics transmit a lot of the light in the blue to blue-green wavelengths, but cut out much of the light in the red wavelengths. From the diagram above looking at PAR, the red light is the most efficient waveband for plant growth. A blue plastic is likely to produce a slower growing, shorter, tougher plant.

Also of interest is that plants use far-red light as a way of determining how much competition there is for light. This is because green surfaces, such as leaves from other plants, reflect a lot of far-red light. If the plant perceives a lot of competition, it puts less energy into growing roots and more into growing tall, quickly.

A white plastic film reduces the total amount of light transmitted by as much as 20%, but the light spectrum entering the greenhouse remains similar to the natural light spectrum.

In recent years, horticultural LED lights have become available. These enable an almost infinite adjustment of the light spectrum in a crop, rendering basic coloured films obsolete.

Light intensity

Plants have an optimal intensity of light. This is the point at which the process of photosynthesis is maximised and plant growth is greatest. If the level of light is less, growth is reduced. The point where an increase in light intensity will not increase photosynthesis any more is called light saturation.

In the greenhouse

At normal growing temperatures, cucumbers require at least 250 $\mu\text{mol}/\text{m}^2/\text{s}$ (~55 PAR Watts/ m^2) of photosynthetically active radiation (PAR). Approximately 450 $\mu\text{mol}/\text{m}^2/\text{s}$ (100 PAR Watts/ m^2) is thought to be close to the optimum at 25°C. Below this level, productivity declines. The amount of light in the greenhouse should be maximised wherever possible because low light conditions slow growth and increase the cost of production. Light is increased by minimising objects above the plants including frames, pipes, lights and other equipment. In general, the management of heat is the only reason for reducing incoming light levels.

The health of a cucumber plant and its yield is related to the average daily light integral (DLI). The DLI is the total amount of PAR received in a 24-hour period. Assuming a 12-hour day, the optimal PAR range equates to an approximate daily light integral (DLI) of 2.4 – 6.5 $\text{MJ}/\text{m}^2/\text{day}$.

Assuming light transmission into a greenhouse is 50%, an outside daily light integral of approximately 5 – 13 $\text{MJ}/\text{m}^2/\text{day}$ is needed to provide required light conditions for cucumbers.

On average, the approximate minimum DLI needed by a cucumber plant for vegetative growth is considered to be 4 $\text{MJ}/\text{m}^2/\text{day}$. Again assuming 50% transmission, growing cucumbers requires an outside daily light integral of approximately 8 $\text{MJ}/\text{m}^2/\text{day}$.

The following table provides the average winter (low) DLI for a few production centres in Australia.

Table 10. Average winter Daily Light Integrals

Cucumber production area	Average winter Daily Light Integral (DLI) ($\text{MJ}/\text{m}^2/\text{day}$)
Adelaide	9.3
Sydney	10.5
Coffs Harbour	12.0
Gatton	13.2
Carnarvon	14.8

Excess light

Too much direct light can damage plants and/or fruit, particularly at low temperatures. Diffused light is preferable. Usually light transmission is only reduced as a way of managing heat. The level of radiation entering a greenhouse can be efficiently managed with retractable screens. In some regions, semipermanent screens or whitewash can be used during summer provided long periods of cloudy, low light conditions are not normally experienced.

Supplementary lighting

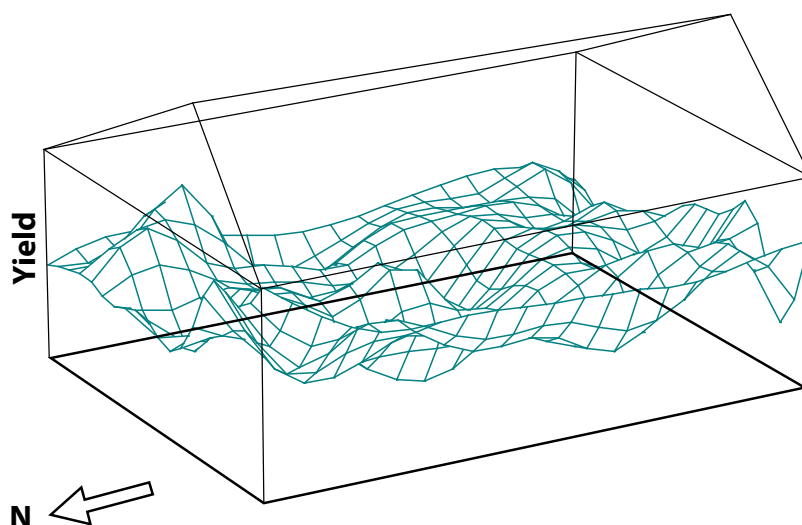
Supplementary lighting, though increasingly used overseas, is not considered economical for producing cucumbers in Australia. However, supplementary light may be used to improve seedling uniformity during propagation.

Uniformity in the greenhouse

Uniformity in the greenhouse is a basic requirement for achieving a good, high yielding uniform crop at the lowest cost. Uniformity increases productivity, labour and resource efficiency and cucumber quality.

One of the main areas of variation in a greenhouse is the irrigation system. A high distribution uniformity (page 95) is critical. Temperature and humidity can also vary significantly in the greenhouse and affect crop growth and production. In some situations, carbon dioxide levels become depleted and affect crop growth. Three key areas need addressing to make sure the greenhouse environment is as uniform as possible.

Uniformity in the greenhouse is a basic aim for achieving a good high yielding uniform crop



Benchmarking the crop in rows and sections of the greenhouse identifies areas of higher and lower yields and is a useful as a management tool. Problems are easily found and fixed.

1. Ventilation

Adequate ventilation is necessary to avoid the build-up of excess heat, humidity and depletion of carbon dioxide. Both passive (using vents) and active (using fans) ventilation should be capable of completely exchanging the air in the greenhouse at least once every minute. It is better to have more venting capacity than you use, rather than not enough.

Roof ventilation is also better than side wall ventilation. Vents in the walls of a greenhouse are limited in their capacity to provide an even environment. While they are very effective at exchanging air in the first couple of rows of the crop, the crop itself acts as a windbreak. This results in very little air movement towards the middle of the crop.

2. Air circulation

Moving and mixing of air throughout the greenhouse evens out temperature and humidity differences. Without sufficient air circulation, pockets of hot and cold air can occur. Humidity also builds up excessively around the plants. Side vents are limited in their capacity to fully mix the air in a greenhouse (a factor of the span width of the greenhouse). Roof ventilation circulates air well when in use. Fans improve air circulation and reduce uneven growing conditions.

3. Heating

Heating is relatively expensive and needs to be efficient. A heating system must distribute heat evenly throughout the crop.

Parts of the greenhouse will be hotter or colder. The northern end and western side of a structure tend to be hotter. The southern end is colder. The northern end also has less shading. Screens can be used to reduce extremes and improve uniformity.

The diagram above is a snapshot showing the level of harvested fruit over a 2-week period mid-crop at different points of a greenhouse. This type of information can give an indication of uniformity in the greenhouse and identify problems. The greater yield gained at the northern end is a factor of higher light levels and day time temperatures. This diagram highlights the impact of site and greenhouse design on crop uniformity.



HYDROPONIC SYSTEMS AND TECHNOLOGY

Hydroponics relies on the supply of nutrients in water to the root zone. Plants grow directly in the nutrient solution or in a non-soil substrate.

Hydroponic production uses water and fertiliser more efficiently than equivalent soil based production systems. It also (potentially) excludes soil-borne plant pathogens. However, hydroponic systems must be tightly controlled to optimise crop growth and productivity.

THIS SECTION COVERS

- Basic principles of hydroponics
- Hydroponic systems
- Irrigation systems
- Irrigation distribution uniformity
- Substrates

Hydroponic systems

There are three broad categories of hydroponic (soilless) production systems – water culture, substrate culture and air culture. These are either recirculated (closed) or flow-through (open).

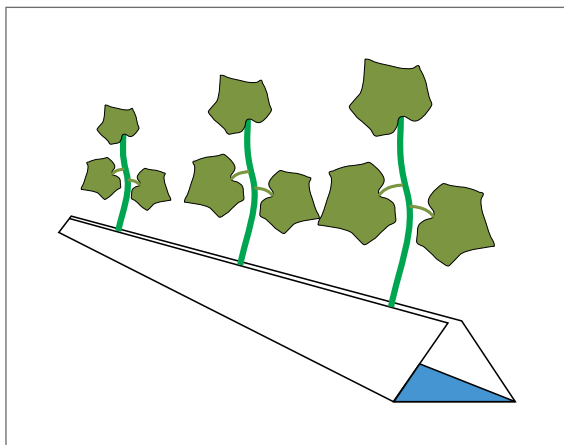
The most common hydroponic system used for commercial production of cucumbers is flow-through substrate culture. Some growers have had reasonable success with water culture. There is an increasing trend towards recirculated systems for both economic and environmental reasons.

Water culture

In this type of system, the plant roots grow directly in nutrient solution. The most commonly used form of this system is nutrient film technique (NFT). Nutrient solution flows down a channel in which the plant sits. Successful crops require higher management skills. Root diseases such as *Pythium* and *Rhizoctonia* can spread quickly if they establish in NFT systems.

Water culture systems, such as NFT, must be carefully managed to maintain sufficient dissolved oxygen levels. Cucumber roots have a greater oxygen requirement when compared with many other crops and can become stressed if levels of dissolved oxygen are not maintained. Continuous aeration of the nutrient solution and avoiding high solution temperatures improve dissolved oxygen levels. For example, at 20°C, only about 9 mg of oxygen is held per litre of water. As the temperature rises to 30°C, the amount of oxygen drops by up to 17% to just 7.5 mg/L. Studies have shown that a cucumber plant may use up to 1.3 mg of oxygen per hour per gram of root mass (dry matter).

Other systems include deep flow and floating tray.



Cucumbers in nutrient film technique.

Substrate culture

Substrate culture refers to hydroponic systems that use a non-soil growing substrate. The plant roots grow through the medium and nutrient solution is typically provided by dripper, microspray or flood and drain.

There are numerous substrates available including sand, gravel, perlite, vermiculite, expanded clay pellets, coco peat, versarock, pumice, scoria, expanded plastics, pine bark, sawdust and rockwool – or combinations of these.

A substrate, while providing support for the plant, also provides a balance of moisture and air in the root zone. Choosing between substrates is often a case of cost, durability, availability, climate, crop and container. The type of substrate impacts directly on the level of control achieved. For optimal control, an inert, inorganic substrate is preferable. Organic substrates reduce the level of control that can be achieved.

Air culture

Air culture (aeroponics) is a system whereby plant roots are kept moist with a mist of nutrient solution. A substrate is not used as such. A young plant is propagated in a small container of substrate, but the roots grow out into the moist air.

Recirculated systems

Known as closed systems, the nutrient solution in a recirculated system is reused several times. Water and air culture systems are almost always recirculated. Substrate culture systems may also be recirculated.

Recirculation involves the nutrient solution returning from the crop straight back to the supply tank from which the crop is irrigated and the nutrients are dosed into.

Recirculated systems must be carefully managed to avoid nutrient imbalances, spreading root diseases and to maintain sufficient dissolved oxygen levels.

Recirculating systems require careful management of the EC and pH. The actual nutrient uptake by plants can vary over the day length (e.g. potassium can be taken up by a plant within a few hours), but the overall nutrient ratios need constant maintenance to avoid nutrient imbalances.



Cucumbers in substrate culture – perlite.



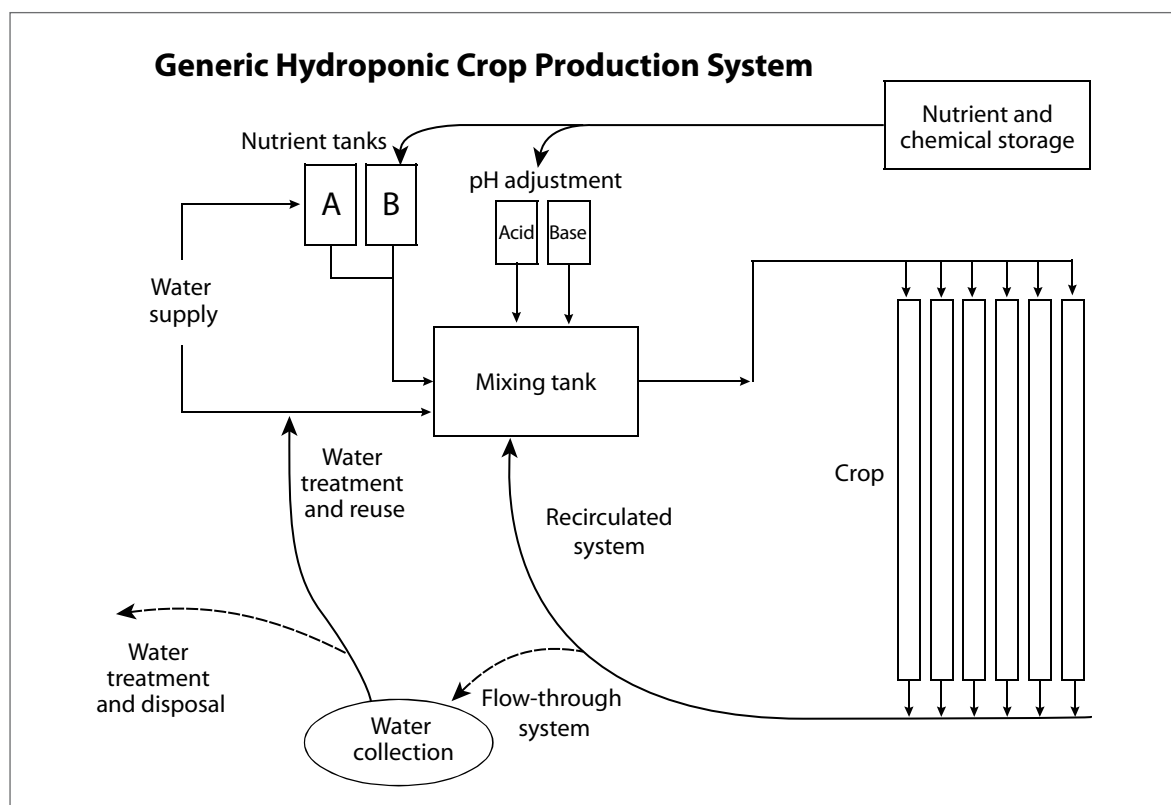
Cucumbers in substrate culture – coco peat.



Cucumbers in substrate culture – sawdust.



Cucumbers in substrate culture – rockwool.



Flow-through systems

In a flow-through system, any nutrient solution supplied to the plants but not used, drains away rather than being recirculated through the system. These types of systems, almost always substrate culture systems, are managed to an EC target run-off level.

The run-off or 'waste water' is collected, treated and reused, or disposed of as waste.

The irrigation system

Irrigation is the practice of supplying water or nutrient solution to the cucumber crop to replace the amount that is used by the plant.

The three key requirements that any hydroponic irrigation system should provide are:

- the right volume of water to the crop and the capacity to do this during periods of peak demand. Peak demand may be up to 3 litres per square metre per hour.
- water uniformly to the crop. How evenly water is distributed can be measured (Distribution Uniformity, DU%) using the methodology described later in this chapter. The distribution uniformity should be at least 90% for drip.
- a water application rate readily absorbed by the substrate.

Other important considerations for an irrigation system include:

- the degree of automation that complements management practices
- the level and frequency of maintenance
- collecting irrigation run-off
- treating runoff water for re-use or disposal
- the flexibility of irrigating sections separately or differently (for example, minimum runtimes required and number of starts per day)
- complying with regulatory requirements such as backflow prevention and pipe materials.

Growers often develop their own specific set ups for growing cucumbers. The set up outlined in this section is a simple workable drip irrigation system using substrate culture. It provides a basic guideline for laying out the production system.

Plants are positioned in rows. There are a range of different containers and substrate that can be used. Avoid using different substrate or different sized containers in one irrigation block. The frequency and volume of irrigation needs to be managed for the container and the water holding capacity of the substrate as well as the growth stage of the plants.

The water holding capacity of the substrate can be easily measured by weighing a pot or bag (with media) on a set of scales, then saturating the pot and weighing again once draining has stopped. The difference in weight is the water holding capacity of the substrate (note that 1 litre of water weighs 1 kilogram).

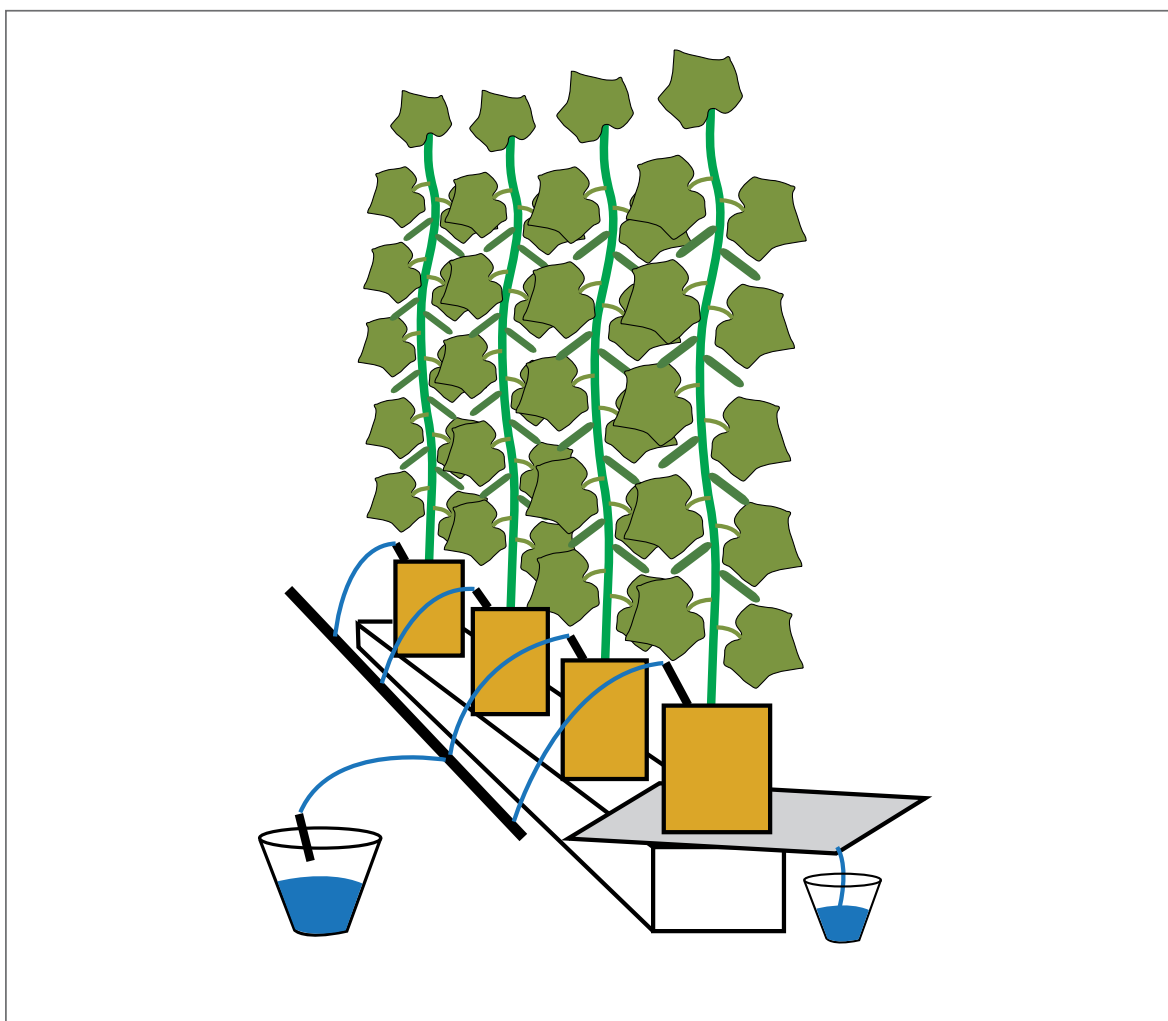
A main or primary irrigation line runs from the nutrient dosing area to the greenhouse. This main line feeds secondary irrigation lines (for example, 19 mm diameter poly pipe) which extend down each row of plants.

Taking off from the secondary line in each row is a single spaghetti line (1.5 mm) per plant with an emitter (dripper). Pressure compensating emitters improve irrigation uniformity. It is important to prevent cucumber plant roots from growing into the dripper as a blockage can result. Emitters on small stakes or risers can be used to hold the water outlet above the substrate surface.

The lengths of spaghetti line are about 500 mm – long enough to reach into the pot/bag comfortably. All lines should be the same length to prevent unequal water supply. There are irrigation takeoffs which provide multiple splits from the secondary line to spaghetti lines. A 4-way split is a popular choice. The design you use will depend upon preference, availability and price.

Drainage water should be collected in a channel or drain and removed from the greenhouse. Avoid stagnant water and algal growth as these encourage pests and disease.

Always include one or more additional emitters (without plants) in each irrigation section. These are used as part of an important monitoring system to measure feed volume, run-off volume, drain and feed EC and drain and feed pH.



Always include an extra emitter to monitor the system.

Filtration

Drip emitters have very small openings for the discharge of water and are easily clogged or blocked. Clogged drippers will not function properly and will not deliver the amount of water you expect to the crop.

To avoid the problems of clogging you should filter the water before it reaches the dripper. The degree of filtration will depend on the quality of the water used. Consider filtration even if your water source is from the town water mains.

When selecting a filtering method, identifying potential clogging hazards is the first step.

Potential clogging hazards include:

- suspended solids such as sand, silt and organic matter (including algae)
- chemical material including the precipitates of iron and manganese
- biological material such as iron bacteria.

Commercially available filters include mesh (screen), media (sand), disc filters and centrifugal separators. Before you buy filtration equipment, have your water analysed to identify the potential clogging hazards.

Your water analysis and advice from your filter supplier will help you select the most appropriate filter for your situation. See Table 11.

Cleaning filters

While operating the filter will become clogged and an increased pressure loss will occur. The more clogged the filter, the higher the pressure loss, and the lower the exit pressure. To ensure satisfactory operation of the filter and maintain a filter exit pressure matching the operating pressure required by the irrigation system, the filter must be cleaned regularly.

When to clean filters

Several different approaches determine when to clean filters:

Time- the filter is checked and cleaned daily, weekly or monthly.

Pressure differential- some filter manufacturers recommend you clean the filter by specifying a filter pressure differential (the difference between the filter entry pressure and exit pressure). If no recommendations exist, clean your filter before the pressure differential reaches 70 kPa.

Flow volume- filter cleaning is undertaken once a certain volume of water is used.

Whichever method you use, filter systems should be inspected at least once per year, if not at the change of seasons.

Table 11. A general guide to the type of filter to be selected under varying water qualities
(✓✓✓ indicates first choice; ✓✓ second choice; ✓ third choice)

Clogging hazard	Recommended filter type			
SOIL PARTICLES	Centrifugal Separator	Media Filter	Disc Filter	Mesh Filter
Low: ≤ 50 mg/L	✓✓✓			✓
High: >50 mg/L	✓✓✓	✓✓		✓
SUSPENDED SOLIDS				
Low: ≤ 50 mg/L		✓✓✓	✓✓	✓
High: >50 mg/L		✓✓✓	✓✓	
ALGAE				
Low: ≤ 50 mg/L			✓✓✓	✓
High: >50 mg/L		✓✓✓	✓✓	✓
CHEMICAL PRECIPITATES				
Low: ≤ 50 mg/L		✓✓	✓✓✓	✓✓✓
High: >50 mg/L		✓✓✓	✓✓	✓✓

Choosing a dripper

Drippers are available with on-line emitters (outside the pipe) or in-line emitters (inside the pipe). Within these two categories they can also be pressure or non-pressure compensating (regulating), have self-flushing characteristics or be designed to be non-draining (i.e. the emitter will not allow discharge below a certain pressure). Table 12 may help you determine the dripper that best fits your irrigation management.

Drippers are generally specified according to their discharge rate, for example 4 litres per hour, 8 litres per hour or 12 litres per hour. This discharge rate is a nominal rate at a particular operating pressure, generally 100 kPa. If the pressure varies from the nominated pressure the dripper discharge will also vary, unless the emitter is pressure compensating.

Consequently, if you want good control over the amount of water you are giving your plants you must monitor and adjust the pressure in the irrigation laterals.

Pressure monitoring should be done at the end and the beginning of laterals. As shown in figures below, pressure monitoring is simple and quick. Adjusting the pressure is also simple and is generally achieved by adjusting the opening of irrigation control valves.



Monitoring pressure at the beginning of a lateral and at the end of a lateral.

Table 12. Types of drip emitters

Emitter Type	Description	Comments
On-Line Dripper	These emitters generally have a barbed inlet port inserted into poly pipe after it has been laid out in the greenhouse.	Often used when water quality could clog drippers because they are easily removed for cleaning or replacement. Emitters can be pressure or non-pressure compensating.
In-Line Dripper	These drippers have an emitter inserted or welded inside the pipe during manufacture. Various dripper spacings are available.	There is no external dripper to be damaged by pickers or machinery. Emitters can be pressure or non-pressure compensating.
Pressure Compensating Dripper	Pressure compensating drippers are designed to provide the same discharge over a wide range of operating pressures. However, they cannot increase the discharge if the pressure is too low but can control the discharge at high pressures.	Generally more expensive than other drippers. Performs well in long rows where it otherwise would be difficult to maintain constant discharge volumes over the length of the row. Continual use of chlorine at high concentrations to clean driplines may harden the rubber diaphragm that controls discharges thus affecting the emitters' performance over time.
Non-Pressure Compensating Dripper	The discharge from these emitters varies with varying operating pressures. However, a well-designed and operated system generally has variations less than $\pm 10\%$	For longer irrigation laterals a larger diameter pipe is often required.
Self-Flushing Dripper	Self-flushing drippers can reduce clogging problems from bacterial growth in irrigation laterals. Good filtration is still required.	Problems can arise if partially flushed matter prevents valves from closing properly.
Non-Draining Drippers	Designed to stop discharging when the irrigation system shuts down.	This feature is particularly valuable when precision irrigation is required.

Dripper discharge

Drip emitter discharge rates are expressed in litres per hour. The current commercially available fixed discharge dripper rates range from about 1 to 8 litres per hour for in-line drippers and from about 1 to 12 litres per hour for on-line drippers. Manifolds for on-line drippers are available that split the discharge rate in 4 or 8 streams.

The application rate from an emitter is matched to the substrate's ability to accept the water and allow it to spread. Application rates that are too high will result in water channelling through the substrate and out of the pot/bag without wetting all the substrate. At the same time, valuable nutrients are flushed. Poor lateral spread of water and nutrient loss adversely affect plant growth and crop yield.

There is not a lot of information available at the moment on suitable application rates for substrates. Research is currently being undertaken to better define substrate characteristics such as water holding capacities and suitable application rates. However, studies of nursery media have indicated that suitable application rates for commercially available potting mixes were up to about 20 mm per hour.

Until such time as the current research is complete, it may be appropriate to adopt application rates below 20 mm per hour for optimum lateral spread of water for greenhouse substrate. Table 13 will help you select an appropriate dripper.

Table 13. Dripper discharge rates

container size diameter (mm)	WITH NO MANIFOLD					WITH 4-WAY MANIFOLD				
	emitter discharge (litres per hour)					emitter discharge (litres per hour)				
	2	3	4	8	12	0.5	0.75	1	2	3
	Application Rates (mm per hour)					Application Rates (mm per hour)				
100	255	◇	◇	◇	◇	64	95	127	255	◇
150	113	170	226	◇	◇	28	42	57	113	170
200	64	95	127	255	◇	16	24	32	64	95
250	41	61	81	163	244	10	15	20	41	61
300	28	42	57	113	170	7	11	14	28	42
330	23	35	47	93	140	6	9	12	23	35

Irrigation distribution uniformity

Irrigation distribution uniformity refers to how well water is distributed through the system. It is basically a way of seeing if your hydroponic system is working properly. It is measured as a percentage and given the abbreviation DU%. The higher the distribution uniformity, the better the system is working.

To make sure that your crop grows evenly, every plant must get the right amount of water. If one section of your greenhouse gets more water than another section when you irrigate, some plants will either get too much or not enough water. This will reduce crop yield. It can also make pest or disease problems worse and affect crop quality.

Knowing exactly how much water is being given to each plant when the irrigation system is in operation is essential to using irrigation as a management tool to control plant balance.

Always check the uniformity of irrigation when a new irrigation system is installed, when repairs or changes have been made to any part of the irrigation system and before each crop. Checking the irrigation system before each crop ensures that water is being delivered effectively, efficiently and uniformly to all plants. This can save a lot of money and time by minimising plant losses and poor starts to crops.

Checking DU%

Water pressure in the pipes affects distribution uniformity and emitters placed on a sloping ground will generally always provide more water and nutrients to the lower levels. Blocked or worn out emitters can affect the whole hydroponic system by changing the amount of water coming out of them.

To check if your hydroponic system is working properly and giving the same amount of water out of every emitter, you need to:

1. work out the average water application rate for all the sampled emitters
2. work out the average water application rate for the lowest quarter of the sampled emitters, and
3. calculate the distribution uniformity (DU%).

Each section of your hydroponic system needs separate checking. Samples of water are collected from different areas of the hydroponic system. If there are any parts or areas of your hydroponic

system where you think there is a problem, take extra samples from there.

How do you work out the average water application rate?

The application rate is the amount of water (in litres) that each emitter puts out in one hour.

1. Choose the locations where you take samples. Select four emitters from each lateral pipe, that is, each crop row. Take one sample from an emitter near the beginning of the lateral pipe and one sample from an emitter near the end of the lateral. The other two samples should be from emitters somewhere along the row, for example, one third and two thirds of the distance along the row. If you have seven (7) rows in the greenhouse, you will end up collecting 28 samples.
2. Place a cup or small container under each emitter that you will sample.
3. Turn on the irrigation system for 60 seconds then turn off the water. Note the amount of time it takes to get all the emitters working at once from start up.
4. Collect each sample and using a measuring cylinder, measure the amount of water (in millilitres) in the cup. Record the amount of water for each emitter on a data sheet.
5. Calculate the amount of water that comes out of each emitter in litres per hour (L/hr). Record these numbers on a data sheet.

$$\text{Amount of water per hour (L/hr)} \\ = \text{Water collected (ml)} \times 60/1000$$

6. Add up the numbers for all the emitters. Record this as the total.
7. Now divide this total volume by the number of emitters sampled. Record this as the average.

How do you work out the average water application rate for the lowest 25% of emitters?

1. Rank the emitters in order of how much water they put out.
2. Mark which ones make up the lowest quarter (25%) of emitters.
3. Now, add up the numbers for the lowest 25% of the emitters. Record this as the total.
4. Divide this total for the lowest 25% by the number of emitters. Record this as the average for the lowest 25%.

How do you calculate the distribution uniformity percentage?

Divide the average application rate of the lowest 25% of the emitters by the average application rate of all the emitters. Multiply this number by 100.

How can you make the distribution uniformity better?

There are a few things you can do to make the distribution uniformity better:

- Have a properly designed irrigation system matched to your water supply.
- Flush hoses and laterals once a week. Flush sub and main irrigation lines every month.
- Keep your filters clean. Make sure they are in good condition.
- Use cleaning substances (such as an acid flush) to remove bacterial and mineral blockages in the system between crops.
- Avoid high and low areas in the hydroponic system.
- Control the water pressure between emitters.
- Make sure the pumping capacity of the pump is correct for the size of the irrigation section.

$$DU (\%) = \frac{\text{Average application rate of the lowest 25\% of sampled emitters}}{\text{Average application rate of all sampled emitters}} \times 100$$

What is a good distribution uniformity percentage?

For a hydroponic system, you should aim to have a distribution uniformity (DU%) of 95 – 100%. You can compare the DU% for your hydroponic systems with the following values:

Excellent	90 – 100%	
Good	80 – 90%	(can be better, but is workable)
Okay	70 – 80%	(some plants may be getting too much or too little water)
No Good	< 70%	(the irrigation system needs to be fixed)

Example Data Sheet

Emitter number	Location	Water collected (ml in 60 seconds)	Application rate (L/hr)	Lowest 25% (28/4 = 7)
1	Greenhouse 1	17	1.02	
2	Greenhouse 1	14	0.84	4
3	Greenhouse 1	15	0.90	
4	Greenhouse 1	16	0.96	
5	Greenhouse 1	15	0.90	
6	Greenhouse 1	17	1.02	
7	Greenhouse 1	15	0.90	
8	Greenhouse 1	16	0.96	
9	Greenhouse 1	14	0.84	5
10	Greenhouse 1	17	1.02	
11	Greenhouse 1	17	1.02	
12	Greenhouse 1	15	0.90	
13	Greenhouse 1	15	0.90	
14	Greenhouse 1	16	0.96	
15	Greenhouse 1	14	0.84	6
16	Greenhouse 1	15	0.90	
17	Greenhouse 1	16	0.96	
18	Greenhouse 1	13	0.78	1
19	Greenhouse 1	15	0.90	
20	Greenhouse 1	14	0.84	7
21	Greenhouse 1	15	0.90	
22	Greenhouse 1	16	0.96	
23	Greenhouse 1	13	0.78	2
24	Greenhouse 1	17	1.02	
25	Greenhouse 1	15	0.90	
26	Greenhouse 1	16	0.96	
27	Greenhouse 1	14	0.84	3
28	Greenhouse 1	15	0.90	
TOTAL	All emitters		25.62	
Average	All emitters		0.915	
TOTAL	Lowest 25%		5.76	
Average	Lowest 25%		0.82	

$$\text{DU (\%)} = \frac{\text{Average application rate from lowest 25\% of emitters}}{\text{Average application rate from all emitters}} \times 100$$

$$\text{DU (\%)} = \frac{0.82}{0.915} \times 100$$

$$\text{DU (\%)} = \mathbf{89.62 \%}$$

Substrates

There is no soil in a hydroponic system, but some hydroponic systems use a non-soil growing substrate, also known as 'media'. Substrate culture is the most commonly used hydroponic system in Australia for cucumbers.

How well your crop performs is summed up by the physical and chemical properties of the substrate you are using. Plants need both air and water around their roots. Physical properties of substrate refer to the physical makeup of the substrate – how much air and water the substrate can hold and how well the substrate can support the plant. The chemical properties of a substrate refer to how nutrients are held and made available to the plant.

There are several key factors when choosing and using a hydroponic substrate. The uniformity of the material will affect how easy it is to manage the crop. The bulk density reflects the weight of the substrate and how easily plant roots grow through it. A light material is easier and cheaper to handle and transport. The water holding capacity and air filled porosity affect the way you will need to irrigate the crop. The pH and the cation exchange capacity (explained further on) impact on the way you apply nutrients to the crop. The rate at which a material decomposes or otherwise breaks down, affects all the other factors because the properties of the substrate will change.

Uniformity

How uniform the substrate is has a significant impact on crop production. If there are variations in the substrate in the greenhouse, it is difficult to manage the irrigation and nutrition of the crop. Variations over time occur, especially as organic substrates decompose and as roots fill air spaces. These changes affect the structure of the substrate and alter how well it performs and how it needs to be managed.

The following table (Table 14) shows how key properties of two types of substrate (sawdust and cocopeat) change during a cropping cycle. By the end of the crop, these substrates hold more water and less air. While both are still within acceptable ranges, these small changes can impact volume and frequency of irrigation, volume of root space and even the potential for disease.

Variation leads to suboptimal growing conditions and reduced productivity. One of the biggest disadvantages of many organic substrates is its potential variability. Every batch of substrate should be thoroughly mixed and tested for its physical and chemical properties. Most of the inorganic substrates used in hydroponics are typically uniform and make crop management much simpler.

Physical properties

All substrates have different characteristics. A substrate is made up of solid material and space. The space (called porosity) can be filled with air or water. A hydroponic substrate should have a total porosity of around 60 – 70% of total volume. The air-filled part of this should be at least 10%, but can be up to 30% of the total volume. This is the air-filled porosity (AFP) and is the volume of air in a substrate after it has been watered heavily and then allowed to drain. If the substrate is dense and there is not enough air space, the cucumber roots will not be properly aerated. If this happens, the roots become damaged and may die. The plant becomes inefficient at taking up nutrients which slows down growth and root diseases can rapidly take hold.

The water holding capacity (WHC), that is, the space filled by water, should be around 30 – 60% of the total volume. The air-filled porosity and the water holding capacity are characteristics of substrates which help you work out how often and how much water you need to give a crop. The air space and the available water mainly depend on the size and shapes of the particles in the substrate. A substrate with larger particles has bigger gaps between the particles. This means that there is more air space and

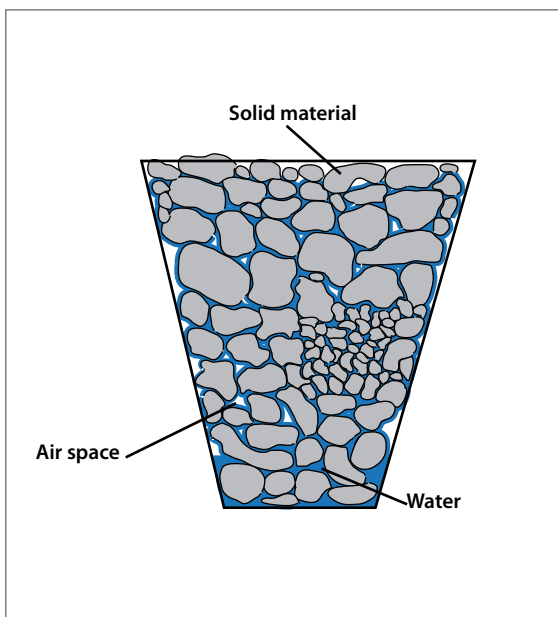
Table 14. Changes in the properties of growing substrates

Growing substrate	Water holding capacity (WHC)		Air filled porosity (AFP)	
	New substrate (Start of crop)	Used substrate (End of crop)	New substrate (Start of crop)	Used substrate (End of crop)
Sawdust	50.8%	61.1%	38.1%	37.5%
Cocopeat	66.75%	74.4%	27.8%	25.7%

the material will drain more readily. Substrates that have smaller particles will have smaller gaps and less porosity.





In addition to particle size, the structure of the particles (shape and surface area) also affects air space and water holding capacity. For example, a material with a rough surface has a greater surface area and therefore more potential to form gaps for air and hold water compared to a material that has a smooth surface.

It is also important to note that the height and width of the container you use will affect the air space and amount of available water. The overall total porosity is not affected by the container, but the proportion of air and water is affected. For example, a tall container will have less water and more air resulting in drier substrate towards the top of the container compared with a shallower, wider container of the same volume, even when the same substrate is used. The amount of solid material stays the same.



Size of particles in hydroponic substrates affects the amount of air and water held by the material.

Table 15. Effect of container height on substrate porosity

Height of container/bag	Proportion of air (white), water (blue) and solid			
	Air	Water	Solid	
2.5 cm	3%	84%	13%	
5 cm	8%	79%	13%	
10 cm	13%	74%	13%	
15 cm	20%	67%	13%	

Even wetting

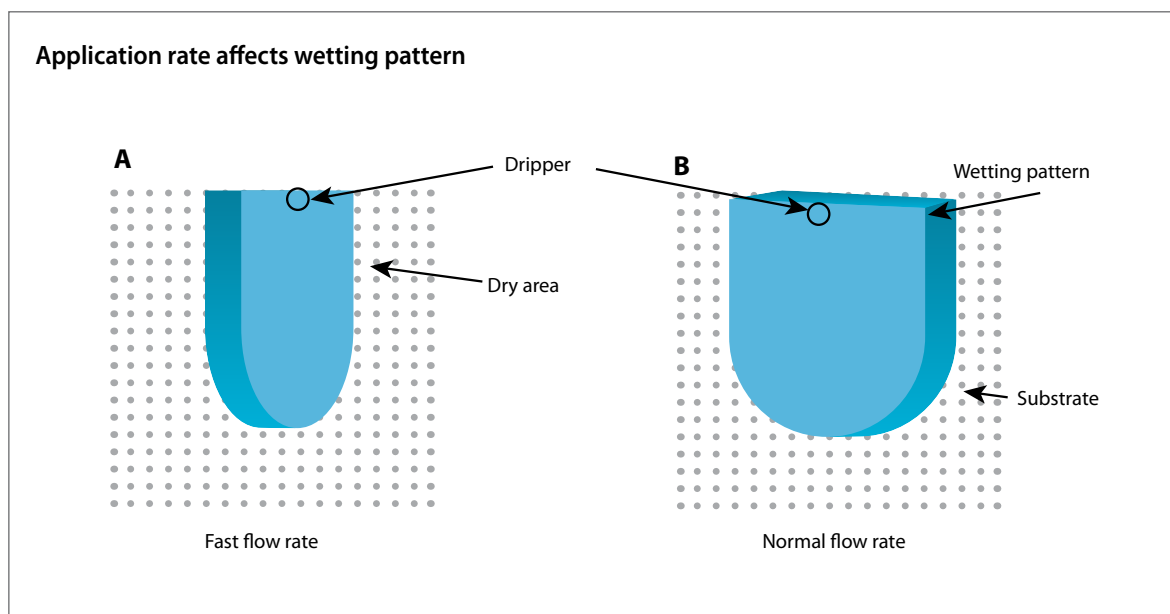
Another key consideration is whether the substrate you are using wets up evenly. To maximise the production of your crop, irrigation must wet all the substrate with each application. The way you irrigate your crop needs to be appropriate for the type of substrate you are using. For example, if you are using a very high drainage substrate such as coarse perlite and if the application rate of nutrient solution is too fast, the nutrient solution will flow straight through the substrate. Dry areas around the edge of the container will result.

The illustration below shows two different wetting patterns in a coarse substrate. In Diagram 'A', the nutrient application rate is too fast for the substrate. The result is that the nutrient solution flows straight through and does not fully wet the substrate. In Diagram 'B', a slower application rate of nutrient solution results in the nutrient solution spreading out through the substrate. This gives a good wetting pattern.

Chemical properties

Hydroponic substrates do not supply the nutrients needed by the plant. Nutrients are added in controlled, balanced amounts. Some substrates used in hydroponics can interfere with nutrients and make them unavailable to the plant. Many organic materials tie up nutrients. Sawdust and cocopeat, for example, tie up as much as four times the amount of some trace elements such as copper and molybdenum, while materials like vermiculite release potassium. This can lead to nutritional problems if not correctly managed. The amount of nutrients added can be adjusted to compensate for the substrate.

Some substrates, such as fresh sawdust, compete with the plants for nitrogen. This may be overcome by composting of the substrate before use or supplying additional nitrogen.



For optimal production, irrigation needs to wet all the substrate each irrigation.

Cation exchange capacity (CEC)

Nutrients available for the plant are either stuck to the substrate particles (at exchange sites) or dissolved in water in the root zone. The capacity for a substrate to hold nutrients ready for the plant is called its '**cation exchange capacity**' or **CEC**.

The CEC of a substrate is a measurement of how readily nutrients are held and released for the plant's growth. Different hydroponic substrates have different cation exchange capacities. Materials with a high CEC have a greater nutrient buffering effect which reduces the risk of over fertilising. However, a high CEC takes away the grower's capacity to precisely manage nutrition thus reducing the control a grower has to manipulate the plant. Substrates which have a low CEC (known as 'inert') give growers greater flexibility and control over plant nutrition.

A high CEC will result in nutrients held within the substrate and having less nutrient flushed out of the substrate.

pH

The optimum pH of a soil, substrate or solution for plants to extract available nutrients is generally 6.3 to 6.5. See page 112 for greater detail on pH.

Capacity to buffer pH

Buffering capacity is the ability of a material to not change pH rapidly, this is also related to the CEC of a substrate. Substrates with a high buffering capacity need a greater amount of acid or base to alter the pH than substrates with a low buffering capacity. Since organic matter has a high pH buffering capacity (and CEC), organic substrates like composted green waste (recycled organics) will have a higher pH buffering capacity than inorganic substrates such as perlite.

Summary of types of substrates

A wide range of substrates can be used in hydroponic systems. The chosen substrate has a significant influence on how the system is managed. Each type of substrate has advantages and disadvantages.

Inorganic (mineral) substrates

Rockwool

Rockwool is a fibrous material made from spinning molten rock. It is generally sold in plastic wrapped slabs. Rockwool has a very high water holding capacity and high air porosity. It has no cation exchange capacity. It tends to be slightly alkaline.

Perlite

Perlite is a light material derived from volcanic rock. It has reasonable water holding capacity and high air porosity. Perlite typically has a suitable pH, tending to be neutral or slightly acidic but has a low pH buffering capacity and a low cation exchange capacity. It holds its structure for quite some time, but poor handling will break particles and reduce their sizes. This can make the product less suitable.

Vermiculite

Vermiculite is a very light material derived from mica. It has good water holding capacity and air porosity. Vermiculite typically has a suitable pH and has a high pH buffering capacity. It has a high cation exchange capacity. It releases potassium, calcium and magnesium. It will lose its structure over time and become less suitable. It is generally used in seedling mixes or mixed with perlite.

Scoria

Scoria has some good properties for use in hydroponics. It is a porous volcanic rock with good water holding capacity and drainage. Scoria is heavy and difficult to handle. It will break over time with handling.

Gravel

Gravel can be used in hydroponics. It has a low water holding capacity and very high drainage and air porosity. Gravel is heavy and can be difficult to manage.

Sand

Sand is a useful substrate, but is heavy. Sand has reasonable water holding capacity and good drainage. It generally has a low CEC. Coarse river sand derived from granite should be used. Calcareous sand which is highly alkaline and beach sand which has a high level of salt are not suitable for hydroponics unless they are appropriately washed.

Expanded clay pellets

Expanded clay has a low air filled porosity and a high water holding capacity.

Sponge foams

Sponge foams typically have very good properties for hydroponics. New products on the market are specifically designed for hydroponics and offer excellent characteristics.

Organic substrates

Sawdust and wood shavings

Sawdust is used extensively in Australia. It is relatively cheap, but not always uniform. If it is not composted before use, decomposition during the cropping cycle will use and deplete nitrogen from the root zone. This needs to be managed. It has a moderate cation exchange capacity. Sawdust can become hydrophobic (repels water) if allowed to dry out. Generally, sawdust has a high water holding capacity and subsequently may have poor aeration, especially at the bottom of the container.

Cocopeat (coir)

Cocopeat is a very stable substrate and supplies are uniform. This substrate has become quite popular. It contains much more lignin (tough fibre) than other organic growing substrates such as sawdust. This stability means that it does not decompose as quickly. Its structure means it has very good water holding capacity and air porosity. It is slightly acidic with a pH between 5.7 and 6.5. Cocopeat has a high CEC.

Green waste (recycled organics) composts and bark

Green waste composts are a commonly used substrate in some regions due to their relatively low cost. These materials are typically middle-of-the-range for most characteristics but uniformity within and between batches can vary. This makes it difficult to know what irrigation schedule and nutrient formulation is needed without thorough testing.

Peat (normally used in blends with other materials)

Peat moss has a very high water holding capacity but can become hydrophobic (repels water) if allowed to dry out. It can have fairly poor aeration and is usually used as part of a mix with sand or perlite. It has a high CEC and low pH. It is sterile on delivery.

Other substrate materials such as zeolite or dimotacaeous earth have also been used in experimental hydroponics.

The substrate you elect to use will depend on several factors. Cost is often a primary consideration but is often misleading. A slightly more expensive substrate that is more uniform, free from pathogens and has better physical and chemical properties will generally produce a better crop, be easier to manage and cheaper overall.

A desirable hydroponic substrate should have:

- high uniformity (between batches and consistent over time)
- good water holding capacity
- good aeration and drainage
- known cation exchange capacity (in general, a low CEC for experienced growers)
- a stable structure (during the cropping period) – low decomposition rate
- no pathogens, weeds or salts
- suitable pH (5.5 – 6.5) and/or easily adjusted
- easy to handle and manage
- available locally
- capacity for pasteurisation (if wanting to reuse it) and
- be cost effective.

Table 16. Summary of general properties of common hydroponic substrates

General physical and chemical properties							
	Air Filled Porosity	Water Holding Capacity	Cation Exchange Capacity Meq/100g	pH	Uniformity	Bulk density (weight) g/cm	Decomposition rate (carbon to nitrogen)
Range							
Low (L)	<10%	< 30%	< 10	3 – 4.9	Low	< 0.25	< 1:200
Medium (M)	10 – 30%	30 – 60%	10 – 100	5 – 6.5	Medium	0.25 – 0.75	1:200 – 1:500
High (H)	> 30%	> 60%	> 100	6.6 – 8.5	High	> 0.75	> 1:500
Hydroponic substrate							
Sawdust	M	H	H	H	L	L	H
Bark/ composts	M	M	M	L	L	L	M
Peat moss	H	H	H	L	M	L	M
Cocopeat	M	H	M	M	H	L	L
Vermiculite	M	H	M	Variable	H	L	L
Perlite	H	H	L	M	H	L	L
Sand	M	L	L	Variable	M	H	L
Polystyrene foam	H	L	L	M	H	L	L
Rockwool	M	H	L	H	H	L	L



FEEDING THE CROP

The nutrients needed by a plant change during growth and fruiting cycles. For the beginner, it is possible to produce a satisfactory crop using a single nutrient recipe depending on the substrate used and provided the vegetative-generative balance is sufficiently managed. However, as more exact management is used to achieve higher yields and lower costs, the nutrient needs of a crop can be separated according to the stage of growth and plant health and performance.

Cucumbers are a medium feeding plant and perform well with an electrical conductivity (EC) drain range of 2.5 – 3.0 mS/cm (provided by an EC feed range of about 1.5 – 2.5 mS/cm in substrate culture). The actual EC used for your crop needs to be adjusted according to growing conditions and also plant balance. A pH range of about 5.6 – 5.8 should be used.

THIS SECTION INCLUDES

- Plant nutrition
- Monitoring plant nutrition
- The nutrient solution
- Electrical conductivity
- pH
- Nutrient formulae
- Volume and frequency of irrigation
- Using foliar fertilisers

Plant nutrition

Incorrect or imbalanced plant nutrition is often a bigger cause of low yields, and is potentially costlier to growers, than pests and diseases. This is because poor nutrition can go unnoticed. Pest and disease management strategies are a waste of resources if crop nutrition is not right. Once plant nutrient disorders become visual, crop yield and/or quality is reduced no matter what corrective action is taken. In hydroponic systems, the plant must be given all the nutrients it needs for prime crop growth and production. This means that as a grower you have much more control over how the plant grows. But, if too much or not enough of a nutrient is available, there will be problems with the plants.

What are nutrients?

Nutrients are **elements** that plants need to grow and function. Nutrients are supplied as soluble fertilisers. In hydroponics, most nutrients are supplied to the plant in water as a nutrient solution for root uptake.

There are 16 key nutrients generally considered essential for plant growth. These are listed below. Plants take carbon, hydrogen and oxygen from the air, but the other 13 nutrients need to be provided in the nutrient solution. If the plant has a large demand for a nutrient, it is called a **macronutrient**. If a plant only has need for a small amount, then it is called a **micronutrient** or trace element.

Some nutrients, such as Silicon and Nickel, plants may use but are not usually supplied in hydroponics. These are called non-essential nutrients.

Macronutrients

Carbon (C)

Carbon is used in all plant materials, taken from carbon dioxide in the air.

Oxygen (O)

Oxygen is used in **respiration**. The plant takes oxygen from the air and water. Roots also need oxygen.

Hydrogen (H)

Hydrogen is used in all plant materials, and is taken from the air and water. Hydrogen is also used by the plant to enable it to take up nutrients.

Nitrogen (N)

Nitrogen is mostly used for **vegetative growth** of leaves and stems. It is generally regarded as driving plant growth because its supply can often be limiting. It is also a key part of **proteins** made and used in the plant. A shortage of nitrogen reduces a plant's ability to trap and use energy through the process of photosynthesis. Internode elongation of the stems is due to too much nitrogen during that period of growth. A plant can take up nitrogen in two different forms. The preferred form of nitrogen is nitrate (NO_3^-). Plants can also use nitrogen in an ammonium form (NH_4^+).

Nitrogen is supplied in the nutrient solution. A number of fertilisers used in hydroponics supply nitrogen. Calcium nitrate and potassium nitrate are major fertilisers used in most hydroponic formulae. Ammonium nitrate and ammonium sulphate are used in small amounts to supply the ammonium form of nitrogen. Magnesium nitrate and di-ammonium phosphate (DAP) and mono-ammonium phosphate (MAP) can be used in hydroponics and will supply a small amount of nitrogen.

Phosphorus (P)

Phosphorus is needed in the development of flowers, fruit, leaves, stems and roots but its greatest demand is during crop establishment and early plant growth. Phosphorus is an important part of the way plants store and use energy and is used in **photosynthesis**.

Phosphorus is supplied in the nutrient solution. The most common fertilisers used to supply phosphorus are MAP, monopotassium phosphate (MKP) and potassium dihydrogen phosphate.

Potassium (K)

Potassium is used in photosynthesis and in making **sugars and starches** in the plant. It is also important for **enzymes** in the plant. It influences plant water regulation by affecting cell turgor and the opening and closing of stomata. Deficient crops are prone to wilting.

Potassium is supplied in the nutrient solution. The main fertilisers used are potassium nitrate, MKP and potassium dihydrogen phosphate. Potassium sulphate and potassium chloride can be used with caution to supply small amounts. Avoid prolonged prolonged use of potassium chloride or muriate as chloride can build up and have a detrimental effect on plant growth and production.

Calcium (Ca)

Calcium is used in the functioning of **plant cells** and their **wall strength**. It is essential for plant growth and in moving sugars and starches around the plant.

Calcium is supplied in the nutrient solution. The major fertiliser used is calcium nitrate. Calcium chloride can be used, but again, in small amounts with caution.

Magnesium (Mg)

Magnesium is a constituent of **chlorophyll**, the green pigment in plant leaves. It is also important in how the plant uses and moves phosphorus and in the activity of many of the enzymes in a plant.

Magnesium is supplied in the nutrient solution as magnesium sulphate (Epsom salts). It can also be supplied with magnesium nitrate.

Sulphur (S)

Sulphur is used in **cell structure** and proteins. Like phosphorus, it is used in producing energy for the plant. Sulphur is supplied in the nutrient solution mainly from magnesium sulphate. Sulphur is also often supplied as a sulphate compound for many of the micronutrients.

Micronutrients

Iron (Fe)

Iron is very important in both photosynthesis and respiration. It is needed to make sugars and starches. Iron is needed to produce chlorophyll and also has an important role in the activity of many of the enzymes in a plant.

Iron is supplied in the nutrient solution most commonly as iron chelate EDTA. There are other types of iron chelates such as EDDTA and DTPA that can also be used. Iron is also supplied as iron sulphate. Note that the availability of iron from the different sources varies with pH.

Manganese (Mn)

Manganese is used in chlorophyll and is closely associated with the function of iron, copper and zinc in making enzymes work. It is also used by the plant to take up nitrogen.

Manganese is supplied in the nutrient solution as either manganese sulphate or manganese chelate. Manganese chloride can also be used with caution.

Zinc (Zn)

Zinc is used by the plant to access stored energy. It is also a part of enzymes and plant hormones. Zinc is supplied in the nutrient solution as either zinc sulphate or zinc chelate.

Boron (B)

Boron is important in the regulation of developing cells. Seed set and fruit development are affected by a deficiency. Boron is supplied in the nutrient solution as sodium borate (borax) or boric acid.

Copper (Cu)

Copper is used in several processes in plants and in enzymes. Copper is supplied in the nutrient solution as either copper sulphate or copper chelate.

Molybdenum (Mo)

Molybdenum is used in a number of enzymes and processes in plants. Molybdenum is supplied in the nutrient solution as either sodium molybdate or ammonium molybdate.

Chlorine (Cl)

Chlorine has a role in photosynthesis and is used by the plant for osmosis and maintaining ionic balance. Sufficient chlorine is generally available in the water source and is not added in the nutrient solution. It can be supplied as potassium chloride in small amounts with caution but chlorine can build up quickly in hydroponics and lead to toxicity.

Silicon (Si)

Silicon is used in cell walls and may improve plant resilience to environmental stress. Silicon is abundant in the environment but may be absent in hydroponic systems. Silicon is not generally supplied in the nutrient solution but is sometimes used as a foliar application.

Monitoring plant nutrition

Leaf analysis is a useful tool to check on the nutritional health or well-being of a crop. When a suspected nutritional problem is encountered, a leaf analysis may identify the likely deficiency or toxicity. Table 16 shows an example of a typical nutrient analysis.

When taking a sample for leaf analysis, it is very important that the leaf is at the right stage.

Table 17 lists the standards for leaf analysis of mini cucumbers. These standards are based on a leaf sample of the youngest fully mature leaf (with petiole) at the early flowering stage.

Leaf analyses can also benchmark nutrient levels in crops performing particularly well for later reference.

The main disadvantage of laboratory leaf analysis is that it takes more than a week for results to come back. Having leaf analyses done routinely can pre-empt or off-set problems and overcomes potential delays created by scientific and objective analyses.

Correctly diagnosing a problem saves money over time and as a professional grower, you can make sure that your experience and knowledge is fine-tuned and is accurate. Pocket-sized LED meters are available for testing nitrate nitrogen and potassium quickly on-farm in sappy plants like cucumbers. There are also different test strips available from various manufacturers for rapid on-farm testing of a range of parameters in plant sap and the nutrient solution. Meters can be used with some of these test strips and give a more precise or objective measurement. Pocket sized meters and/or test strips are available for testing pH, ozone, water hardness, chlorine, iron, copper, nitrate, nitrite, ammonium, phosphate, magnesium, potassium, calcium, molybdenum, manganese, sodium and aluminium.

Table 17. Example leaf analysis for cucumber					
Nutrient	Normal	Pre irrigation deficit	Post irrigation deficit	Non symptom leaves	Symptom leaves
%					
P	0.64	0.81	0.85	0.88	1.33
K	2.4	4.54	4.42	3.05	3.52
Ca	3.5	3.52	3.78	7.28	4.71
Mg	0.48	0.9	0.8	0.83	0.65
S	0.7	0.77	1.25	0.98	0.78
Na	0.08	0.07	0.032	0.12	0.07
mg/kg					
Cu	7.9	3.6	9.3	3.0	3.3
Zn	80	71	83	72	84
Mn	99	96	120	150	96
Fe	227	131	127	142	172
B	39	129	51	76	44
Al	30	15	25	30	68

Table 18. Leaf analysis standards for cucumbers

Nutrient	Unit	Deficient	Normal	Excess
Nitrogen (N)	%	< 1.8	2.5 – 4.5	> 6.0
Potassium (K)	%	< 2.0	2.5 – 4.0	> 5.0
Phosphorus (P)	%	< 0.2	0.3 – 0.7	> 1.0
Calcium (Ca)	%	< 1.0	2.5 – 5.0	
Magnesium (Mg)	%	< 0.15	0.3 – 1.5	> 2.5
Sulphur (S)	%		0.3 – 1.0	
Sodium (Na)	%		0.0 – 0.35	
Chlorine (Cl)	%		0.0 – 1.5	> 2.0
Iron (Fe)	mg/kg	*	50 – 300	
Manganese [†] (Mn)	mg/kg	< 15	60 – 400	> 500
Zinc [†] (Zn)	mg/kg	< 15	20 – 100	> 300
Boron (B)	mg/kg	< 20	30 – 70	> 100
Copper [†] (Cu)	mg/kg	< 3	8 – 20	> 30
Molybdenum (Mo)	mg/kg	< 0.2	0.5 – 2.0	

[†] Values for manganese, zinc and copper are not reliable if fungicides or nutrient foliar sprays have been used on the crop.

* Leaf analysis for iron deficiency is not a reliable guide. If iron deficiency is suspected, directly apply a solution of iron chelate to small areas of a few leaves. If the treated areas turn a darker green in 24 hours, the plants may be deficient in iron.

The nutrient solution

The nutrient solution is a dilute mix of nutrients and water. The nutrient solution is what feeds and irrigates the crop. The nutrient solution must contain all the nutrients needed by the plant in specific amounts or concentrations. The two most basic management requirements in hydroponics are the electrical conductivity (EC) and pH of the nutrient solution. Closely monitor and manage these to make sure that plants have the EC and pH values they require throughout the day and night.

A stock solution is the mixture of nutrients in a concentrated form before it is diluted to make the nutrient solution. Some nutrients become insoluble if mixed in concentrated forms. Calcium should never be mixed with either a sulphate or a phosphate when making up stock (concentrate) solutions. Stock solutions are therefore typically split into 'A' and 'B' tanks. The division of nutrients into 'A' and 'B' tanks when making stock solutions is done to avoid fertilisers forming non-soluble compounds. The 'A' and 'B' tanks are typically 1000 litre plastic containers. Single mix formulations are available commercially.

There are variations. Some systems use a 'C' tank for acid (or alkali). An 'A2' or a 'B2' which has a different

balance of nutrients may also be used in order to make frequent adjustments of the nutrient solution easier. Most formulae are given as an 'A' and 'B' recipe. These are mixed in equal parts with water to make the nutrient solution.

Nutrients are either purchased as premixed formulations or as separate fertilisers and mixed to a specific recipe on-farm. While premixed formulations are more convenient, they are difficult to adjust for individual needs or to address specific problems when the nutrient formula is unknown.

The 'A' tank contains the calcium (as calcium nitrate) and iron if using an iron chelate, such as iron EDTA. A common mistake made is when iron EDTA (in the 'A' tank) is replaced with iron sulphate. If using iron sulphate, put it into the 'B' tank. Potassium can be put into the 'A' tank provided it does not include phosphate. Potassium nitrate is commonly divided evenly between A and B stock solutions to even up the amount of fertiliser dissolved in the respective tanks. This is to overcome the solubility limits of the fertiliser, i.e. the amount of fertiliser dissolved in a set volume of water. Splitting the potassium nitrate reduces the total amount of fertilisers to be dissolved in the 'B' tank.

The 'B' tank will contain the phosphorus and usually all the trace elements. If trace elements are provided as chelates, they can be mixed into the 'A' tank.

With the various security restrictions on the transport, storage and use of ammonium nitrate, it can be substituted with ammonium sulphate at approximately 0.83g/kL for every 1g/kL of ammonium nitrate. Ammonium sulphate must be put in the 'B' tank.

Some example nutrient recipes are presented in Tables 20 – 24, starting on page 115. Dissolve nutrients in the order listed in the recipe. Mark off each fertiliser as you add it to make sure that one is not left out. If your water supply is particularly cold, add some warm water to help the fertilisers dissolve.

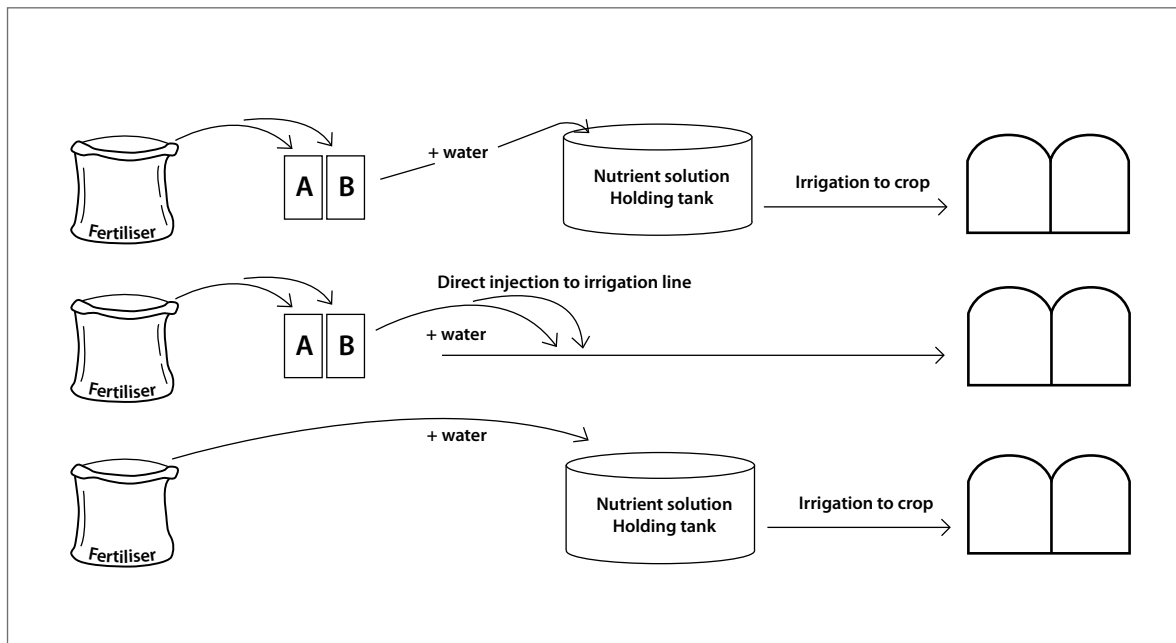
Fertilisers are available in 'Fertiliser' (Agricultural) or 'Technical', 'Industrial' and 'Analytical' grade quality. The Technical Grade of some fertilisers, such as magnesium sulphate, calcium nitrate and potassium nitrate, are also called Greenhouse Grade and are made especially for use in fertigation, hydroponics and foliar applications. Technical Grade fertilisers, while still the same analysis as Fertiliser Grade, are

of higher quality (less impurities) and solubility than Fertiliser Grade. Fertiliser (Agricultural) Grade, while cheaper, is made mainly for soil applications and can cause crop burn, nutrient imbalances and system problems such as blockages, if regularly used in hydroponic systems. A few fertiliser compounds such as boric acid and chelates are of the highest quality which is Laboratory (analytical) Grade quality. Most acids and alkalis are Industrial Grade quality.

Mixing systems

The most basic system for mixing nutrients is to make up stock solutions then add equal parts of these to water in a holding or day tank to make the nutrient solution. The nutrient solution is then used to irrigate the crop.

Another system – more common when automated controllers are used – bypasses the nutrient tank by directly injecting the stock solutions into the irrigation line during irrigation. This system enables adjustments in pH and EC to be made regularly depending on growing conditions. A potential disadvantage is that if something goes wrong with



There are three variations of how nutrient solutions are mixed.

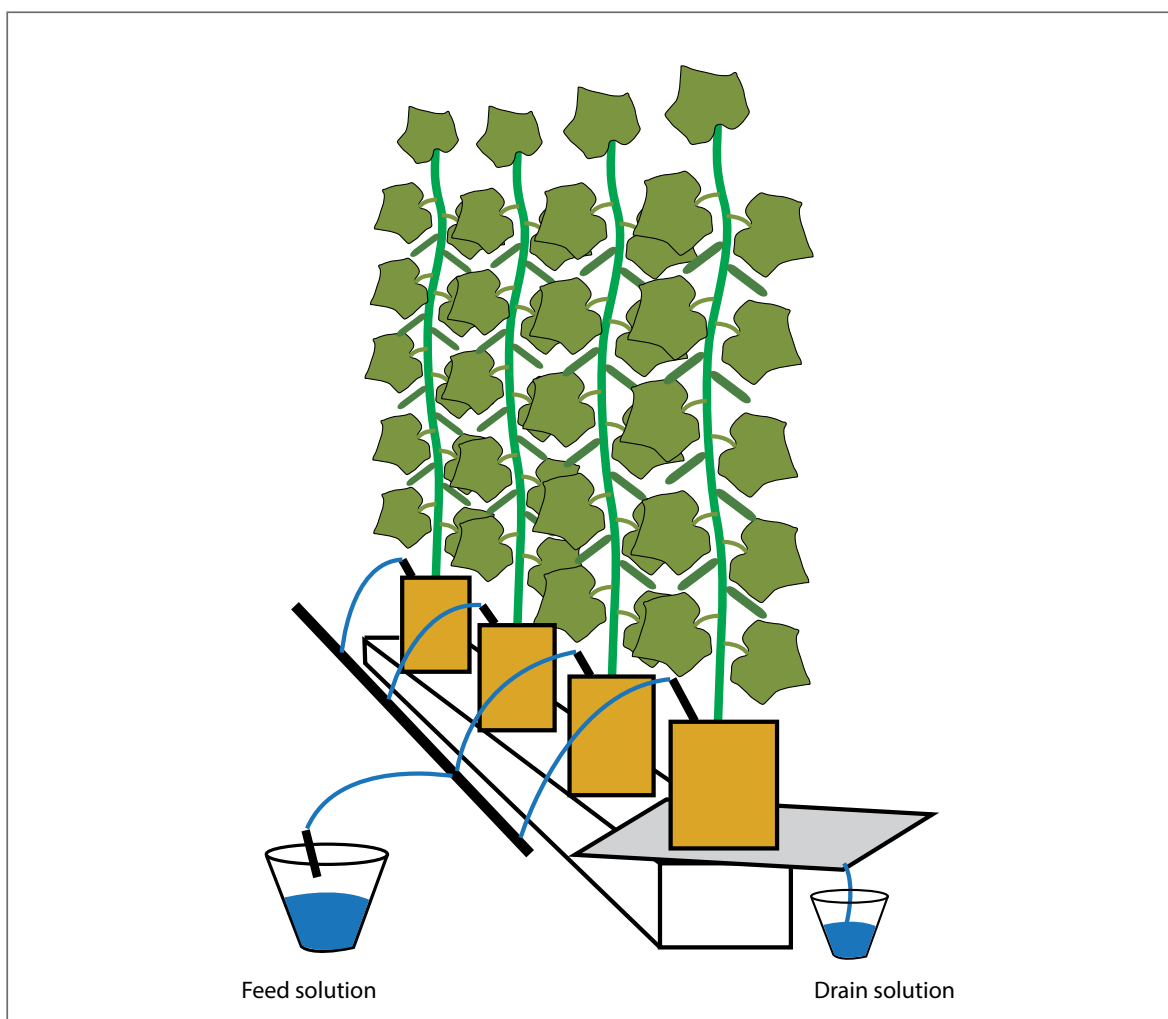
the system, the solution is likely to reach the crop before you have a chance to fix the problem. When fertilisers are injected/mixed automatically, check that the correct EC is achieved. If not, the stock solution may be out of the range of the injector, and need adjusting

A third system does not use stock solutions. The fertilisers are mixed directly in the nutrient tank. If using this method, half fill the nutrient tank with water then add the 'A' fertilisers while mixing well. Add more water until the tank is three quarters full then add the 'B' fertilisers while mixing well. Add more water until you reach your fill line.

Feed and drain solutions

Nutrient solutions are often described as being the 'feed' solution (in) or the 'drain' solution (out). The feed solution is the nutrient solution which is given to the plant through the irrigation system. The feed solution is the one which is made up from the fertilisers. The drain solution is the nutrient solution or run-off water which comes out of the bottom of the container (in substrate culture) or flows back to the nutrient tank (in water culture).

Decisions regarding the management of the plant and nutrient solution should always be based on the drain solution. This is the best sample of what is actually around the roots of the plant. When making adjustments, these are then made to the feed solution.



Nutrient solutions are described as the 'feed' solution (in) and the 'drain' solution (out).

Electrical conductivity

Electrical Conductivity (EC) measures the strength of the nutrient solution or, in other words, the amount of salts in the water. Fertilisers dissolve in water to form a saline solution. This means EC can measure the amount of nutrients in the root zone solution, feed water or drain water. Water with a high EC has more salt in it than water with a low EC.

EC is measured with an EC meter. Most people measure EC in milliSiemens per centimetre (mS/cm) or deciSiemens per metre (dS/m).

$$1 \text{ mS/cm} = 1 \text{ dS/m} = 1000 \mu\text{S/cm} \approx 10 \text{ CF}$$

There are two other ways to measure the strength of the nutrient solution:

1. Conductivity Factor (CF) is an older way but still used. An EC reading of 1 mS/cm \approx 10 CF.
2. Total dissolved solids (TDS) is measured in parts per million (ppm). In Australia, an EC reading of 1 mS/cm \approx 640 ppm TDS.

It is important that you know what unit of measurement you are using. For example, a CF of 10 is a weak solution, but an EC of 10 mS/cm is very strong.

An EC meter should have a range of at least 0 – 6 mS/cm. It also needs to be correct to at least 0.1 mS/cm.

EC should be measured at least once a day.

Recording the EC on a chart makes it easy to see any trends or problems over time. In general practice, you should measure and manage the EC of the nutrient water given to the crop (feed EC) and the EC of the drainage water (drain EC).

Cucumbers are a medium feeding plant and perform well with an EC drain range of 2.0 – 3.0 mS/cm. In substrate culture this would normally be provided by an EC feed range of about 1.5 – 2.5 mS/cm. The actual EC used for your crop needs to be adjusted according to growing conditions, the substrate used, the water quality and also plant balance.

If adjusting EC, avoid sudden, large changes to the nutrient concentration in the root zone. A sudden change will damage the roots. This includes flushing a substrate. Use a weaker nutrient solution, not plain water.

pH

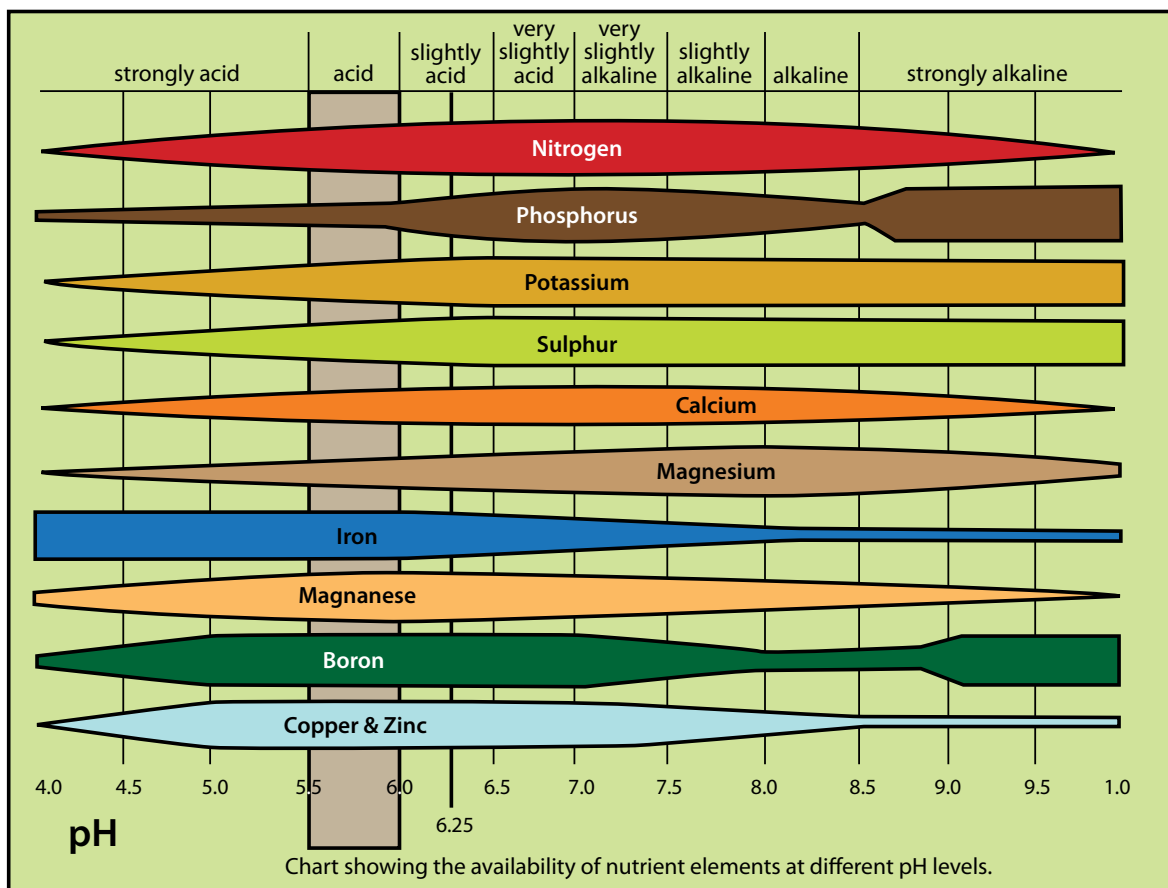
Measuring the pH of a nutrient solution or substrate shows you how acid (< 7) or alkaline (> 7) it is. A pH of 7.0 is considered neutral. A pH meter is used to measure pH.



The pH will affect how easily nutrients react with each other to dissolve in water, or precipitate/fall-out of solution and drop to the bottom. This in turn affects how available the nutrients are to the plant. If the pH changes the nutrients could react to form different compounds. Some of these are not soluble or the plants can't take them up properly. If the pH is below about 4, plant roots will be damaged. Incorrect pH can cause a number of problems for the crop.

The optimal feed pH for cucumbers ranges from 5.0 – 6.2. You should target a root zone pH of 5.5 – 6.2. If the pH of the nutrient solution is greater than about 6.2, calcium and iron phosphate precipitates can form in the nutrient tanks reducing the levels of these nutrients as well as physically blocking irrigation systems.

The pH should be measured at least once a day. Record the pH on a chart every time you measure it. This makes it easier to plot and see any trends or problems that may be happening over time.



Standard approximate availability of nutrients at different soil pH levels. Although the shape of different nutrient availability arrows will vary between different substrates, the usual target pH range for hydroponics is shown by the vertical grey band above.

Nutrient formulae

Cucumbers can grow satisfactorily with a range of formulae and there are a number of formulae successfully being used. The balance of nutrients in a hydroponic solution should reflect the general balance of nutrients required by the crop being grown.

Variations are made according to growing conditions, the substrate or hydroponic system used, the water used and even the type and variety of cucumber. The stage of growth is also important. A vegetative plant has a higher requirement for nitrogen while a generative plant has a higher requirement for potassium. Adjustments to nutrient mixes are generally minor changes to the 'standard' formula. Always monitor your crop, keep records and benchmark the crop to fine tune the nutrient recipe for your farm and management style.

In most situations, the best approach is to use a standard formulation and adjust it, if necessary, on the basis of plant performance and health. Adjustments cannot be readily made with premixed formulations, so while these can be convenient, addressing nutritional imbalances due to growing conditions and the system you are using is more difficult.

Common adjustments to provide more accurate management of the nutritional needs of the crop include:

- increasing feed EC during cooler, lower light conditions (less evapotranspiration) and decreasing feed EC under warm, high light conditions (high evapotranspiration)

- increasing the potassium to nitrogen (K:N) ratio as the plants become generative
- increasing (or decreasing) the proportion of nitrogen supplied in the ammonium form to manage root zone pH.

Most nutrient formulations used are fairly similar. The ranges of elements (Table 19) have been shown to provide a good nutritional supply for cucumbers grown hydroponically. Most recipes will reflect these ranges.

The following example recipes (Tables 20 – 23) have been used in industry to produce commercial cucumber crops. Given the wide variations and numerous factors which impact on plant growth, it is important to understand that crop management, root zone EC and pH as well as the frequency and volume of irrigation are more important factors to consider than specific nutrient recipes – provided basic nutrients are not completely out of balance. You always need to check and record drain EC and drain pH, drainage volume, irrigation frequency and plant health. If necessary, you may need to make adjustments to your management program.

More prescriptive nutrient and irrigation management programs are available. An example from The Harrow Research Centre in Ontario, Canada (A. Papadopoulos) in Table 24 for a spring crop (increasing light) is included to illustrate the level of adjustments that can be undertaken to make sure a crop is well balanced and production is optimised.

Table 19. Ranges of elements for hydroponic cucumbers

Element	Range in mg/L (ppm)	Common source
Nitrogen (N)	150 – 250 (2 – 10% as ammonium*)	Calcium nitrate, Potassium nitrate and Ammonium sulphate
Phosphorus (P)	25 – 50	MKP, MAP, DAP
Potassium (K)	150 – 300	Potassium nitrate, Monopotassium phosphate and Potassium sulphate
Calcium (Ca)	150 – 200	Calcium nitrate
Magnesium (Mg)	25 – 45	Magnesium sulphate
Iron (Fe)	2 – 3	Iron EDTA, Iron DTPA, Iron sulphate
Manganese (Mn)	0.3 – 0.5	Manganese chelate, Manganese sulphate
Zinc (Zn)	0.2 – 0.5	Zinc chelate, Zinc sulphate
Boron (B)	0.2 – 0.4	Boric acid, Borax
Copper (Cu)	0.05 – 0.3	Copper chelate, Copper sulphate
Molybdenum (Mo)	0.01 – 0.05	Sodium molybdate, Ammonium molybdate

*The Ammonium form of nitrogen is often used to manage pH in the root zone. When ammonium nitrogen is used by the plant, the plant releases positively charged hydrogen ions which result in a lower pH. Note, with the security restrictions on the use of Ammonium nitrate, Ammonium sulphate is used instead (approximately 0.83 g/kL ammonium sulphate for each 1 g/kL of ammonium nitrate). Ammonium sulphate must be put in the 'B' tank.

Table 20. Fertiliser recipe Example 1
General Substrate – prefruiting

Volume of stock solution = 1000 L							Dilution rate = 1:100						
Approximate solution EC (mS/cm) = 1.8							Approximate solution pH = 5.99						
Fertiliser	Amount in grams												
PART A													
Calcium nitrate	105000												
Potassium nitrate	20513												
Iron EDTA	2000												
PART B													
Potassium nitrate	20513												
Mono potassium phosphate (MKP)	19048												
Magnesium sulphate	35714												
Ammonium sulphate	500												
Manganese chelate	234 OR												
Manganese sulphate	95												
Zinc chelate	135 OR												
Zinc sulphate	88												
Boric acid	167 OR												
Borax	260												
Copper chelate	135 OR												
Copper sulphate	89												
Sodium molybdate	7.56 OR												
Ammonium molybdate	6.13												
K:N ratio	0.96												
Ca:N ratio	0.88												
Approx. proportion of nitrogen as Ammonium (NH ₄₊)	8.2%												
Element	N	p	k	ca	Mg	S	Fe	Mn	Zn	B	Cu	Mo	
Target amount of nutrient in mg/l (ppm)	217	43	209	191	35	47	2.5	0.3	0.2	0.3	0.2	0.03	

This recipe has been generated to produce the target element concentrations. Amounts are approximate. Calculations do not consider salts in the water source. Differences will occur depending on the source of fertiliser used because elemental compositions of fertilisers vary. Fertiliser amounts for trace elements using both chelates and sulphates have been included for illustration.

Table 21. Fertiliser recipe Example 2													
General Substrate – fruiting													
Volume of stock solution = 1000 L								Dilution rate = 1:100					
Approximate solution EC (mS/cm) = 1.9								Approximate solution pH = 6.0					
Fertiliser		Amount in grams											
PART A													
Calcium nitrate		83,011											
Potassium nitrate		27,436											
Iron EDTA		2000											
PART B													
Potassium nitrate		27,436											
Mono Potassium phosphate (MKP)		19,048											
Magnesium sulphate		42,857											
Manganese chelate		234 OR											
Manganese sulphate		95											
Zinc chelate		135 OR											
Zinc sulphate		88											
Boric acid		167 OR											
Borax		260											
Copper chelate		135 OR											
Copper sulphate		89											
Sodium molybdate		7.56 OR											
Ammonium molybdate		6.13											
K:N ratio		1.3											
Ca:N ratio		0.75											
Approx. proportion of nitrogen as ammonium (NH ₄₊)		7%											
Element	N	p	K	Ca	Mg	S	Fe	Mn	Zn	B	Cu	Mo	
Target amount of nutrient in mg/l (ppm)	201	43	262	151	42	55	2.5	0.3	0.2	0.3	0.2	0.03	

This recipe has been generated to produce the target element concentrations. Amounts are approximate. Calculations do not consider salts in the water source. Differences will occur depending on the source of fertiliser used because elemental compositions of fertilisers vary. Fertiliser amounts for trace elements using both chelates and sulphates have been included for illustration.

Table 22. Fertiliser recipe Example 3**General substrate – Commercial, Australia**

Volume of stock solution = 1000 L						Dilution rate = 1:100							
Approximate solution EC (mS/cm) ≈ 4.0						Approximate solution pH ≈ 6.03							
Fertiliser		Amount in grams											
PART A													
Calcium nitrate		184,000											
Potassium nitrate		15,000											
Iron EDTA		1300											
PART B													
Potassium nitrate		121,000											
Mono potassium phosphate (MKP)		34,000											
Magnesium sulphate		68,000											
Ammonium sulphate* <i>(Original formulae used ammonium nitrate.)</i>		3000											
Manganese sulphate		340											
Zinc sulphate		280											
Borax		480											
Copper sulphate		36											
Sodium molybdate		24											
K:N ratio		1.29											
Ca:N ratio		0.71											
Approx. proportion of nitrogen as ammonium (NH ₄₊)		8%											
Element		N	p	K	Ca	Mg	S	Fe	Mn	Zn	B	Cu	Mo
Target amount of nutrient in mg/l (ppm)		472	76	612	335	66	95	1.66	1.08	0.62	0.53	0.09	0.093

These approximate element concentrations have been generated from a commercially available formulation for cucumbers used in industry and are provided only for illustration of the variation in formulae being used (not a recommendation). Amounts are approximate and would generally not be considered reflective of crop needs. Calculations do not consider salts in the water source. Differences will occur depending on the source of fertiliser used because elemental compositions of fertilisers vary.

Table 23. Fertiliser recipe Example 4 NFT – Cooper (1979)*												
Volume of stock solution = 1000 L								Dilution rate = 1:100				
Approximate solution EC (mS/cm) = 2.02								Approximate solution pH = 5.95				
Fertiliser	Amount in grams											
PART A												
Calcium nitrate	79750											
Potassium nitrate	29257											
Iron EDTA	12245											
PART B												
Potassium nitrate	29257											
Mono potassium phosphate (MKP)	28526											
Magnesium sulphate	50939											
Manganese chelate	2000 OR											
Manganese sulphate	813											
Zinc chelate	100 OR											
Zinc sulphate	44											
Boric acid	166.7 OR											
Borax	283											
Copper chelate	100 OR											
Copper sulphate	44.4											
Sodium molybdate	50.4 OR											
ammonium molybdate	41											
K:N ratio	1.5											
Ca:N ratio	0.85											
Approx. proportion of nitrogen as Ammonium (%NH ₄₊)	4%											
Element	N	p	K	Ca	Mg	S	Fe	Mn	Zn	B	Cu	Mo
Target amount of nutrient in mg/L (ppm)	200	60	300	170	50		12	2	0.1	0.3	0.1	0.2

*This recipe has been generated to produce the target theoretically ideal element concentrations for NFT offered by Cooper. Calculations were made using Suntec Nutron 2000+ Hydroponic Nutrient Formulation Software. Fertiliser amounts for trace elements using both chelates and sulphates have been included for illustration.

Table 24. Fertigation optimisation over the cropping season (spring crop)From A.P. Papadopoulos (2001) 'Computerized fertigation for cucumber production in soil and soilless media', *Acta Hort* 548.

Week	Nutrient concentration (ppm) in final nutrient solution												Expected EC (mS/cm) *
	N-NO3	N-NH4	P	K	Ca	Mg	Fe	Mn	Zn	Cu	B	Mo	
1	72	3	235	300	95	25	1.4	0.4	0.08	0.02	0.26	0.012	1.30
2	117	5	69	218	95	25	1.4	0.4	0.08	0.02	0.26	0.012	1.45
3	162	22	69	275	95	25	1.4	0.4	0.08	0.02	0.26	0.012	1.75
4	170	30	69	275	95	25	1.4	0.4	0.08	0.02	0.26	0.012	1.85
5	176	30	69	294	95	25	1.4	0.4	0.08	0.02	0.26	0.012	1.90
6	182	30	69	313	95	25	1.4	0.4	0.08	0.02	0.26	0.012	1.95
7	188	30	69	332	95	25	1.4	0.4	0.08	0.02	0.26	0.012	2.00
8-11	194	30	69	351	95	25	1.4	0.4	0.08	0.02	0.26	0.012	2.05
12-17	182	30	69	313	95	32	1.4	0.4	0.08	0.02	0.26	0.012	1.95
18-22	176	30	69	294	95	32	1.4	0.4	0.08	0.02	0.26	0.012	1.90
22-end	170	30	69	275	95	32	1.4	0.4	0.08	0.02	0.26	0.012	1850

* The EC of the water has been assumed to be 0.30 mS/cm and is included in the expected EC

Calculating nutrient formulae

When deciding on a 'recipe', it is important to know what nutrients are already present in the water you are using. This way, these nutrients can be adjusted for in the formulation. This applies whether you are drawing water from an urban mains supply, rain tank, bore, creek, dam or recirculated water in your production system. For example, hard water from bores may contain high levels of calcium and magnesium while iron may be abundant in water that has low levels of oxygen. Town water often contains sodium, chloride and/or fluorine and may also be alkaline.

When formulating a nutrient solution, small variations in actual amounts of fertilisers are unlikely to make a significant difference unless the amount of specific nutrients are present at toxic or deficient levels, so there is generally room to round off amounts.

Nutrient calculations

To calculate the amount of fertiliser to use, you need to know the percentage of the relevant element in the fertiliser being used (a list of commonly used fertilisers is given in Table 26) and your selected composition of nutrient to be in the solution (your recipe or formulation).

The sample formulation in Table 25 is given in grams per kilolitre (g/kL). This is the same as milligrams per litre (mg/L) and parts per million (ppm), for example, 200 g/kL equals 200 ppm. Often minor elements are reported as a percentage (%). To convert a percentage to ppm, multiply the percentage by 10,000 and to convert ppm to a percentage, divide ppm by 10,000. For example, to convert to 0.03% to ppm, multiply 0.03 by 10,000, that is, 0.03% = 300 ppm

One way of calculating nutrients, is to use 2 equations:

Equation 1: To find the amount of fertiliser needed

$$\begin{array}{rcl} \text{Amount of} & & 100 \\ \text{element} & \times & \text{Percentage of element in} \\ \text{(g/kL or ppm)} & & \text{fertiliser [from Table 26]} \end{array}$$

Equation 2: To find how much of the element is supplied by a specific amount of fertiliser

$$\begin{array}{rcl} \text{Amount of} & & \text{Percentage of element} \\ \text{fertiliser} & \times & \text{in fertiliser} \\ \text{(g/kL or ppm)} & & 100 \end{array}$$

In calculating your formula, the simplest method is to begin with the 'lesser' macroelements – sulphur (S), magnesium (Mg) and calcium (Ca) – then top up the nitrogen (N), phosphorus (P) and potassium (K) levels, before doing the microelements. Always make sure that elements present in the water source are included before calculating how much to add.

For example, if your water has 40 g/kL of calcium, calculating from the sample formulation in Table 25, you would only need to supply 150 – 40 = 110 g/kL of calcium. Note also, that adding acid or base to adjust pH, can add an amount of nutrient, for example phosphorus from phosphoric acid and potassium from caustic potash.

Dilution

The following calculations assume that there is no dilution, that is, they are for the nutrient solution not the stock solution. If you are making a stock solution, the figures calculated need to be multiplied by the dilution rate. Most formulations are based on a dilution rate of 1:100. In this case, each of the calculated values needs to be multiplied by 100. When using fertigation injectors, check the dilution ratio on your unit.

Using the elemental percentages in Table 26 and the sample formulation provided in Table 25, a worked example of the calculations follows:

To supply sulphur, using magnesium sulphate

Using equation 1:

$$\begin{array}{rcl} \text{Amount of} & & 100 \\ \text{element} & \times & \text{Percentage of element in} \\ \text{(g/kL or ppm)} & & \text{fertiliser [from Table 26]} \\ \text{[from Table 25]} & & \\ \\ 40 & \times & \frac{100}{13} \\ \\ & = & 307.69 \end{array}$$

Therefore, we need to add 307.69 grams of magnesium sulphate per 1000 litres of nutrient solution. Some **magnesium** is also supplied. To calculate the amount, we use equation 2.

$$\begin{array}{rcl}
 \text{Amount of} & & \text{Percentage of element} \\
 \text{fertiliser} & \times & \text{in fertiliser} \\
 \text{(g/kL or ppm)} & & \hline
 & & 100 \\
 \\
 307.69 & \times & \frac{9.8}{100} \\
 \text{[from above]} & & \\
 \\
 & = & 30.15
 \end{array}$$

This is close enough to our selected formula. We now know that 307.69 grams of magnesium sulphate in 1000 litres of water supplies both the sulphur and magnesium needs.

Next, to supply calcium, using calcium nitrate

Using equation 1:

$$\begin{array}{rcl}
 150 & \times & \frac{100}{18.8} \\
 \\
 & = & 797.87
 \end{array}$$

This will also supply some nitrogen, as both ammonium and nitrate. Use equation 2 to work out how much of each.

$$\begin{array}{rcl}
 \text{Nitrogen as ammonium:} & & \frac{1.0}{100} \\
 797.87 & \times & \\
 \text{[from above]} & & \\
 \\
 & = & 7.98
 \end{array}$$

$$\begin{array}{rcl}
 \text{Nitrogen as nitrate:} & & \frac{14.5}{100} \\
 797.87 & \times & \\
 \text{[from above]} & & \\
 \\
 & = & 115.69
 \end{array}$$

So, from our sample formulation, we can see that we need another $10 - 7.98 = 2.02$ g of N as NH_4 and $200 - 115.69 = 84.31$ g N as NO_3 . We can use ammonium sulphate to complete the **ammonium** and calculate the amount using equation 1;

$$\begin{array}{rcl}
 2.02 & \times & \frac{100}{21.2} \\
 \\
 & = & 9.53
 \end{array}$$

By adding 9.53 grams of this fertiliser we satisfy the ammonium requirement.

To supply **phosphorus**, using monopotassium phosphate (MKP or also known as potassium dihydrogen phosphate)

Using equation 1:

$$\begin{array}{rcl}
 40 & \times & \frac{100}{22.8} \\
 \\
 & = & 175.44
 \end{array}$$

Therefore, we need to add 175.44 grams of monopotassium phosphate per 1000 litres of solution. **Potassium** (50.35g) is also added:

Using equation 2:

$$\begin{array}{rcl}
 175.44 & \times & \frac{28.7}{100} \\
 \text{[from above]} & & \\
 \\
 & = & 50.35
 \end{array}$$

However, we need $230 - 50.35 = 179.65$ g more potassium. We could use potassium nitrate to supply this.

Using equation 1:

$$179.65 \times \frac{100}{38.7} = 464.21$$

This will give us (equation 2) another 64.06 g N, leaving $84.31 - 64.06 = 20.25$ g N to get.

In this situation, you may elect to leave the formulation short a little nitrogen or top it up with calcium or potassium nitrate. Small variations in the nutrient composition will not usually adversely affect plant growth and yield, so there is no need to be absolutely exact. Recalculating the formula with different fertilisers may also give a closer result.

Supplying the microelements, using equation 1:

- Iron using iron chelate:
 $3 \times 100 \div 15.3 = 19.6$ g
- Manganese using manganese sulphate:
 $0.3 \times 100 \div 32.5 = 0.92$ g
- Boron using borax:
 $0.3 \times 100 \div 11.5 = 2.6$ g
- Zinc using zinc sulphate:
 $0.1 \times 100 \div 22.7 = 0.44$ g
- Copper using copper sulphate:
 $0.05 \times 100 \div 25.6 = 0.2$ g
- Molybdenum using sodium molybdate:
 $0.05 \times 100 \div 39.7 = 0.13$ g

Table 25. Example nutrient solution

Element	Sample formula (g/kL)
Nitrogen (NO ₃ ⁻)	200
Nitrogen (NH ₄ ⁺)	10
Phosphorus	40
Potassium	180
Calcium	200
Magnesium	30
Sulphur	40
Iron	3
Manganese	0.3
Boron	0.3
Zinc	0.1
Copper	0.05
Molybdenum	0.05

Elemental make up of common fertilisers

The percentages in Table 26 are calculated from the atomic weight of the element and the atomic weight of the molecule. There will be variations between different fertiliser products, sometimes as much as a few percent. Technical Grade fertilisers are more soluble and of higher quality than Agricultural Grade fertilisers. Hydroponic nutrient solutions should be based on using Technical or Greenhouse Grade quality fertilisers to avoid potential problems from impurities, nutrient imbalances, crop damage and blockages.

Table 26. Common soluble fertilisers

Fertiliser	Nutrient	Approximate (%) percentage
Calcium nitrate	N (as NO ₃ ⁻)	14.5
	N (as NH ₄ ⁺)	1.0
	Ca	18.8
Ammonium nitrate	N (as NO ₃ ⁻)	17.5
<i>*No longer in common use. Substitute with ammonium sulphate</i>	N (as NH ₄ ⁺)	17.5
Ammonium sulphate	N (as NH ₄ ⁺)	21.2
Monopotassium phosphate (MKP)	P	22.8
	K	28.7
Mono-ammonium phosphate (MAP)	N (as NH ₄ ⁺)	12.2
	P	27.0
Di-ammonium phosphate (DAP)	N (as NH ₄ ⁺)	21.2
	P	23.5
Potassium nitrate	N (as NO ₃ ⁻)	13.8
	K	38.7
Potassium sulphate	K	44.8
	S	18.4
Magnesium sulphate	S	13.0
	Mg	9.8
Magnesium nitrate	Mg	9.5
	N (as NO ₃ ⁻)	10.4
Iron chelate (EDTA)	Fe	13.0
Iron chelate (DTPA)	Fe	11.0
Iron sulphate	Fe	20.1
Manganese sulphate	Mn	25.0
Manganese chelate	Mn	12.8
Manganese chloride	Mn	27.7
Zinc sulphate	Zn	22.7
Zinc chelate	Zn	14.8
Borax	B	11.5
Boric acid	B	17.7
Copper sulphate	Cu	25.6
Copper chelate	Cu	14.8
Sodium molybdate	Mo	39.7
Ammonium molybdate	Mo	53.0

Volume and frequency of irrigation

The amount of nutrient solution needed by the crop will vary. There are a number of factors which influence how much water is needed. These include:

- level of solar radiation
- temperature
- relative humidity/vapour pressure deficit (VPD)
- age of crop/leaf area
- type of crop (and variety)
- fruit load
- type of substrate
- water quality

As the growing conditions change, the volume and frequency of irrigation needs to be changed. It is important that the level of water in the substrate is monitored to better plan irrigation. The growing conditions and the crop type and stage can be used to estimate the expected water demand but regular monitoring is needed. An irrigation system should be flexible so that you can alter the supply of water when needed.

As a general guide, mature cucumber plants need between 2.0 and 3.5 litres of water per day in some parts of Australia. Information from Canada suggests a crop like cucumber needs 0.3 L per megajoule per square metre (MJ/m²) of light energy. Solar radiation is most commonly used to work out how much water is needed and is often used in automated systems because it gives a good indication of the level of evapotranspiration – plant water use. In Sydney in mid summer, this equates to about 2.9 L per plant per day (assuming a plant density of 2.5 plants per square metre).

Irrigation based on evaporation tends to be set at about 30 – 40% of evapotranspiration up to first flowering then increased to up to 60% of evapotranspiration between flowering and first harvest. Finally irrigation is increased up to 90% of evapotranspiration until harvest is finished.

Run-off targets

Run-off targets are a useful way monitoring the amount of irrigation to use. This is done in conjunction with managing EC and pH of the run-off. Target a run-off volume of between 10% and 30%. A higher run-off volume will use more water and fertilisers and result in the EC and pH being closer to the feed EC and pH. It will also direct the plant to be more vegetative. A high run-off target can also be used to manage poorer water quality. A lower target run-off is more water and fertiliser efficient but will also result in greater differences between feed and drain solutions. It will tend to direct the plant to be more generative.

Under hot sunny conditions (summer) a higher run-off percentage is generally used to manage the drain EC and pH while a lower run-off target is used during low light (winter) conditions.

Collect the output of at least one emitter and the run-off from at least one plant. Use these measurements to calculate the run-off percentage. The run-off percentage is calculated over the whole day however, the day is usually divided in periods (for example early, middle and late) each with a different run-off target. For example, a target daily run-off percentage of 20% may be used so for every litre of nutrient solution given to the plants, you would expect 200 ml in total to be collected as run-off after the last irrigation of the day.

Table 27. Example of target run-off percentages during the day

Irrigation period	Run-off target (% of irrigation)
Early (sunrise to mid-morning)	0 %
Middle (mid-morning to mid-afternoon)	20 – 40%
Late (mid-afternoon to sunset)	5 – 10%
Whole day	20%

Weights

Scales to measure approximately how much water is in the substrate can also be used to make irrigation decisions. At least one container is positioned on scales so that its weight can be monitored. By knowing the weight of a container full of dry substrate and the weight of a container at 'container capacity' (wet), a weight range can be set. The weight of the container will change during the day. As the plant uses water, the container becomes lighter and when the plant is irrigated, the container weight moves back to capacity. The weight can therefore be used to decide the amount and timing of irrigations. The 'container capacity' is the point after a container full of substrate is fully saturated and then allowed to drain freely. When using scales, some allowance for the weight of the plant and crop has to be made.

Age and type of crop

The age of the crop influences how much water it needs. As a plant grows, the surface area of the leaves increases (more leaves and bigger leaves). Water is evaporated from the leaf surface so more water is evaporated as the leaf surface of the plant increases. Irrigation, therefore, needs adjusting throughout the crop cycle to match the needs of the crop.

The type of crop grown also affects how much water is needed. The size and shape of leaves affects the amount of water evaporated while the speed a plant grows is an indicator of how much water is used. The type of root system a crop has also affects how much and how often a crop needs irrigation. Depending on the substrate used, the depth of roots and the amount of fine feeder roots have an impact on how much water is used.

Fruit load

As a crop grows and produces fruit, a greater amount of water and nutrients are needed to develop the fruit. The amount of root and leaf growth in a crop changes depending on what stage the crop is at. For example, as a crop ripens, the plants reduce the amount of roots that they grow. This means that the plant has less capacity to take up water and nutrients and so the amount of nutrient solution given to the crop can be reduced.

Type of substrate

The level of drainage in a substrate affects how much nutrient solution is needed. A substrate with a low water holding capacity and a higher level of drainage, needs irrigating more often. A substrate with a higher water holding capacity may be irrigated less often.

The growing environment

A number of environmental conditions affect how much water a plant uses. The light intensity, temperature, relative humidity (or more accurately the vapour pressure deficit) all influence the amount of water needed by the plant. A heated greenhouse generally requires more water than an unheated greenhouse. If heating, one or more night irrigations may be necessary to maintain moisture levels in the substrate.

Water quality

Growing greenhouse cucumbers requires a reliable supply of good quality water. A water analysis is the only comprehensive way to check on the quality of water used in the hydroponics system. Table 28 lists some quality guidelines suitable for hydroponic cucumbers. Results in parts per million (ppm) are the same as mg/L.

When water quality is poor, a greater volume of water may be needed. The extra water is used to flush unwanted salt away from the roots. The leaching volume, (run-off) is an important management tool used to control electrical conductivity (EC) in the root zone and manage nutrient balance.

Amount of water remaining in the substrate

The amount of water in the substrate when you irrigate is very important. If the time between irrigations is too long for the conditions, your crop might become water stressed. This means that there is not enough water available to the plant.

If there is still plenty of water in the substrate when you irrigate, then you may be wasting water and nutrients by irrigating too much or reducing the amount of oxygen available to the roots. Water availability is important and refers to how easily the plant 'pull' the water out of the substrate. Again the type of substrate affects how easy the water is to use.

Table 28. Water quality guidelines for hydroponic cucumbers

Test	Result	Comment
Electrical conductivity or EC (mS/cm or dS/m)	< 3.0	Cucumbers have a medium tolerance to salinity Above 3.0 mS/cm, specialised management strategies will be needed to minimise yield losses
pH	5.5 – 7.0 < 5.0 > 7.5	Nutrient additions will lower pH a little. A pH less than 5.0 will affect nutrient uptake and phytotoxicity may occur. A pH more than 7.5 will affect nutrient availability and cause precipitation of some nutrients. If treating with chlorine, a pH above 7.5 will reduce efficacy of chlorine.
Chloride (mg/L)	< 70 70 – 200 > 250	Good Okay for cucumbers, but need to keep a check on plant nutrition. Risk of leaf margin / tip burn under extreme conditions No good for cucumbers
Sodium (mg/L)	< 60 > 100	Okay Need to keep a check on plant nutrition. Real problems start occurring if levels reach about 150 mg/L
Alkalinity (mg/L Calcium carbonate)	< 40 50 – 100	Good Increasing problems
Water hardness (mg/L Calcium carbonate)	< 75 75 – 300	Soft water Hard water
Bicarbonate (mg/L)	< 60 > 60	Okay Increasing problems with crop health and equipment
Aluminium (mg/L)	< 5	Okay
Fluoride (mg/L)	< 1	Okay
Nitrates (mg/L)	> 10	Adjust nutrient formula to accommodate
Phosphorus (mg/L)	> 10	Adjust nutrient formula to accommodate
Iron (mg/L)	< 0.2 0.3 – 1.5 > 1.5 > 4.0	Good Adjust nutrient formula to accommodate Blockages and orange staining will occur Not suitable
Manganese (mg/L)	< 1.5	Adjust nutrient formula to accommodate
Zinc (mg/L)	< 0.2 0.2 – 1.5 > 1.5	Okay Adjust nutrient formula to accommodate Not suitable
Copper (mg/L)	< 0.02 0.02 – 0.2 > 0.2	Okay Adjust nutrient formula to accommodate. May affect plant health
Boron (mg/L)	< 0.5 > 2.0	Okay, but adjust nutrient formula to accommodate Not suitable

Sometimes over irrigation is a management tool, e.g. to reduce nutrient concentration in the root zone. However, as mentioned above, over irrigation can lead to problems with aeration depending on the characteristics of the substrate in use. High quality hydroponic substrates provide better root zone conditions and offer more management options to the grower.

In substrate culture, it is very important to avoid a wetting and drying cycle. If the substrate dries out between irrigations, the crop will suffer water stress. A wet and dry cycle can lead to nutritional and fruit quality problems. Some substrates become hydrophobic if they dry out. This means that they do not wet properly when next irrigated.

Using foliar fertilisers

Foliar fertiliser applications should not be relied upon to continually supply nutrients to a crop. They can, however, be an effective way of minimising losses when a problem with plant nutrition has occurred. Calcium nitrate and potassium nitrate are commonly used as foliar fertilisers to improve plant performance and fruit quality when the growing system is not optimal.

While foliar applications may be used, the actual problem needs to be addressed in the root zone through adjustments to the nutrient solution, the substrate, the irrigation schedule, cultural or environmental management or a combination. Some nutrients are not readily absorbed by plant leaves so the total supply of nutrients must be made to the root system. When making foliar applications, make sure you use Technical or Greenhouse Grade fertilisers as they are made especially for better and safer foliar application. They are more soluble and of a higher quality than Fertiliser or Agricultural Grade fertilisers.

To minimise the risk of salt burn of leaves when applying foliar sprays, spray late in the afternoon or during overcast conditions. Use a high volume of water (500 – 1000 litres per hectare) when using foliar fertilisers.

Some typical foliar applications of fertilisers to provide short term treatment of nutrient problems include:

- Calcium - use a foliar spray of calcium nitrate at a rate of 800 g calcium nitrate per 100 L of water.
- Nitrogen - a fortnightly foliar spray of urea at a rate of 2 kg per 100 L of water can be used. (Do not use urea in the nutrient solution.)
- Magnesium - use a fortnightly foliar spray of magnesium sulphate at a rate of 2 kg magnesium sulphate per 100 L of water.
- Manganese - use a foliar spray of manganese sulphate at a rate of 100 g manganese sulphate per 100 L of water.
- Boron - use a foliar spray of borax at a rate of 100 g borax per 100 L of water.
- Iron - use regular foliar spray of iron sulphate at a rate of 150 g iron sulphate per 100 L of water.

Monitoring

Growing a crop requires thinking about and checking that a lot of things are working together and changing as the environment changes. Monitoring of nutrition and irrigation are essential.

Monitoring is about gathering useful information, recording it and comparing results to make informed and effective decisions.

Some things that should be measured include:

- EC – at the injection point or tank, at the emitter and runoff from the pots /bags
- pH – at the injection point or tank, at the emitter and runoff from the pots /bags
- Water pressure – at the pump or inlet, at the filter inlet and outlet and at the emitter
- Water flow – at the emitter
- Boxes of product per area – recording how many kilograms or boxes sold per area.

Other parameters could be monitored dependent upon your production objectives.



FARM BIOSECURITY AND FOOD SAFETY

Both biosecurity and food safety rely on farm hygiene. Protected cropping, using sterile media in secure greenhouses, makes it possible to exclude many plant pests, plant diseases and human pathogens from the growing environment. So long as hygiene is strictly controlled, greenhouse cucumbers are kept cleaner and healthier than their counterparts growing in the open field.

THIS SECTION INCLUDES

- Managing visitors and workers
- Keeping your farm secure
- Pest surveillance
- Food safety - microbial, chemical and physical hazards
- Avoiding contamination
- Worker hygiene and training

Farm biosecurity

On-farm biosecurity is what protects your greenhouse from external pests and diseases. These include local pests, such as mites and thrips, as well as exotic new diseases such as cucumber green mottle mosaic virus (CGMMV) or exotic pests such as brown marmorated stink bug.

Local and exotic pests may be brought into the growing environment on equipment, through packaging and pallets, on people, with planting materials and substrates or simply carried by the wind. However, greenhouses have a clear advantage over field cultivation in their control over entry of pests into the crop. Maintaining a pest-free environment has obvious advantages, so preventing transmission into the crop is an essential tool in farm management.

Signage

Biosecurity signage is the first thing that visitors, workers and delivery staff should see as they enter the property. Effective signs must be large, brightly coloured and well maintained. Display them prominently in locations where visitors cannot help but notice them.

Signage needs to warn people entering the property that they are entering a biosecure farm, and that they must contact the office immediately on arrival. Provide directions to designated visitor parking or delivery areas, and clearly indicate that entry to other parts of the farm is prohibited.

Farm biosecurity sign templates, as well as ready-made signs, are available from AUSVEG www.ausveg.com.au/biosecurity. Signs are also available from Local Land Services in NSW.

On-farm biosecurity practices

Visitors should sign a register on arrival, and undergo a basic farm induction. Take extra care if they have recently visited other farms, especially ones growing cucurbits. If possible, do not allow visitors into the greenhouse if they have come directly from another growing facility.

Dirty boots pose a very real biosecurity risk. Dirt is easily carried between farms, taking with it soil-borne pests such as fungal diseases and nematodes. Anyone entering the greenhouse needs to either change their footwear or clean and disinfect their boots. If their boots are very dirty, they need to remove the soil by pre-washing before treating with disinfectant.

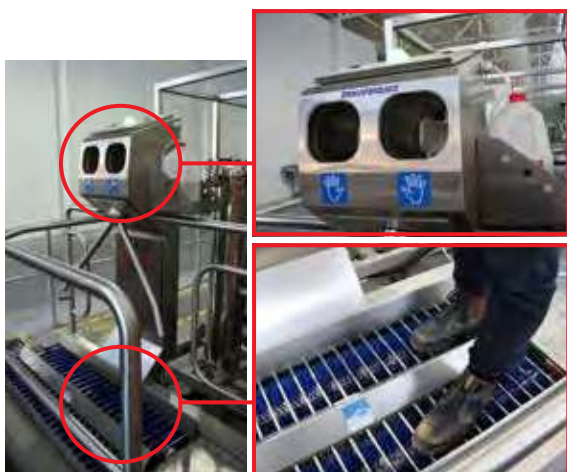
A foot pad or footbath should be installed at all entrances to the greenhouse. Make sure every person entering the greenhouse uses the footbath every time they enter. Commercial foot pads are available, or you can make your own footbath using a plastic tub and some sponge or rubber matting. The baths must be kept well supplied with fresh disinfectant. If the solution dries out or becomes dirty it will be



Farm biosecurity signs are available from AUSVEG or Local Land Services offices in NSW.



Biosecurity signage should be prominently displayed at the entrance to the property.



This biosecurity station at the entrance to a greenhouse complex includes both hand sanitation and boot cleaning.



A foot pad should be installed at each entry to the greenhouse and kept well supplied with sanitiser.



Ensure that all people entering the glasshouse use the foot pad.



Wiping down tools and equipment with disinfectant before moving to other parts of the greenhouse can help reduce spread of pests and diseases.

ineffective. For example, chlorine products such as bleach (sodium hypochlorite) soon lose their activity if the water is dirty. Check the solution regularly to make sure it is topped up, and changed at least every few days.

Hand washing is also important. Provide hand washing stations at the entrance to the facility. Equip these with soap, disposable paper towels and, if possible, warm water; although warm water doesn't increase the effectiveness of hand washing, it does encourage people to wash for longer! Workers and visitors must wash their hands thoroughly, or wear clean gloves, if they are touching plants and fruit.

Hi-tech greenhouse operators usually require visitors to wear disposable protective clothing. Staff should also have dedicated clothing that remains at the farm, which they change into on arrival at work. Some facilities provide colour-coded clothing to staff working in specific greenhouses. If they enter another greenhouse, they need to change their clothes. This helps prevent any cross-contamination between different growing environments.



Staff and visitors must wash their hands before entering the greenhouse and/or touching fruit and plants.



Farm visitors are often required to wear disposable clothing, including hairnets and boot covers, if entering the greenhouse.

Cleaning tools and equipment regularly as it moves around the greenhouse can also help prevent the spread of pests and diseases. This is especially important for clippers, work platforms, and other equipment that contact the plants directly. Regularly dipping clippers in a disinfectant solution, and wiping down equipment before it moves to a new part of the greenhouse, are simple but effective measures that limit the spread of pests around the growing environment.

Pest surveillance

Proper surveillance is essential for plant health and can provide security against exotic or quarantine pests.

Monitor plants regularly to identify possible outbreaks and control them before they spread. Staff involved in monitoring need training to accurately identify both local and exotic pests, such as CGMMV. Record monitoring activities, even if nothing is found. Include the observation date, pests identified (if any), growing areas affected, infestation level and proposed treatment plan. Surveillance data such as this can be extremely important for maintaining market access in the event of an outbreak, including those at other businesses. Any sightings of exotic pests must be reported to the relevant state or territory agriculture agency on the exotic plant pest hotline 1800 084 881.



Train staff to recognise local and exotic pests, such as CGMMV.



Clean and disinfect trucks that have previously visited another greenhouse facility before they enter your property.

Planning for biosecurity

Maintaining good farm biosecurity is an essential tool when managing a greenhouse. Farm managers must consider how and where pests and diseases could enter the crop, and implement measures to reduce the likelihood of this happening. Some of these actions are summarised in the table opposite. A range of resources including biosecurity plans, gate signs and pest information are available through AUSVEG (ausveg.com.au/biosecurity).

Clean down facilities

Delivery trucks, trades people's utes, and other vehicles should preferably be kept within designated areas, not allowed into the farm itself.

If vehicles or equipment do need to come onto the farm and/or into the greenhouse, then it is essential they are cleaned first.

Provide a clean down facility to clean and disinfect all farm equipment and machinery entering the greenhouse and its immediate surrounds. High pressure hoses or compressed air can be used to clean incoming (and outgoing) vehicles and machinery. Follow this with decontaminant solution if the equipment is considered high risk (e.g. it was previously used at another greenhouse cucumber farm) and cannot be thoroughly cleaned throughout.

Clean down facilities should be concrete or gravel, with sumps to collect removed soil and debris.

Table 29. Developing a farm biosecurity plan; issues to consider

Transmission pathway	Actions to reduce transmission
Vehicles and equipment Soil and plant material potentially carrying disease can collect in tyre treads, on equipment and under vehicles	<ul style="list-style-type: none"> • Direct traffic with gate signs and inform visitors they must contact the office on arrival • Restrict visitor parking to designated areas • Maintain clean down facilities on site but away from the greenhouse • Ensure runoff from the clean down area is collected in a sump away from the greenhouse • Keep dedicated equipment and farm vehicles on the property and ensure they keep to pathways • Clean and disinfect vehicles and equipment before moving them between greenhouses
Crates, bins and pallets Plastic crates and pallets are re-used and commonly transferred between properties	<ul style="list-style-type: none"> • Do not use recycled cardboard packaging materials • Store clean crates and bins on sealed floors in a covered area • Wash and sanitise picking crates before re-use • Store dirty pallets away from the greenhouse
Staff and farm visitors Insects, weed seeds, nematodes and viruses can all hitchhike on clothing, hands and footwear, especially if the person has recently visited another farm	<ul style="list-style-type: none"> • Ensure all visitors report to management on arrival • Check visitor clothing, footwear and tools for plant material and soil • Provide footbaths and handwashing facilities at the entry to the greenhouse and ensure they are used every time • Induct staff and visitors in on-farm biosecurity • Maintain communication with neighbours regarding farm biosecurity
Waste and weeds Pests, diseases and viruses can 'hide' in organic waste and weeds	<ul style="list-style-type: none"> • Store waste away from growing areas and irrigation water sources • Dispose of waste as soon as possible through composting, burning or burying • Maintain a weed free buffer zone around the greenhouse
Planting materials Seedlings, seed and growing media are all potential sources of viruses such as CGMMV	<ul style="list-style-type: none"> • Request that imported seeds used to generate planting material follow the seed testing requirements listed in the Australian Biosecurity Import Conditions Database • Only use planting material from reliable sources • Arrange additional virus testing if necessary and keep diagnostic results on record • Discard growing media such as cocopeat after each crop
Wind Small insect pests and fungal spores are commonly carried on the wind	<ul style="list-style-type: none"> • If possible, install mesh on greenhouse vents to exclude insects such as thrips • Use traps to survey insect populations within the crop • Train staff to look for local and exotic plant pests, providing posters, pest guides or other information to aid identification • Monitor the crop regularly and record details of pests identified, area affected, level of infestation and proposed treatment plan • Surveillance should include documenting the non-presence of pests that may affect trade, such as CGMMV or fruit flies

Food safety

While quality is obviously desirable, food safety is non-negotiable. Consumers expect that the food they eat will not injure them or make them sick. This is especially important for cucumbers as they are not normally cooked. Do not assume that all consumers will wash them thoroughly before eating.

All greenhouse cucumber producers should have a food safety scheme in place. This may be a simple system based on HACCP (Hazard Analysis at Critical Control Points), Freshcare, and/or one of the other recognised food safety systems including HARPS (Harmonised Australian Retailer Produce Scheme), BRC (British Retail Consortium), SQF (Safe Quality Food), or GLOBALG.A.P.

The purpose of food safety systems is to reduce the likelihood of microbial, physical or chemical contamination of the end product.

Microbial contamination

A huge range of microbes are present, even in the most sterile and hygienic growing environment. Most of these are harmless, some may be beneficial, a few cause plant diseases and a handful are harmful to humans. These human pathogenic organisms include species of bacteria such as *Escherichia coli* (*E. coli*), *Salmonella* spp. and *Listeria monocytogenes*, as well as viruses such as norovirus and Hepatitis A.

Human pathogens generally cause symptoms such as diarrhoea, vomiting, stomach cramps and nausea, often simply referred to as “gastro”. While in most cases symptoms last only a few days, human pathogens can cause severe illness and death.

In 2011 an outbreak of a virulent strain of *E. coli* O104:H4 occurred in Germany. Nearly 4,000 people were affected, 800 suffered hemolytic uremic syndrome, which potentially leads to kidney failure, and 53 people died. Unfortunately, German health authorities initially linked the outbreak to Spanish greenhouse cucumbers. This was subsequently shown to be false, with the source identified as an organic sprout producer.

Despite this, the initial link led to a massive drop in sales of all salad vegetables and bans on fresh produce imports from Spain in general. It is estimated that association with the outbreak cost the Spanish greenhouse cucumber industry US \$200million per week during the crisis. Even once the industry was cleared, sales took months and even years to fully recover.

Contaminated water, soil, equipment, packaging materials and people are all potential sources of human pathogens. As cucumbers do not usually contact irrigation water, and the majority are grown in soilless culture, this greatly reduces the risk of contamination. However, handling by contaminated workers or inadequate cleaning of picking and packing equipment remains potential sources of risk.

Chemical contamination

The public often expresses a high level of concern about chemical contamination, however illnesses caused by pesticide applications to produce are extremely rare. Other chemical contaminants include heavy metals, allergens and natural toxins, none of which are likely to occur in greenhouse cucumbers.

Chemical contamination is most likely to occur accidentally through incorrect mixing of pesticide; non-observance of withholding periods; contact with spilled oil; cleaners or sanitisers not used according to label directions; or residues in picking containers.

Physical contaminants

Physical contaminants are surprisingly frequent and a common cause of customer complaints. Unlike microbial contaminants, the number of people potentially affected by physical contamination is generally limited, however the effect on the business can be considerable.

Physical contaminants include foreign objects from the growing environment (such as insects, spiders, dirt and sticks), as well as those that may be introduced from people and equipment (such as glass, metal and plastic fragments, hair, fingernails and a multitude of other items). Physical contaminants may also be introduced maliciously through deliberate tampering; in this case the issue is no longer about food safety, but is a criminal offence.

Damaged picking containers or packaging, careless or untrained staff and lack of proper use of PPE are all likely causes of physical contamination.

Contamination from the growing environment

Most greenhouse cucumbers are grown under hygienic conditions. Inert media is frequently used rather than soil and is unlikely to contact the fruit during production. Even if plants are grown in the ground, they are protected from wind and water splash, reducing risk from dust. Moreover, irrigation

water is supplied using drippers, so also does not contact the fruit. These two factors greatly reduce the risk of contamination of harvested cucumbers compared to field crops.

Contamination may still occur from trimming, training and harvesting equipment. These tools should be cleaned regularly to reduce risk of contamination. Equipment that contacts the crop, such as trimmers and harvest crates, should never be used for opening or storing chemicals, or other unintended purposes.

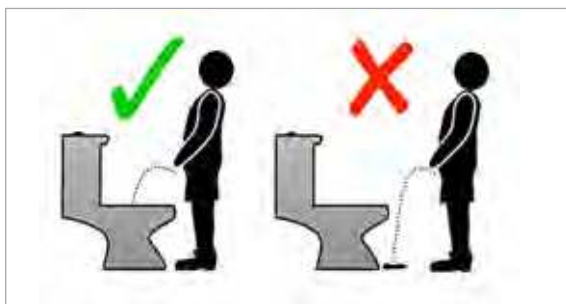
Managing people

For greenhouse cucumbers, the most likely sources of contamination are the workers involved in picking and packing the crop.

Microbial contamination can be caused by workers who are sick or who have poor personal hygiene. Pathogenic bacteria and viruses are found anywhere on the human body, but particularly in and around the anus, nose, mouth and any open sores. Going to the toilet, blowing the nose, sneezing, coughing or smoking can transfer germs onto workers' hands and then onto the product.

Workers can also introduce physical contaminants such as hair, jewellery, bits of clothing, broken fingernails and equipment such as pen lids or staples.

All workers should receive a basic induction to food safety before working in the greenhouse or packing cucumbers. If workers are from non-English speaking backgrounds, then using a translator will help ensure they understand what is expected. Signs may also be provided in the workers' native language, with clear images where appropriate.



If workers are from non-English speaking backgrounds, then providing translated signs and clear illustrations where appropriate will help ensure they understand the standards of hygiene required.

Key points include:

Hand washing

Use clean, drinking quality water and soap to wash hands thoroughly. Handwashing should take around 20 seconds and include between the fingers and up the wrists. Providing warm water encourages workers to spend longer washing their hands.

Dry hands thoroughly using disposable paper towels. If air dryers are used, it is important that hands are left underneath long enough to thoroughly dry. Do not use re-usable hand towels, as they can re-contaminate freshly washed hands.

Wash hands:

- before starting work
- after visiting the toilet
- after coughing, sneezing or blowing the nose
- after eating or smoking
- after handling domestic animals
- after handling rubbish or working on equipment



Providing clean, well equipped toilet and handwashing facilities, with paper towels for drying hands, will encourage workers to maintain good personal hygiene.

Sickness and injuries

Staff who are sick must not handle the cucumbers. Even after a person starts to recover from illness, they may still be infective to others. If they are well enough to work, give a recovering worker tasks that do not involve handling the crop, such as cleaning or checking equipment. This encourages workers to report if they are sick, instead of covering it up.

Cover cuts, minor wounds and sores with bandages and dressings. These should then be secured to prevent them falling off. For example, cuts on hands should be covered with a band-aid held in place using a glove. Coloured dressings (blue) are easier to detect if they do fall off. It is essential that all potentially contaminated product is thrown away if a person is injured while working.



Blue bandaids are easier to see than skin coloured dressings should they inadvertently fall into packed cucumbers.

Gloves

Disposable gloves are preferable to re-usable gloves, as they are less likely to be a source of contamination. However, it is important gloves are replaced after visiting the toilet, blowing the nose or any of the other actions that would make it necessary to re-wash the hands.



Hair, jewellery and clothing

Tie back long hair while working in the greenhouse. If cucumbers are being packed for retail, then use hairnets and beardnets to prevent hairs falling into the packed product. Do not wear jewellery while harvesting or packing. Parts of dangling jewellery break off, creating a physical contamination. Jewellery can provide a place where dirt and microbes can accumulate, contaminating produce.

Dirty clothes, or clothes with loose threads and buttons, can also introduce potential contaminants. Contents of top pockets, such as pens, can easily fall into packed product. Employees packing cucumbers should either wear single use PPE such as aprons and gloves, or supplied clothing that is washed daily.


Treating workers properly

Treating workers with respect and paying them correctly according to the award is not only legally mandated but good business practice. Workers who are angry or resentful do not care about food safety. They are more likely to cut corners, fail to follow procedures and allow packed product to pass through unchecked. In extreme cases they can even cause deliberate and malicious damage to the produce.

It is therefore essential that staff share the values of the business and understand the importance of producing food which is safe for consumers. Creating a food safety culture among the workforce presents its own challenges. However, this is the best defence any business has against contamination risks.



Wear gloves, hairnets and, if necessary, beardnets when handling cucumbers, especially if they are being packed into retail ready punnets.



CUCUMBER DISORDERS AND THEIR MANAGEMENT

Crop disorders are non-pathological problems. Most disorders are related to plant nutrition and caused when a plant gets too little or too much of a particular nutrient. Some disorders are a result of growing, environmental and soil or substrate conditions.

On-farm visual leaf symptoms give a quick clue as to the identity of a disorder. Pocket-sized LED meters are available for testing nitrate nitrogen and potassium in sappy plants like cucumbers quickly on-farm. There are also different test strips available from various manufacturers for rapid on-farm testing of a range of parameters in plant sap and the nutrient solution. Meters can be used with some of these test strips and give a more precise or objective measurement, Pocket-sized meters and/or test strips are available for testing; pH, ozone, water hardness, chlorine, iron, copper, nitrate, nitrite, ammonium, phosphate, magnesium, potassium, calcium, molybdenum, manganese, sodium and aluminium.

Plants respond to nutritional shortages and excesses by expressing characteristic symptoms for each problem. These symptoms can be used as the basis for diagnosis. However, some visual diagnoses can be confused with non-nutritional factors caused by disease, pests, chemicals and/or environmental conditions.

Laboratory plant nutrient analyses are used to confirm or identify and fix nutritional problems. Fast remedial actions are often needed to minimise yield loss or even plant deaths. It is important to recognise symptoms which may indicate nutrients out of balance. Plants only produce symptoms when a nutritional problem becomes serious. Often yield or quality is significantly reduced before symptoms appear.

THIS SECTION INCLUDES

- Macro and micro nutrient deficiencies and their treatment
- Nutrient toxicities
- Physiological disorders

Nutrient disorders

Macro-nutrient deficiencies

Nitrogen deficiency

Most plants need nitrogen in large amounts. A shortage of nitrogen reduces the plant's capacity to trap energy through photosynthesis. Nitrogen is required in the production of chlorophyll (the green pigment in leaves), which is responsible for converting sunlight to useable plant energy.

Both vegetative growth and fruit production are severely restricted when nitrogen supply is inadequate. Plants appear pale and spindly. New leaves are small but remain green, whereas the oldest leaves turn yellow and die. If the problem is not corrected, the yellowing spreads up the shoot to younger leaves. Yield is reduced and fruit are pale, short and thick.

For hydroponic cucumber production, use a nutrient solution containing 150 – 200 ppm N.



Nitrogen deficiency: Compare the grossly stunted pale plant lacking in flowers and fruit (left) with a healthy plant (right). Older leaves turn a uniform pale green to yellow; this condition spreads to younger leaves up the plant.

Phosphorus deficiency

Plants require phosphorus at all stages of growth, but demand is greatest during crop establishment and early plant growth. If phosphorus becomes limiting, it is translocated from older to younger tissues, such as the leaves, roots and growing points. In a crop such as cucumbers, which has a succession of new vegetative and fruiting tissues, a regular supply of phosphorus (and other elements) is needed to ensure that the plant can sustain quality fruit production over a prolonged period.

Phosphorus deficient plants have weak roots, are stunted, and produce small, dark, dull, grey-green leaves. The oldest leaf, at the base of the shoot, turns bright yellow. However, unlike nitrogen deficiency, the leaf directly above this leaf remains dark green. Brown patches appear between the veins on mature leaves. These become scorched and spread until the leaf dies prematurely. Fruit set is reduced and so production is impaired.

For hydroponic cucumber production, use a nutrient solution containing 25 – 50 ppm P.



Phosphorus deficiency: The oldest leaf of this stunted plant is bright yellow but the leaf above it remains dark green.



Phosphorus deficiency: This older leaf shows brown, scorched spots between the veins.

Potassium deficiency

Potassium deficiency influences plant water regulation by affecting cell turgor and the opening and closing of stomata. Deficient crops are prone to wilting.

As potassium is mobile in the plant, it moves to the younger leaves when supplies are short. Although the growth of deficient plants may not be seriously impaired, the yield and quality of fruit are often greatly reduced.

Potassium deficiency causes yellowing and scorching of older leaves. These symptoms begin at the margins of the leaf and spread between the veins towards its centre. Large areas of tissue around the major veins remain green until the disorder is well advanced. A brown scorch develops in the yellow areas and spreads until the leaf is dry and papery. As each leaf dies, others further up the shoot develop the same symptoms. These symptoms can develop rapidly in hot weather. Fruit may not expand fully at the stem end, although they look swollen at the tip end, a symptom that is also caused by water stress.

For hydroponic cucumber production, use a nutrient solution containing 150 – 200 ppm K.

Calcium deficiency

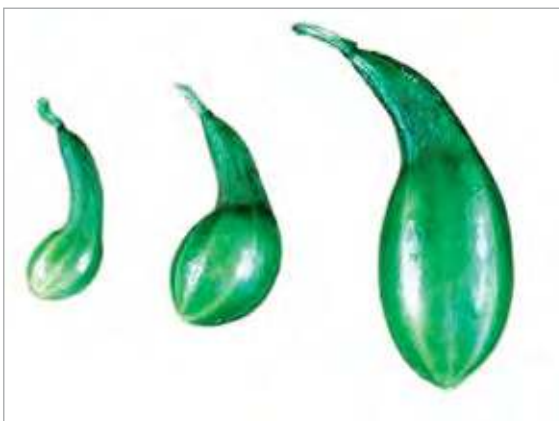
Calcium is important for the functioning of cell membranes and the strength of cell walls. Most calcium related disorders of crops are caused by unfavourable growing conditions and not by inadequate supply of calcium to the roots. Rapidly growing crops in hot and dry conditions are most at risk. Deficiencies can also develop when cucumbers grow quickly under continuously humid conditions. Other contributing factors are waterlogging, soil or substrate salinity, high potassium or ammonium supply and root disease.

Calcium is one of the slowest nutrients taken up by the plant because roots exchange two hydrogen ions for one calcium ion, yet only have to exchange one hydrogen ion for a potassium ion.

Calcium moves in the plant's transpiration stream and is deposited mainly in the older leaves. Deficiencies are found in the youngest leaves and growing points, which have low rates of transpiration. Emerging leaves appear scorched and distorted and may cup downwards because the leaf margins have failed to expand fully. Mature and older leaves are generally unaffected. With a severe deficiency, flowers can abort, and the growing point may die. Fruits from calcium deficient plants are smaller and tasteless. They may fail to develop normally at the blossom end.



Potassium deficiency: Yellowing and scorching of the older leaves begins at the edges (left and centre) and eventually spreads between the main veins towards the centre of the leaf (right).



Potassium deficiency: Fruit fails to expand at the stem end.



Calcium deficiency: Youngest leaves cup downwards and their edges become scorched.

For hydroponic cucumber production, use a nutrient solution containing 150 – 200 ppm Ca. Keep the conductivity of water in the substrate below 2 mS/cm as the incidence of deficiency increases with increasing conductivity, especially during hot weather.

Crop setbacks and fruit losses from calcium deficiency can be reduced by regular foliar sprays of calcium nitrate (800 g/100L) during sudden periods of adverse growing conditions.

Magnesium deficiency

Magnesium is a constituent of chlorophyll. Magnesium deficiency can be induced by heavy rates of potassium fertilisers. Symptoms are more likely to show during cold weather or on heavy wet substrate, when roots are less active.

Magnesium deficiency causes yellowing of older leaves. The symptoms begin between the major veins, which retain a narrow green border. A light tan burn will develop in the yellow regions if the deficiency is severe. Fruit yields are reduced.

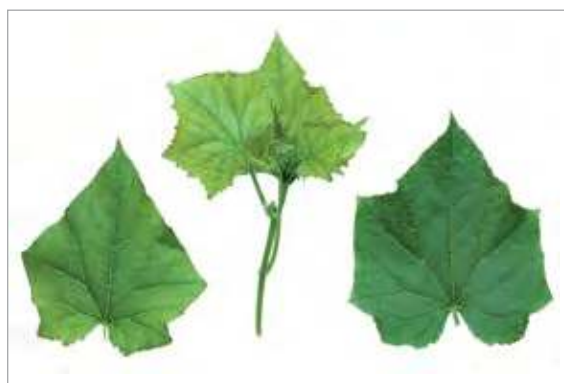
For hydroponic cucumber production, use a nutrient solution containing about 30 ppm Mg.



Magnesium deficiency: Yellowing between the major veins of older leaves (left) turns to a light tan papery burn (right). Younger leaves (centre) are less affected.



Manganese deficiency: The veins of the middle to upper leaves remain green while the rest of the leaf becomes a uniform pale green to yellow.



Iron deficiency: Youngest leaves (left and centre) are pale green to yellow with green veins. In severe cases (centre) the minor veins also fade, and affected leaves appear light yellow to white. Compare with healthy leaf (right).

Micro-nutrient deficiencies

Manganese deficiency

The function of manganese in the plant is closely associated with the function of iron, copper and zinc as enzyme catalysts. Manganese is needed for photosynthesis, respiration and nitrate assimilation. Deficiencies are more likely in alkaline substrates or when amounts of calcium, zinc, magnesium or ammonium are high.

The veins of middle to upper leaves of manganese deficient plants appear green against the mottled pale green to yellow of the blade.

For hydroponic cucumber production, use a nutrient solution containing about 0.3 ppm Mn.

Iron deficiency

Iron is needed to produce chlorophyll and activate several enzymes, especially those involved in photosynthesis and respiration. The most common reason for iron deficiency is a high pH. Iron availability decreases when the pH is above 7. Iron deficiency can be induced by poor substrate drainage, or high concentrations of metallic ions in the substrate or nutrient solution. Iron deficiency can be induced by too much manganese.

Iron deficiency causes a uniform pale green chlorosis of the newest leaves; all other leaves remain dark green. Initially, the veins remain green, creating a net-like pattern. If the deficiency is severe, the minor veins also fade, and the leaves may eventually burn, especially if exposed to strong sunlight.

For hydroponic cucumber production, use a nutrient solution containing 2 – 3 ppm Fe. Iron chelates are generally less likely to precipitate under alkaline conditions and are normally preferred in hydroponic solutions.



Boron deficiency: Older leaves develop a yellow border (centre and left). New leaves are distorted and appear mottled (right).

Boron deficiency

Cucumbers have a fairly narrow requirement for boron. The difference between deficiency and excess is small. For example, in Lebanese cucumbers, a leaf boron concentration of 30 – 70 $\mu\text{g/g}$ is desirable, but deficiency occurs at less than 20 $\mu\text{g/g}$ and toxicity occurs when levels exceed 100 $\mu\text{g/g}$.

Boron is not readily moved from old to new parts of the plant so continuous uptake by roots is needed for normal plant growth. Boron is important in the regulation of developing cells and in pollination. Seed set and fruit development are affected by deficiency.

Boron deficiency causes both leaf and fruit symptoms. The main leaf symptoms are a distortion of newer leaves (in severe cases the growing point dies) and the appearance of a broad yellow border at the margins of the oldest leaves. Young fruit can die or abort; abortion rates are high. The symptoms of boron deficiency on mature fruit are distinctive and include stunted development and mottled yellow longitudinal streaks, which develop into corky markings (scurfing) along the skin. These symptoms are often most severe near the blossom end of the fruit. Similar symptoms can occur on fruit grown with inadequate winter heating. Developing and mature fruit can taper and curve at the blossom end. The proportion of pith to seed is often higher in boron deficient fruit.

Do not confuse symptoms of fruit scurfing and severe twisting with damage by western flower thrips or cold growing conditions.

For hydroponic cucumber production, use a nutrient solution containing about 0.3 ppm B.



Boron deficiency: Aborted fruit (top); twisting and scarring (centre and bottom).



Boron deficiency: Deficient fruit (bottom) have a high proportion of pith to seed and corky markings on the skin compared to normal fruit (top).



Boron deficiency: Longitudinal, mottled yellow streaks (left and centre) develop into corky markings on the skin (right).

Nutritional toxicities

Excess salt

Cucumbers are sensitive to excess fertiliser. Too strong a nutrient solution raises the salinity in the growing substrate. Plants grown under conditions where the growing substrate has a high electrical conductivity (EC) are stunted and produce dark green, dull, leathery leaves prone to wilting. A narrow band of yellow necrotic tissue is often present on leaf edges. This can affect leaf expansion, causing a slight downward cupping of the leaf. After serious water stress, the oldest leaves may develop a uniform pale green chlorosis and small necrotic areas within the leaf. If water supply is maintained, leaves may only develop a band of pale green tissue around their edges. Plants are likely to wilt in warm weather.



High salt or EC: Salinity causes wilting. Leaves appear dull, dark green and cup downwards.



High salt or EC: Leaves appear dull and leathery. A narrow yellow border develops around the leaf margin.

If salt levels are too high, the irrigation volume can be increased to leach the salts from the substrate. Adjust the EC of the nutrient solution or irrigation volume to prevent continued build up of salts.

When general or a range of nutrient problems persist and the nutrient solution is suspected, make up a new solution and flush the substrate well before returning to your normal irrigation schedule.

Phosphorus toxicity

Phosphorus toxicity in vegetable crops occurs almost exclusively in hydroponics. Soils have phosphorus-fixing qualities and limit its availability; however, in a hydroponic solution, phosphorus is available as the phosphate ion. The typical symptoms of phosphorus toxicity are necrotic leaf margins and necrotic lesions on the blades of older leaves. This is similar to symptoms of excess salt. Interveinal chlorosis may also be evident on new leaves, typical of iron deficiency. Symptoms of excess phosphorus tend to be at foliar concentrations of greater than 1% in cucumber. Phosphorus toxicity in hydroponic systems can be a risk if using phosphoric acid to reduce the pH of nutrient solution, particularly in recirculated systems. If adjustments are made frequently, excessive amounts of phosphorus can be added to the nutrient supply. An alternative for adjusting pH downwards is to switch to nitric acid or increase the proportion of ammonium in the nutrient formulation.

In one case study of phosphorus toxicity known to the authors, symptoms of necrotic leaf margins and cupping of expanded leaves were observed in a cucumber crop which utilised a run-to-waste hydroponic system and a coir growing medium. The nutrient solution was normal in its composition but plant analyses showed an excessive concentration of phosphorus in mature leaves (1.33%). The non-symptom leaves also had a phosphorus concentration considered high for cucurbits (0.88%). The crop was growing in a poorly controlled, low-technology greenhouse, exposed to hot and dry conditions a week prior to the symptoms being observed. As a result, the crop most likely suffered a water deficit which manifested as excess fertiliser and yellowing of the leaf margins. Further expansion of leaves at these margins was not possible and resulted in the puffing out of the leaf blade as it grew. The problem may have been avoided by lowering the electrical conductivity (EC) of the solution so that the crop had an increased water supply at the time.

Excess nitrogen

Plants given too much nitrogen are generally stunted and have strong, thick stems, short internodes, a mass of tendrils, short side shoots, fewer flowers, and small fruit. The middle and older leaves cup downwards and wilt easily in warm conditions. Leaf scorching is common. Transparent spots occur between the veins or at the leaf edges, which eventually turn yellow and then brown.

Treat as recommended for excess salt or EC.



Excess nitrogen: Symptoms include wilting and downward cupping of the older leaves, followed by yellow and brown burnt areas on lower leaves.

Chloride toxicity

Cucumbers are moderately sensitive to chloride. Chloride is present in town water supplies and also in some fertilisers, such as muriate of potash (potassium chloride). Do not use these fertilisers if salt is a problem.

Chloride toxicity reduces plant vigour and causes yellowing and scorching of leaf margins, and premature leaf fall.

Find out the source of the chloride and take appropriate steps to prevent the problem occurring again. Water quality should be checked regularly.



Excess chloride: Band of pale green tissue around the leaf margin with some edge scorching associated with 3% chloride in tissue.

Boron toxicity

Cucumber plants are very sensitive to high boron levels (boron compounds have actually been used as herbicides).

Boron toxicity is indicated by yellowing between the veins of older leaves. This is followed quickly by the development of small, brown necrotic spots, which eventually join to form large areas of dead tissue. At the same time, newer leaves become chlorotic and distorted because of damage in the bud. Few female flowers may develop.

Boron toxicities are harder to correct than deficiencies. Problems in crops are usually caused by inaccurate or careless application of boron when batching nutrients or use of foliar applications to treat suspected deficiencies.



Excess boron: Symptoms of boron toxicity are first seen in older leaves. They include yellowing between the veins (left) followed by necrosis. Note small brown necrotic spots (centre) and large areas of dead tissue (right).

Manganese toxicity

Cucumbers are not particularly sensitive to excess manganese. High tissue concentrations are needed before toxicity symptoms show. Manganese toxicity is recognised from the appearance of numerous small, reddish-brown spots between the veins of the oldest leaves and on leaf petioles. In time, the tissue around each spot becomes chlorotic, and the older leaves turn pale and age prematurely. Manganese toxicity can induce iron deficiency.

Manganese toxicity is often linked with acidic conditions and poor drainage. Improve drainage and irrigation scheduling.



Excess Manganese: numerous small reddish-brown spots appear between the veins and on the leaf petiole (overlaid on the leaf).

Zinc toxicity

Zinc toxicity causes a pale green chlorosis of newer leaves. If toxicity is severe, pinhead-sized light-brown spots may appear between the veins. Older leaves may wilt and appear dull. All leaves are a lighter green than is normal.

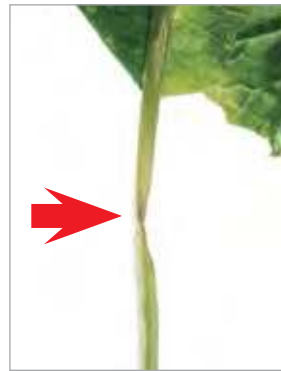
Zinc toxicity in hydroponic systems can be caused by contamination of the water. Contact of corrosive nutrient solutions with galvanised pipes or fittings has been known to lead to zinc toxicity in sensitive seedlings. Galvanised greenhouse frames and wires are other possible sources of excess zinc.



Excess zinc: The older leaf (left) appears dull. The younger leaf is pale green with pinhole-sized light brown spots between the veins (right).



Typical symptoms of water stress when transpiration from the leaves is shut-down but root pressure continues to pump water up the plant.



Arrow indicates water stress on cucumber seedling.



Excess ozone can damage cucumber crops – dosing units need to be regularly checked for any leakages.



There are several factors that can cause curved fruit.

Environmental disorders

Environmental disorders are abiotic or non-parasitic disorders, but they can also result in entry points on the plant for parasitic diseases.

Excess water

Cucumbers may show a range of symptoms if aeration is insufficient. This may be due to over irrigation, poor drainage or decomposition of substrate resulting in loss of porosity. Plants may be slow growing with spindly heads which can wilt and/or turn yellow – similar to iron deficiency. Roots may die back and be prone to disease infection.

Ozone and air pollution

Small white dead flecks on older leaves may indicate damage caused by ozone or other air pollutants. Older leaves can cup downwards and become mottled with pronounced veins. Younger leaves can be small and pale green with dark veins. Severe damage can result in leaves falling off the plant.

Curved fruit

Excessively curved fruit are generally unsaleable. Damage by thrips or mechanical injury when the fruit are first developed can result in curved fruit. Curved fruit may also be caused by poor control of temperature, fluctuating moisture levels in the root zone with periodic waterlogging and poor nutrition. Air pollution such as carbon monoxide and ethylene (from heaters or machinery) can also cause curved fruit.

Tanned upper leaves

Leaves at the top of the plant with a light brown to tan colour may indicate a high leaf temperature. This can occur during very hot dry periods. The day temperature needs to be reduced and the relative humidity increased. Shading or screening of the greenhouse may be needed.

Excess Heat

Temperatures over 32°C in bright sunny conditions can cause cucumber plants to wilt. Plants generally recover when temperatures are reduced but if excessive temperatures continue, the edges of the lower leaves may die. This problem is more common in young plants with underdeveloped and inadequate root systems. Temporary wilting may also occur when hot sunny conditions follow a long period of overcast weather.



Arrow indicates heat stress on cucumber seedling.

Cold

If temperatures drop suddenly, e.g. when a heating system breaks down, cucumbers may respond by wilting. They usually recover once temperatures rise but if cold conditions continue, plant growth is stunted.



Chilling damage on cucumber fruit

Humidity

Guttation and the poor movement of calcium in cucumber plants can occur at high humidity. See page 54 for more information on guttation.



High humidity causes guttation.

Chemical injury

Most pesticides can cause damage to cucumber plants and even kill them. Applying pesticides for 'peace of mind' rather than to manage a specific identified problem can be costly in terms of crop productivity. Copper sprays for example, if overused, can cause copper toxicity in cucumbers and lead to resistance problems.

When mixing different chemicals, it is essential that you check which chemicals are compatible when mixed together. You also need to check whether the temperature (usually not above 30°C), the time of day, the available substrate moisture and foliage wetness are suitable for applying a pesticide.

Many pesticides can cause symptoms which can be confused with other disorders or diseases. Be careful to avoid drift into the crop when applying herbicides around greenhouses, particularly if they are open for ventilation.



Pesticide injury on cucumber seedlings.




Hormone herbicide damage on cucumber plants.



Although widely used on several horticultural crops as a fungicide and miticide, cucumber plants are not so tolerant of sulphur.

Table 30. Quick guide to common nutritional disorders

Symptoms first in older leaves – uniform leaf colour	
Pale green to yellow leaves; stunted growth. Stems are slender, hard and fibrous.	Nitrogen deficiency
Leaves are dull (no lustre), grey green or purple; poor plant growth.	Phosphorus deficiency
Plants are wilting; leaves dull, dark, leathery; leaf edges yellowing.	Chloride toxicity
Symptoms first in older leaves – coloured or mottled pattern on leaves	
Leaves are scorched and yellow around the edges and between main veins. Leaves stay green near veins for some time.	Potassium deficiency
Yellowing between veins spreading all over leaf, followed by light brown burn. Veins remain green.	Magnesium deficiency
Reddish spots appear between veins and on petioles.	Manganese deficiency
A broad yellow band forms around edge of leaves. When severe, new leaves are yellow and distorted.	Boron toxicity
Necrotic leaf margins and necrotic lesions appear on older leaves.	Phosphorus toxicity
Symptoms first in young leaves – coloured or mottled pattern on leaves	
Leaves become clear between veins leaving a faint green network ('skeleton') of veins.	Iron deficiency
New leaves are pale green to yellow. Light brown spots appear between veins.	Zinc toxicity
Symptoms in young and mature leaves – coloured pattern on leaves	
Leaves have a mottled, diffused pale green to yellow colour between green veins.	Manganese deficiency
Necrotic leaf margins and necrotic lesions appear on older leaves. Interveneal chlorosis may also be evident on new leaves.	Phosphorus toxicity
Symptoms first on fruit and growing points	
Growing points die; fruit breakdown; youngest leaves cup downwards; misshapen fruit; water soaked and necrotic lesions on blossom end; 'pillowy' fruit disorder; short, thick fruit.	Calcium deficiency
Fruit has long mottled yellow streaks; fruit is corky; new leaves are distorted (puckered or crinkled); growing points die.	Boron deficiency
Symptoms on fruit and growing points	
Fruit are short, pale and may be pointed at the stem or distal end.	Nitrogen deficiency
Fruit fail to expand at stem end. Plant growth is slow as symptoms move to younger leaves.	Potassium deficiency
Fruit are dull green to bronze.	Phosphorus deficiency
Plants are small and appear weak as symptoms move upwards from lower leaves. Yields are low and fruit quality is poor.	Magnesium deficiency
Symptoms in roots	
Root growth is stunted.	Nitrogen deficiency
Poor root growth.	Both phosphorus & calcium deficiency



CUCUMBER DISEASES AND THEIR MANAGEMENT

Diseases can cause severe losses to greenhouse cucumber crops. The warm, humid greenhouse environment favours a number of plant pathogens (disease-causing organisms) that can infect cucumbers.

Good Agricultural Practice in greenhouse cucumber disease management is reliant on good crop hygiene practices and getting a fast positive diagnosis of any unfamiliar or unusual plant symptoms.

THIS SECTION INCLUDES

- Principles of integrated disease management
- Diagnostic services
- Fungal diseases
- Bacterial diseases
- Viruses
- Nematodes

Integrated disease management

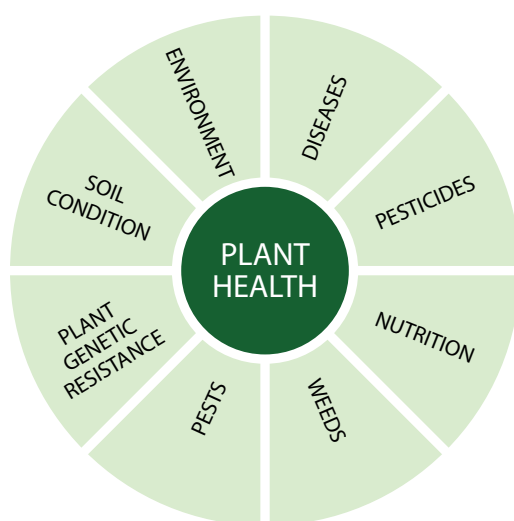
Integrated disease management is the practice of using preventative measures to minimise the risk of disease infection and spread. During the cropping cycle regular crop monitoring is used to decide if and what action is needed.

Today, the term integrated pest management (IPM) is used to describe the use of a range or suite of practices to managing any kind of pest, including diseases. IPM is fundamentally a subset of the good agricultural practices used to produce profitable and productive crops in a sustainable way. For convenience, diseases (caused by plant pathogens) and pests are addressed in separate sections.

A disease is a debilitating condition in a plant, affecting the plant's normal functioning or development. For a disease to impact on a crop, three predisposing criteria must exist:

1. A pathogen is present, on or in the plant.
2. There are suitable environmental conditions for the pathogen to grow and infect the plant.
3. The plant is susceptible to the disease.

Maintaining plant health is the best way to manage disease.



Plant health and susceptibility to disease are affected by many factors in the growing environment, not just the presence or absence of a pathogen.



Foot pads or baths at every entrance to the greenhouse.

Hygiene

The most effective way of managing diseases in cucumbers is to prevent pathogens getting into the crop. Make sure that all materials, containers, or equipment that you bring into the greenhouse are clean. Install and maintain a foot pad or bath at every entrance to the greenhouse. Although commercial foot pads are available, a rectangular tub with a piece of foam and disinfectant solution is an effective do-it-yourself alternative. Make sure every person entering the greenhouse uses the footbath each time they enter. Change the disinfectant solution at least every few days; more frequently if it looks muddy.

Note that it may not be possible to keep all pathogens out of a greenhouse – some diseases of greenhouse cucumbers first appear on plants under the vents or other openings because airborne spores blow into the greenhouse. Despite this risk, good hygiene significantly reduces losses caused by disease.

If possible, empty the greenhouse completely between crops and clean the structure. Cucumber growers with clean greenhouses have significantly fewer problems with disease.

Control entry

Control access to the greenhouse. It is important to understand that pathogens (and pests) are easily carried on clothing and shoes. Many diseases in greenhouse crops first appear near doorways. The fewer people entering the greenhouse, the smaller the chance that pathogens (and pests) will be carried into the crop.

When people are visiting, have them wear disposable overalls and keep to marked paths wherever possible. Avoid having visitors who have come directly from another greenhouse. If visitors and workers are



Visitors should keep to designated paths and wear disposable protective clothing before entering the greenhouse.

moving between different crops, always move from the youngest and healthiest crop plantings through to the older crops (that may be infected) to reduce the risk of spreading pathogens.

Start with disease-free plants

If buying seedlings, inspect them upon delivery. If any plants have disease symptoms, tell the delivery person or truck driver immediately. Remove the diseased looking plants, put them in sealed plastic bags and submit them for diagnostic testing. Have a special designated clean area or greenhouse to store seedlings prior to transplanting. Before moving new plants into the greenhouse, check them for any sign of pests or diseases. Do not plant out any plants that are, or appear to be, diseased or infested with pests.

Choose crops and varieties that are resistant to pests and diseases if possible. Many cucumber cultivars are resistant or tolerant to several diseases, including powdery mildew, downy mildew and cucumber mosaic virus. However, no cultivar is resistant or tolerant to all diseases. Good disease management is essential to minimise crop losses.

Control the growing environment

Controlling the greenhouse environment to make conditions less favourable for disease organisms is a very effective method of disease control. Good temperature and humidity management are essential to minimising disease in greenhouse cucumbers, particularly for downy and powdery mildews



Water remaining on flowers can allow infection by several pathogens, notably grey mould (*Botrytis*), white mould (*Sclerotinia*) and gummy stem blight.

(opposite environmental conditions favour each) and grey mould (*Botrytis cinerea*). Condensation or dew on leaves predisposes the plant to attack from diseases, particularly if plant tissue is damaged by pruning and picking wounds, or chilling or heat damage to the upper extremities of the plant. Condensation or dew can also dilute fungicide applications so that, over time, resistance problems become evident. Guttation is another way diseases can attack greenhouse cucumber crops. The exudate, along with any pathogen, is sucked back into the plant during the day.

Inspect plants regularly

Monitoring the crop regularly enables early detection of diseases and improves the efficacy of control strategies. Walk up and down every row and inspect at least 5% of all plants in the crop. Some diseases occur in certain locations in a greenhouse because of localised 'microclimates'. For instance, powdery mildew usually commences in the shadier areas, while grey mould occurs where moisture sits on plants. Target these areas for closer inspection or surveillance to catch diseases at an early stage of development. Tie coloured plastic tape or ribbon in these areas to signify 'hot spots' for diseases. If required, 'spot-spray' these areas with a small compression or backpack sprayer rather than needlessly treating the whole crop.

Waste management

Remove and destroy crop residues as soon as possible after pruning and harvest. Do not pile removed plant material near the greenhouse. Put pruned material directly into bags or a rubbish skip bin for disposal – not on the ground. Make sure the skip bin is removed regularly to avoid a breeding place for diseases. Crop debris can be buried if done immediately and not left stockpiled. Burning crop debris may contravene local environmental plans.

Control insects and weeds

Control insects and weeds inside and outside the greenhouse. Weeds can harbour diseases and pests of cucumbers. Insects can carry diseases. If feasible, place insect screens over all openings in your greenhouse. Be aware that screens reduce the flow of air and will impact on the ventilation capacity of the structure. Poor air circulation can increase diseases such as grey mould, *Alternaria* and downy mildew. A vestibule area – a sort of ‘air lock’ or double-doors – at the entrance helps reduce insect entry.

Fungicides

There are two different types of fungicides used to manage diseases – protectants and eradicants.

Protectants sit on the surface of plants. To be effective they need to contact the pathogen. As new growth needs to be protected, growing plants need on-going protectant spray applications. These chemicals generally control a wide range of fungal pathogens. When using protectants, make sure plant coverage is thorough and even.

Eradicants, or curatives, are pesticides absorbed by plants. They can control pathogens at sites some distance away from where the chemical droplets land on the plant. These chemicals may move into new growth or from the upper to lower leaf surface. As a result, they do not need to be applied as often as protectants. Unfortunately, because these pesticides act at a specific chemical site in the pathogen’s metabolism, their continued use can lead to resistance developing. This occurs regularly with both downy and powdery mildews, and grey mould.

Identifying cucumber diseases

Be aware that other factors can cause symptoms in cucumbers which may look like a disease. These include nutritional deficiencies or toxicities, unfavourable environmental conditions including temperature and light, and phytotoxic effects (crop burn) from pesticides and other chemicals.

Plants grown in environmental conditions that favour rapid growth, tend to be attacked by pathogens that only develop in living tissues (obligate parasites) such as powdery mildew. However, when plants are stressed they are more susceptible to pathogens that have the ability to live under different conditions and get their food from non-living organic matter (facultative parasites) such as grey mould and *Pythium* species.

Effective management of diseases depends on the ability to quickly recognise cucumber disease symptoms and correctly identify the cause. However, be careful when attempting to diagnose diseases from pictures or descriptions – you may have an uncommon or new disease that superficially looks like another, or the symptoms may be a result of growing conditions or other factors.

At the first sign of an unfamiliar symptom, send sufficient samples for diagnosis by an expert. Not only will this ensure that you apply the correct and legal control method, but new diseases are identified.

Correct diagnosis requires a plant sample that shows the full range of symptoms present on the crop. When sending plant specimens, include several affected plants that range from early symptoms to some with severe or ‘full-blown’ symptoms. It is useful to also include an apparently healthy plant.

Samples should consist of whole plants including roots and some attached growing substrate. Keep samples as fresh as possible by wrapping in moist newspaper. Refrigerate them if they are kept overnight. Hand deliver, courier or send the sample by Express Post. Clearly mark your name and address on the package. Material dispatched by post or courier should be sent early in the week to avoid being held over during the weekend.

Plant Health Diagnostic Service

NSW Department of Primary Industries

Location: Elizabeth Macarthur Agricultural
Institute (EMAI)
Woodbridge Rd, Menangle

Postal address: Private Bag 4008 Narellan NSW 2567

Telephone: (02) 4640 6428

Crop Health Services

Agriculture Victoria

Location: AgriBio Specimen Reception Main
Loading Dock 5 Ring Road
La Trobe University Bundoora VIC
3083

Telephone: (03) 9032 7515

Grow Help Australia

Delivery address for courier and sample drop-off
(preferred)

Attn: Grow Help Australia
Department of Agriculture and Fisheries (DAF)
Ecosciences Precinct 41 Boggo Rd Loading Dock,
Basement 3 Joe Baker Street DUTTON PARK QLD 4102

Postal address for Australia Post deliveries, including
express post

Note: Overnight express post doesn't guarantee
overnight delivery to this address—delivery
sometimes takes 2 days.

Attn: Grow Help Australia
DAF
Ecosciences Precinct (ESP) GPO Box 267 BRISBANE
QLD 4001

Telephone: 13 25 23

Email: growhelp@daf.qld.gov.au

Plant Diagnostic Services

Department of Primary Industries, Parks, Water and
Environment (Tasmania)

Address: New Town Laboratories
13 St Johns Avenue,
NEW TOWN TAS 7008

Telephone: (03) 6165 3252, 1300 368 550

Plant Research Centre

Location: Waite Campus, 2b Hartley
Grove, Urrbrae SA 5064

Telephone: (08) 8303 9400

Postal address: GPO Box 397, ADELAIDE, SA 5001

Email: pisa.sardi@sa.gov.au

**Department of Primary Industries and
Regional Development (DPIRD)**

Address: 3 Baron-Hay Court
South Perth, WA 6151

Telephone: 1300 374 731

Email: enquiries@dpiird.wa.gov.au

Plant Diagnostic Service

Courier address: Plant Pathology Section, BAL
Building, Berrimah Farm, Makagon
Road, Berrimah NT 0828

Postal address: GPO Box 3000, DARWIN, NT 0801

Telephone: (08) 8999 2218

Email: plant.pathology@nt.gov.au

Fungal diseases

Alternaria leaf spot

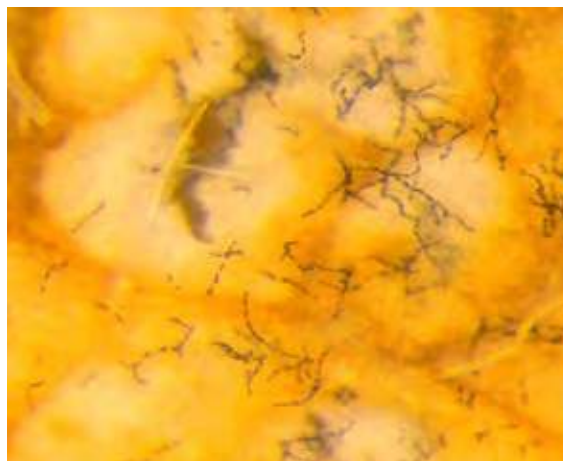
Alternaria leaf spots are caused by the fungi *Alternaria cucumerina* and *A. alternata*. These fungi survive on crop debris in soil and substrate and may also be carried on seed. This disease is spread by air and water. Warm temperatures and moisture on leaves favour this fungus. Crops that have developed lush growth from excess fertiliser application are more prone to infection.



Early stages of infection, showing small spots on the upper leaf surface.



Advanced leaf spot symptoms.



Close up of chains of dark fungal spores on dead tissue in the centre of spots.

Symptoms

Small, circular, tan spots develop on upper leaf surfaces. These turn brown, enlarge and may cover entire leaves. Infected fruit develop sunken brown spots. Under humid conditions and in transit or storage these spots become covered with a black powdery mat of fungal spores.

Management

Some cultivars have greater tolerance of this disease than others. Growing these cultivars should be the primary management strategy. It is important that residues from previously infected crops are removed and the greenhouse cleaned before planting a new crop.

Excess vegetative growth can also encourage this disease. Avoid over fertilisation and control plant growth balance.

Check with your pesticide supplier, InfoPest® or the APVMA website (www.apvma.gov.au) for more information and for what is registered, or has a current off-label permit, in your state or territory.

Anthracnose

Anthracnose is caused by the fungus *Colletotrichum orbiculare*. The fungus can survive in soil and on crop debris, especially discarded fruit. It can survive for up to two years without a host. It can also survive in infected seed.

Anthracnose can be spread by splashing water, insects, and people and machinery moving through the crop when it is wet. The fungus is favoured by warm, humid conditions.

Symptoms

Leaves, stems and fruit may be affected. Red-brown to black spots occur on leaves, while long, dark, sunken spots appear on stems. These lesions may completely encircle stems, causing vines to wilt and die. Masses of pink spores ooze from lesions under humid conditions. Fruit have characteristic round, sunken spots with masses of pink spores. Fruit which is unblemished when picked may develop symptoms during storage and transport. The disease develops rapidly on ripening fruit.

Management

Good environmental control greatly reduces the risk of this disease. Keeping plants dry will help avoid disease development. Control humidity in the greenhouse to avoid dew forming on surfaces, particularly when nights are cool. Time application of pesticide/biological sprays to avoid leaving the crop wet for long periods. For example, avoid spraying plants in the late afternoon or evening.

Make sure plants are dry before vents close for the evening. If plants are wet, raise the temperature and increase air circulation to speed up drying. During the night, conduct purge cycles – heating then venting for short periods (up to 15 minutes) to remove moisture.

If plants become wet during the night, it is due to condensation. This can happen when the plants are colder than the humid air around them. To control this problem, include strategies such as reducing the air temperature or reducing humidity.

Make sure that residues from previously infected crops are removed and the greenhouse is cleaned before planting a new crop. Do not market fruit from diseased plants, as symptoms may appear later in transit or storage. This can adversely affect your reputation in the marketplace.

There are a number of chemical actives for controlling Anthracnose on cucumbers in Australia. Check with your pesticide supplier, InfoPest® or the APVMA website (www.apvma.gov.au) for more information and to find out what products are registered, or have a current off-label permit, in your state or territory.

Botrytis rot (grey mould)

Grey mould is caused by the fungus *Botrytis cinerea*. Any dead or dying plant debris can be a primary source of infection. Spores are produced on infected plants under very humid conditions and are spread by wind, air currents and people's movement in and around the greenhouse.

The fungus is favoured by moist air and mild temperatures between 18 and 24°C. Infection is rare above 25°C but can occur at temperatures below 20°C. It is most likely when condensation forms on plants. Water is required for spores of the fungus to germinate and infect.

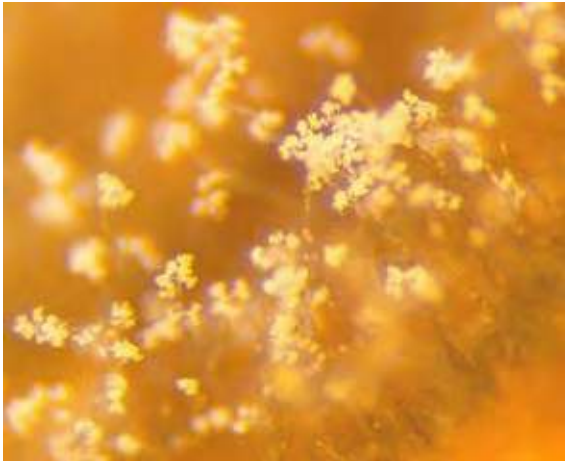
Botrytis can attack several parts of a cucumber plant. Fruit is infected through dying flower petals. Infection also occurs through wound sites and aborted fruit. For example, pruning, growth cracks, tissue damaged by other diseases or scalds due to the wrong application of chemicals all provide potential entry sites for this fungus. *Botrytis* also tends to prefer plant tissue sites that have higher assimilate (sugar) levels.

Symptoms

The disease develops rapidly as a slightly sunken, water-soaked, greyish green area with a definite margin. In humid conditions grey spore masses form on infected areas.



Grey mould leaf spot.



Closeup of clusters of spores.

Management

Good environmental control greatly reduces risk of this disease. Rising and falling humidity release grey mould spores for airborne dispersal. Controlling humidity in the crop is one of the most important strategies to prevent and control this disease.

Guttation favours the development of diseases such as grey mould. When the leaves transpire normally during the day, some of the exudate – along with any spores – is sucked back into the xylem. Here it is protected from fungicides. Grey mould spores can remain latent inside the plant for up to 10 weeks before germinating. Keep relative humidity below 90%. Control greenhouse temperatures, ventilation and air circulation. Keep leaves and flowers dry to prevent condensation. Avoid excess vegetative

growth. Overcrowded plantings reduce air circulation and increase humidity.

Make sure plants are dry before vents close for the evening. If plants are wet, raise the temperature and increase air circulation to speed up drying. During the night, conduct purge cycles – heating then venting for short periods (up to 15 minutes) to remove moisture.

If plants become wet during the night, it is due to condensation. This can happen when the plants are colder than the humid air around them. To control this problem, include strategies such as reducing the air temperature or reducing the humidity.

Make sure that residues from previously infected crops are removed and the greenhouse is cleaned before planting a new crop. Do not market fruit from diseased plants, as symptoms are likely to appear during transport, storage or retail. This can adversely affect your reputation in the marketplace.

Do not handle diseased plants before healthy ones. Avoid unnecessarily wounding plants. Remove fruit and leaves with secateurs or a picking knife rather than snapping or breaking the plant with fingers.

Excess vegetative growth can also encourage this disease, so avoid over fertilisation and control plant nutrient balance.

There are several products registered for controlling *Botrytis* on cucumbers in Australia. Check with your pesticide supplier, InfoPest® or the APVMA website (www.apvma.gov.au) for more information and to find out what products are registered, or have a current off-label permit, in your state or territory.



Grey mould lesions on cucumber stem.



Grey mould on cucumber fruit.

Damping-off

Damping-off is caused by the fungi *Rhizoctonia solani* and several species of *Pythium*.

These fungi are common soil organisms and infect a wide range of crop and weed hosts. Decaying crop residues in soil and substrate can act as a source of infection. Fungi can therefore spread on soil, equipment and workers that have contacted contaminated soil or substrate. *Pythium* is also spread in water.

Damping-off is generally favoured by cool temperatures. However, some *Pythium* rots are specific to high temperatures. Overcast conditions, wet soil and poor aeration also increase damping-off.

Root damage can lead to increased infection by *Pythium*. Roots can be damaged by a high concentration of nutrients (cucumber roots and root hairs have been found to be damaged when soluble nutrient levels have an EC measurement of 3.5 to 5.0 mS/cm). High temperatures, chemicals, insufficient water, poor aeration and some pests such as fungus gnats (sciarid flies) also damage roots.

Symptoms

A water-soaked lesion occurs at the soil level, and seedlings wilt and collapse. These fungi are also associated with other organisms that cause premature death after the first few fruit have set. See the section on fungal root rot diseases (page 154) for further information.



Pythium root rot/ Damping-off on a cucumber seedling.

Management

Hygiene and good sanitation are the primary strategies for controlling damping-off. Good irrigation management is essential. Always use clean substrate. Make sure that the water supply used does not carry *Pythium* fungus. Reduce plant stress by optimising irrigation and nutrition. Poor aeration, high root zone EC and high root zone temperatures can damage roots and encourage this disease.

It is important that plant residues, substrate and dirty containers from previously infected crops are removed and the greenhouse and hydroponic system rigorously cleaned before planting a new crop.

There are limited products registered for controlling damping-off. Check with your pesticide supplier, InfoPest® or the APVMA website (www.apvma.gov.au) for more information and to find out what products are registered, or have a current off-label permit, in your state or territory.

Fusarium Wilt

Fusarium wilt is caused by the fungus *Fusarium oxysporum* f.sp. *cucumerinum* (referred to here as *Foc*).

In Australia, *Foc* causes serious losses of greenhouse cucumbers in lower technology structures. *Foc* can infect the roots of other plant species, including the solanaceous vegetables (tomatoes, capsicums and eggplants), but symptoms do not develop in these plants. Once established on farms it becomes an ongoing problem. It survives in plant residues and in soil and media. This fungus can be spread by soil, water, equipment and insects such as fungus gnats (sciarid flies). Roots damaged by sciarid fly larvae are readily infected by *Foc*.

High moisture levels surrounding roots, high ammonium nitrogen fertilisers and poor aeration increase the likelihood of Fusarium wilt.

Infection and disease development is favoured by root damage, high temperatures, chemicals, insufficient water, poor aeration and pests such as fungus gnats (sciarid flies).



Yellowing older leaves on plants infected by *Fusarium* wilt.



Salmon pink fungal growth on the stem base.

Symptoms

Water-soaked lesions at the plant base are similar to diseases such as *Pythium* and *Rhizoctonia*. Often *Pythium* and *Foc* occur together causing seedling collapse. The characteristic symptoms of *Fusarium* wilt are yellowing of the older wilted leaves and the development of orange or pink fungal growth on stem lesions.

Management

Grafting cucumbers onto resistant rootstocks is required since all commercial cucumber varieties are susceptible to the common strain of this pathogen in Australia. Having sound hygiene and sanitation



Adventitious roots growing into the media from above the graft.

practices are the primary strategy for controlling *Fusarium* wilt in susceptible cucumber varieties.

Irrigation management is important; applying less volume of nutrient solution more frequently is preferable to applying large volumes that saturate roots. In cooler months, withholding nutrient supply earlier in the afternoon is required to ensure roots don't remain saturated overnight.

When using grafted plants ensure they are not planted too deep. This will help ensure that adventitious roots do not grow from the susceptible variety into the medium. Grafted seedlings established on rockwool cubes avoid this issue.

Use clean substrate if the disease occurred in the previous crop and ensure that the greenhouse surfaces are sanitized before commencing a new cropping cycle. All crop residues and substrates from the previous crop should be removed and disposed of.

Downy mildew

Downy mildew is caused by the oomycete *Pseudoperonospora cubensis*.

Spores are carried on wind, air currents, people and tools. Symptoms develop very rapidly at warmer temperatures, providing conditions are moist and humid. Moisture is needed for infection to occur. High humidity at night is required for spores to develop. A drop in humidity (usually at sunrise) allows them to detach and spread.

Symptoms

Infected leaves first show light green markings that develop into angular yellow leaf spots. These eventually turn brown. The spots can be confused with angular leaf spot, a bacterial disease. A fine white to grey growth develops on the lower surface.

In humid conditions this turns grey to purple as spores form. If there are many spots, the leaf shrivels inwards and dies. Severe infections result in defoliation, stunting and poor fruit development.

Management

Hygiene and good sanitation are the primary strategies for controlling downy mildew. Good environmental control greatly reduces the risk of this disease. Cultivars vary from highly susceptible to moderately tolerant. Select a tolerant cultivar when possible.

Monitor crops closely for the first sign of this disease. Reduce the humidity in the greenhouse before spores have formed. Maintain good air circulation in the greenhouse. Remove older crops infected by mildew as soon as possible. Prevent condensation and keep plants dry.

Make sure the crop is dry before vents close for the night. Do not spray plants in the late afternoon or evening. If plants are wet, raise the temperature and increase air circulation to speed up drying. During the night, conduct purge cycles – heating then venting for short periods (up to 15 minutes) to remove moisture.

If plants become wet during the night, it is due to condensation. This can happen when the plants are colder than the humid air around them. To control this problem, include strategies such as reducing the air temperature or reducing the humidity.

It is important that plant residues, substrate and dirty containers from previous infected crops are removed and the greenhouse and all surfaces are sanitised before planting a new crop.

Various preventative and curative agrichemicals are registered for control of this disease. Check with your pesticide supplier or the APVMA website (www.apvma.gov.au) for more information and for what is registered, or has a current off-label permit, in your state or territory.



Symptoms of downy mildew.

Powdery mildew

Powdery mildew is caused by the fungus *Podosphaeria fusca* (formerly called *Sphaerotheca fuliginea*). The main source of infection is other infected cucurbit crops, other plants and weeds.

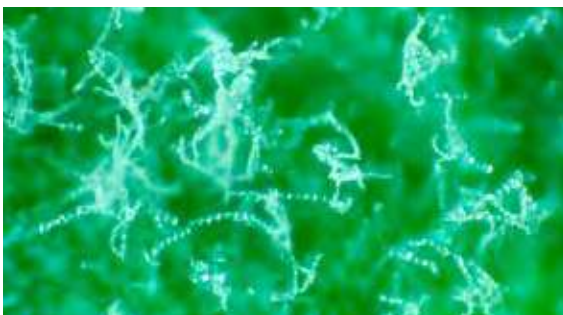
The spores of this fungus are carried on wind and air currents. The disease is favoured by moderate temperatures (20–25°C), relatively dry conditions, low light intensity and luxuriant plant growth. Plants that are slightly deficient in potassium, phosphorus or magnesium are also more likely to become infected. Late (autumn) crops are usually affected more severely than early or mid-season crops.

Symptoms

White, powdery leaf spots first appear on the lower surfaces of the older leaves and may later spread to cover both leaf surfaces and the stems. Older leaves gradually turn yellow and die, and vines become stunted.



Symptoms of powdery mildew.



Closeup of chains of powdery mildew spores.

Management

Hygiene and good sanitation are the primary strategies for controlling powdery mildew. Good irrigation and nutrient management is essential.

While some cultivars are moderately resistant to powdery mildew, others are susceptible. A number of races of this fungus exist, but there are no extensive studies of which occur in Australia. Cultivars may have resistance to one race of this fungus but be susceptible to another.

Monitor crops closely for the first sign of this disease.

It is important that plant residues from previous infected crops are removed and the greenhouse and surfaces sanitised before planting a new crop.

A number of protective and curative fungicides are registered for control of this disease in cucumbers. Check with your pesticide supplier or the APVMA website (www.apvma.gov.au) for more information and for what is registered, or has a current off-label permit, in your state or territory.

If disease pressure is high, use protectant fungicides until early fruit set and then alternate protectant and systemic fungicides.

Gummy stem blight

The fungi *Stagonosporopsis species* (formerly known as *Didymella bryoniae*) cause gummy stem blight. The main sources of infection are infected crop residues and seed.

The spores of this fungus are carried on wind and air currents. An important method of disease transmission is through wounds caused by pruning, harvesting, insects, other diseases or environmental conditions. Wounding is essential for infection of older plant parts and fruit but not of younger tissue, which has not developed a waxy surface layer. Flowers can also be infected, after which the fungus grows into fruit.

The disease is favoured by moist conditions and very high relative humidity (approaching 100%) especially when coupled with cool night temperatures.

Symptoms

Stems, leaves and fruit may be affected. The stem is most frequently attacked, particularly around the crown. Water-soaked cankers develop and may become light brown or whitish and sunken. They are covered with small black dots, which are the fruiting bodies of the fungus. The cankers may split open and

exude a reddish gum. If the canker encircles the stem, the vine wilts and dies. Spots on the leaves are black and may contain small black fruiting bodies.

Round or irregular sunken spots form on the fruit after harvest. Fruit infected through flowers have pinched and angular outlines at the flower end. When cut lengthwise, a brown streak is seen running along the centre. Infected fruit often have a black, leathery appearance. This black rot stage of the disease may cause losses in the field, in transit or in storage.

Management

Hygiene and good sanitation are the primary strategies for controlling gummy stem blight. Good environmental control greatly reduces risk of this disease. If nights are clear and cold, then plant tissue, particularly the upper parts of the plant, can become chilled and damaged. Dew formation at these sites can predispose the plant to gummy stem blight infection.



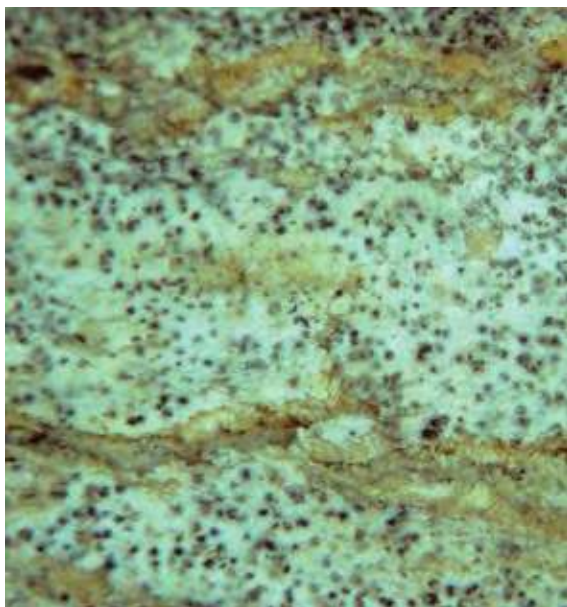
Reddish gum oozing from the stem of a plant infected by gummy stem blight.



Brown internal rot at the flower end of cucumber fruit.



Gummy stem blight effects on cucumbers.



Closeup of gummy stem blight infection. Black dots are spores.

Control humidity in the crop, especially during the transition periods between night and day. Raise the greenhouse temperature gradually before sunrise. If plants are wet, increase the temperature and air circulation to speed up drying. During the night, conduct purge cycles – heating then venting for short periods (up to 15 minutes) to remove moisture.

If plants become wet with dew, it is due to condensation. This can happen when the plants are colder than the humid air around them. To control this problem, include strategies such as reducing the air temperature or humidity.

Make sure the crop is dry before vents close for the night. Time application of pesticide/biological sprays to avoid leaving the crop wet for long periods. For example, avoid spraying plants in the late afternoon or evening.

Vent in the afternoon to reduce humidity before the transition from day to night. Water stressed cucumbers are much more prone to internal fruit rot caused by gummy stem blight but the flowers are less prone to infection.

Monitor crops closely for the first sign of this disease. Where gummy stem blight has occurred in a crop, pick fruit carefully, avoid injury and market produce promptly. It is important that plant residues from previous infected crops are removed and destroyed and the greenhouse and hydroponic system cleaned before planting a new crop.

Varieties vary in their sensitivity to this disease. Single fruited varieties are best used during periods when gummy stem blight is expected as they have a faster growth rate and offer less opportunity for this pathogen to infect fruit. Plants overloaded with early stem fruit are more susceptible to gummy stem blight infection.

There are a number of products registered for control of gummy stem blight on cucumbers. Check with your pesticide supplier, InfoPest® or the APVMA website (www.apvma.gov.au) for more information and to find out what products are registered, or have a current off-label permit, in your state or territory. Use a spray strategy that reduces the risk of resistance problems. If disease pressure is high, use protectant fungicides.

Fungal root rot, stem and wilt disease complex

Various species of *Pythium* and sub-species of *Fusarium oxysporum* can infect plants together, forming a root rotting and plant wilting disease complex. The main sources of infection are infected crop residues, recycled irrigation water, dust and wind-blown debris. Cucumber plants of all sizes and ages are susceptible.

Although these pathogens commonly occur together they can also infect plants separately. *Fusarium* wilt described separately above is caused by a discrete strain of *F. oxysporum*. There are several other strains of this species that can cause root and collar rots which can eventually cause plants to wilt. In warmer conditions, a particular species of *Pythium* (*P. aphanidermatum*) can cause root rots leading to mature plants wilting and dying.

These fungi are widespread and survive for long periods in soils and substrates. They are spread by water and soil adhering to machinery, shoes or other items.

Continual cropping and persistent hot or cool weather (depending on the species involved) favour these diseases. Root damage increases sites for infection.

Symptoms

Root rot fungi cause stunting, wilting and death of plants. This fungi disease complex can also be associated with damping-off of young seedlings. Older infected plants or surviving seedlings are stunted, with yellowed, wilting leaves. Initial symptoms are a pale-yellow to brown rot on stems near the base of infected plants. *Fusarium* infects the vascular (water conducting) tissue inside the stem near the base of the plant, which turns reddish-brown as the disease progresses. Maggots of sciarid or compost flies and soft rotting bacteria may become numerous in lesions at the base of plants as the disease develops. Wilting tends to be more severe during the middle part of the day.

Management

This disease complex affects cucumbers and capsicums. Hygiene and good sanitation are the primary strategies to control these diseases. Tomato roots can be infected with the *Fusarium* that affects cucumbers without causing any disease symptoms. It is therefore very important that plant residues including used substrates and dirty containers



Plant wilting due to root rots.



Root rot can be caused by various species of *Fusarium*, *Rhizoctonia* and *Pythium*.

from previously infected crops are removed and the greenhouse cleaned before planting a new crop. Careful hygiene by workers is very important, particularly in handling plants and contaminated clothes.

Only use clean, disease free seedlings. Always use clean, fresh seed. Grafting onto a tolerant rootstock may also provide a feasible management strategy.

Good nutrient and irrigation management is essential. Avoid long irrigation periods and high fertiliser rates that can create poor aeration and high root zone EC (3.5 to 5.0 mS/cm). These conditions can damage roots and encourage infection from these fungi.

It is common practice in many countries to manage early *Fusarium* crown and root rots in greenhouse cucumbers by manipulating or directing sugars in plant tissue. *Fusarium* pathogens tend to prefer plant tissue sites that have lowered assimilate (sugars) levels (opposite to *Botrytis*). For this reason, it is recommended to remove the early stem fruit, so that the sugars will be diverted away and into the stem tissue where *Fusarium* is trying to enter the plant.

Currently there are no chemical actives for controlling *Fusarium* crown or root rots lawfully on cucumbers in Australia. Check with your pesticide supplier, InfoPest® or the APVMA website (www.apvma.gov.au) for more information and for what is registered, or has a current off-label permit, in your state or territory. Fumigation treatments are registered for soil disinfection.

White (Sclerotinia) rot

White rot of greenhouse cucumbers is generally caused by the fungus *Sclerotinia sclerotiorum*. The resting bodies of the fungus (called sclerotia) can survive in soil and substrates for long periods. Under suitable conditions sclerotia will germinate. The germinating sclerotia can either infect the base of the plant directly or produce small, brown, mushroom-like bodies on the surface of the soil or substrate. These bodies release spores, which are carried by air currents in the greenhouse, infecting stems, leaves and fruit.

The disease is favoured by cool to moderate temperatures and prolonged periods of high humidity. Excessive irrigation can also favour this fungus.

Symptoms

Leaves, stems and fruit can be infected. Cottony white growth covers infected plant parts, and a soft and watery rot develops. Black sclerotia (fruiting bodies) up to about a centimetre long develop on infected fruit or inside infected stems. They have the appearance of rat dung.



Sclerotinia infection of a cucumber plant stem.



Sclerotinia rot on cucumber fruit. Note the black fruiting bodies.



Sclerotinia and black sclerotia on infected fruit.

Management

Hygiene and good sanitation are the primary strategies for controlling white rot. Control humidity in the greenhouse to avoid dew forming on surfaces, particularly when nights are cool. Time application of pesticide/biological sprays to avoid leaving the crop wet for long periods. For example, avoid spraying plants in the late afternoon or evening.

Make sure plants are dry before vents close for the evening. If plants are wet, raise the temperature and increase air circulation to speed up drying. During the night, conduct purge cycles – heating then venting for short periods (up to 15 minutes) to remove moisture.

If plants become wet during the night, it is due to condensation. This can happen when the plants are colder than the humid air around them. To control this problem, include strategies such as reducing the air temperature or reducing the humidity.

Make sure that residues from previously infected crops are removed and the greenhouse is cleaned before planting a new crop. When removing crop trash, make sure to remove any black sclerotia.

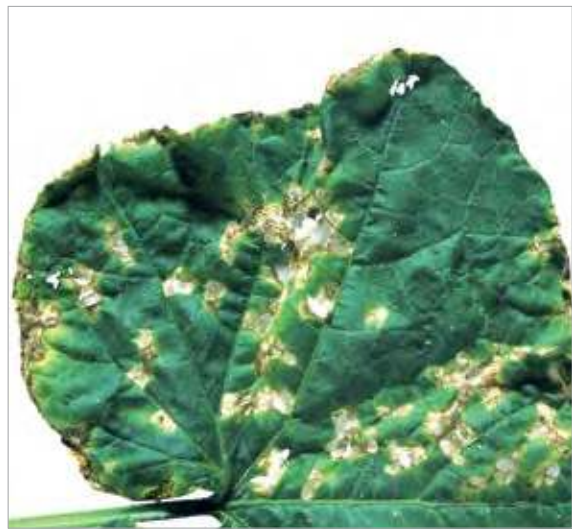
Bacterial diseases

Angular leaf spot

Angular leaf spot is caused by the bacteria *Pseudomonas syringae* pv. *lachrymans*. Seed and infected crop residues are the main sources of infection.

This bacterium is spread by water including condensation run-off, rain and nutrient solution. It can also be carried on people's hands and clothing.

The disease is favoured by warm (24 – 27°C) and humid conditions.



Leaf symptoms of angular leaf spot.



Cucumber fruit symptoms of angular leaf spot.

Symptoms

The disease first appears on leaves as small, water-soaked spots which enlarge to about 3 mm diameter. The spots become tan on the upper surface and gummy or shiny on the lower surface owing to bacterial ooze. This dries out and turns white. The spots are an angular shape because they are limited by the leaf veins. The centre of the spots may drop out. Spots can also develop on leaf stalks, stems and fruit, which become covered with a white, crusty bacterial exudate. A brown rot can develop in the fleshy tissue beneath the fruit.

Management

Hygiene and good sanitation are the primary strategies for controlling angular leaf spot. Control humidity and prevent condensation. Maintain air circulation and venting. Do not work in the crop if it is wet.

Make sure the crop is dry before vents close for the night. Do not spray plants in the late afternoon or evening. If plants are wet, raise the temperature and increase air circulation to speed up drying. During the night, conduct purge cycles – heating then venting for short periods (up to 15 minutes) to remove moisture.

If plants become wet during the night, it is due to condensation. This can happen when the plants are colder than the humid air around them. To control this problem include strategies such as reducing the air temperature or reducing the humidity.

It is important that plant residues from previous infected crops are removed and the greenhouse cleaned before planting a new crop.

Currently copper is the only chemical active available for lawfully controlling angular leaf spot on cucumbers in Australia. Copper sprays help contain infections. Check with your pesticide supplier, InfoPest® or the APVMA website (www.apvma.gov.au) for more information and to find out what products are registered, or have a current off-label permit, in your state or territory.

Viral diseases

Cucumber green mottle mosaic virus (CGMMV)

CGMMV causes serious losses of cucurbit crops in Europe, Asia, the Middle East and parts of North America. The first known outbreak in Australia was on watermelons in the Northern Territory in 2014. Since then it has been found a number of times in different crops, including greenhouse cucumbers.

The most common source of the virus is infected seed. It can easily spread in infected plant materials and media, by root contact between plants, through the nutrient solution or on equipment and workers during pruning, clipping, vine training and harvest operations. It can also be transmitted by bees.

Symptoms

Young leaves develop a mottled appearance, with light and dark green spotting across the leaf. The light areas fail to expand, with the result the leaf develops a bubbled, deformed appearance. Plants are stunted, and fruits fail to develop or abort.



Cucumber green mottle mosaic virus symptoms.

Management

The key control strategies are to avoid using contaminated seed or seedlings and maintaining strict farm biosecurity. Infected plants cannot be cured, so it is essential to prevent CGMMV entering the crop.

Dry heat treatment (2 days at >65°C) greatly reduces the risk of virus transmission in seeds. ELISA tests are used to verify that seeds are disease free.

Monitor crops closely for signs of the disease. Suspect plants should immediately be removed and destroyed by burning and/or burying. Equipment or machinery that may have contacted infected plants must be thoroughly cleaned and disinfected; sodium hypochlorite (bleach) is effective for this purpose.

CGMMV can spread easily through movements of people and equipment. Ensure trucks, machinery, materials and people coming onto the property are not carrying soil or plant debris, especially if they have visited other sites where cucurbits are grown. Vehicles should be left in a designated carpark away from the production area, or high pressure washed if coming on-farm.

There are no chemical controls for CGMMV.

Beet Pseudo-yellows virus (Cucumber yellows virus)

Beet pseudo-yellows virus (BPYV) is spread by greenhouse whiteflies (*Trialeurodes vaporariorum*). Overseas there is another virus that displays similar symptoms on cucumbers which is spread by silverleaf whiteflies (*Bemisia tabaci*). Called cucurbit yellow stunting disorder virus, this virus has not yet been detected in Australia.

BPYV can infect some members of 12 plant families. Hosts include weeds such as shepherd's purse and some species of mallow (*Malva*), goosefoot (*Chenopodium*) and some solanaceous plants. Lettuce and endive are also affected.

Symptoms

Leaves, particularly old ones, yellow between the veins and may be puckered and roll downwards. Fruit are unaffected, although developing fruit may abort on badly affected plants. Plants may become stunted. The leaf yellowing is very similar to some nutritional deficiency symptoms, particularly magnesium.



Symptoms of BPYV on cucumber leaves.

Management

Hygiene and good sanitation are the primary strategies for controlling cucumber yellows virus. The disease cannot be controlled once a plant is infected so prevention of the disease getting into the crop is essential. Remove weeds from around the greenhouse and destroy all infected plants. Do not store, pile or compost plant residues and old crops near the greenhouse.

Monitor and control whitefly to reduce risk of infection. Insect screens and biological controls such as the whitefly parasitoid *Encarsia formosa* may be feasible management strategies.

There are no chemical controls for cucumber yellows virus.



Nematode disease

Root knot

Root knot is caused by root knot nematodes of the genus *Meloidogyne*. These nematodes can infect a wide range of vegetables, ornamental plants, fruit trees and weeds. The main source of infection for a crop is infested soil or substrate, infected crop residues and other infected plants.

Nematodes are spread by water as well as equipment and shoes carrying infested soil and are favoured by light sandy soil or substrate and warm weather.

Symptoms

Root swellings and stunting and yellowing of plants are symptoms. Death may follow, but often plants struggle on with reduced yields and quality. Roots commonly become infected by a range of secondary bacteria and fungi.

Management

Hygiene and good sanitation are the primary strategies for controlling the root knot nematode. Always use clean substrate. Do not let substrate come into contact with soil. Do not bring soil into the greenhouse. Clean equipment and machinery before bringing it into the greenhouse.

Remove weeds from around the greenhouse and destroy all infected plants. Do not store, pile or



Root knot nematode damage to roots (top), and wilting of the above-ground parts as a result.

compost plant residues, old crops and used substrate near the greenhouse.

In greenhouse hydroponic systems, replacing infested substrate is a better option than using pesticides. In soil production systems planting and incorporating cover crops such as biofumigant mustards can reduce nematode populations in soils. Check with your pesticide supplier, InfoPest® or the APVMA website (www.apvma.gov.au) for more information and for what nematicide or fumigant products are registered, or have a current off-label permit in your state or territory.



CUCUMBER PESTS AND THEIR MANAGEMENT

Pests can cause severe losses to greenhouse cucumber crops and are often the most visible problem that growers encounter. The protected greenhouse environment favours the presence of a number of pests of cucumbers. Losses from pests occur directly through reduced yields. Many pests, such as whiteflies and thrips can also spread viruses.

THIS SECTION INCLUDES

- Integrated Pest Management (IPM)
- Insect lifecycles
- Biological control agents
- Key pests
- Managing pests in the greenhouse

Integrated Pest Management

Integrated Pest Management (IPM) is a package of interchangeable techniques used to manage pests in a crop, effectively keeping damage below economic thresholds.

The IPM approach does not eliminate use of all pesticides. Rather it includes cultural, physical and biological methods, as well as chemicals where appropriate. The aim is to minimize hazards to the health and safety of crop, people and the environment. Pesticide sprays, particularly broad spectrum insecticides, are only used when all alternatives have been exhausted.

Key tools in IPM systems include:

- Sanitation and hygiene
- Monitoring
- Biological controls
- Physical controls
- Managing the environment
- Pest specific, “soft” chemistry
- Keeping records

Recognising and understanding the lifecycles of pests and predators is key to implementation of IPM systems. Taking action to control pests when they are at their most vulnerable, and helping beneficial insects establish in the crop, are both effective strategies used in IPM.

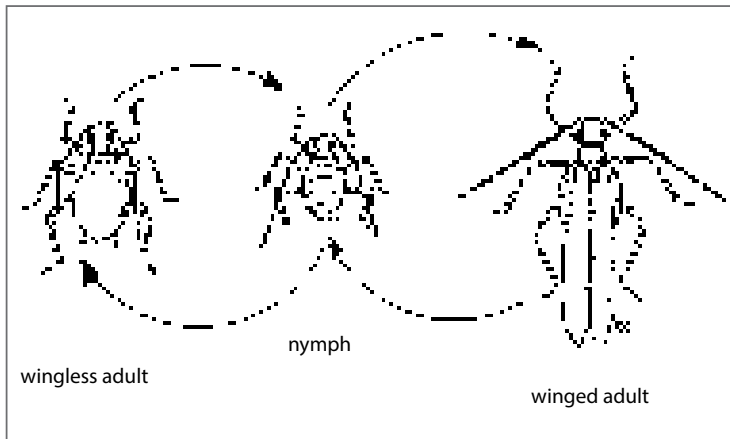
Routine monitoring allows the grower to manage pests before major problems occur. Management decisions can then be based on the stage of crop growth as well as the actual pest population. This is more efficient than routine calendar spraying and can improve economic returns over the life of the crop.

It is important to keep written records of observed pest (and beneficial) populations. These should include their distribution within the greenhouse, level of damage and stage of crop growth. Over time, such records become the basis for benchmarking the production system and developing action thresholds for major pests. Such records also provide an objective review of the effectiveness of corrective actions that have been taken.

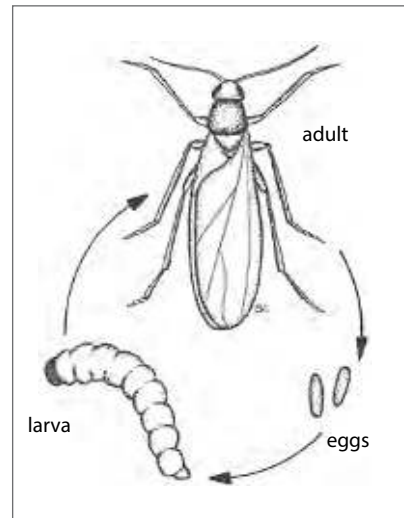


All above: Crop monitoring or scouting is essential so you know if there are pest or natural enemy insects in your crop.

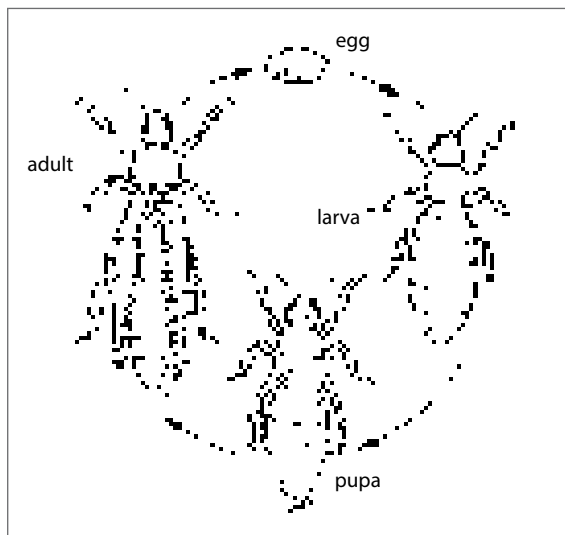
Generalised life cycles of common cucumber pests



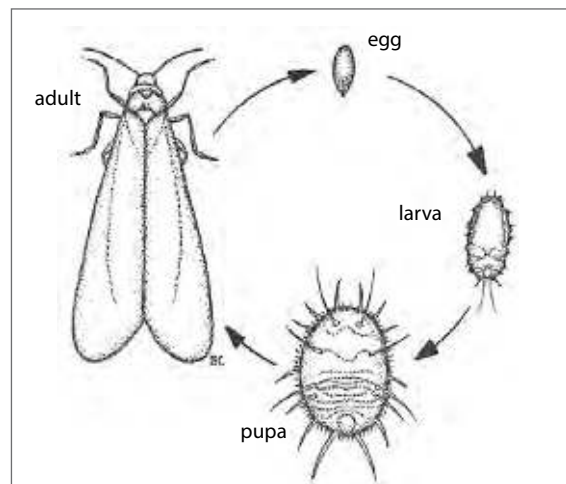
Aphid life cycle.



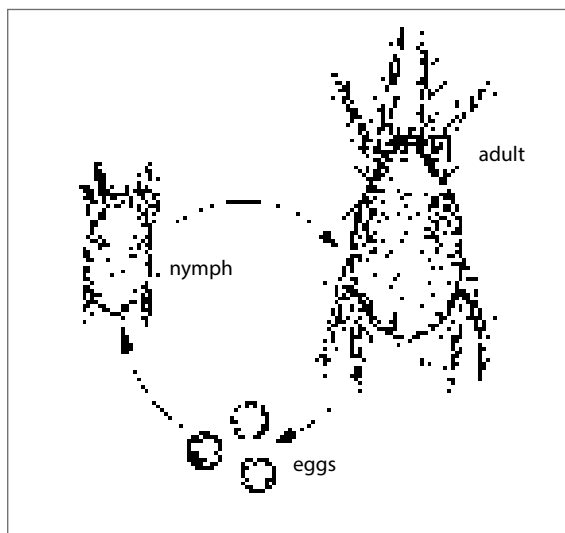
Fungus gnat life cycle.



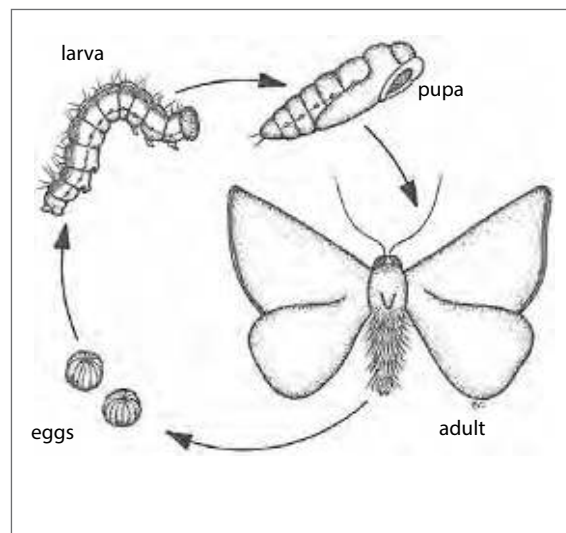
Thrips life cycle.



Greenhouse whitefly life cycle.



Two spotted mite life cycle.



Caterpillar life cycle.

Sanitation

Sanitation is the first step in managing any pest. Always start a crop with clean (pest free) plants. Always clean up before, during and after a crop. Surfaces should be sanitised between and before new crops with diluted chlorine to prevent algae from growing in drains, channels and other areas of the greenhouse. Weed management is critical. Control weeds on your farm and any in the greenhouse. Work with neighbours to control weeds around the local area. Clean clothing, footwear and equipment, as well as the use of gloves, disposable coveralls and 'booties' and footbaths, all help to reduce the risk of spreading pests. Complete jobs in younger, pest free plantings before going into older crops. *Do not move from an infested greenhouse to a clean crop without first showering, changing clothes and wearing new disposables.*

Physical control

Prevention is easier than cure.

Windbreaks can be an effective way of reducing the pressure on the farm from 'blow-in' pests. Trees or shade cloth windbreaks on the windward side of the property can be effective.

Where possible, the vents and doors of glasshouses should be screened to prevent pests being blown into the structure. There are different grades of mesh material for screening, ranging from very fine 'thrips proof' netting to more open shade cloth material. Consideration must be given to air movement through the greenhouse and how much this is impeded by the screening material. However, most insects are not strong flyers and even the comparatively wide mesh of shade cloth can reduce the numbers and incidence of 'blow-in' pests. This is particularly effective across the ends and sides of open polytunnels.

Environmental control

Providing the right environment for the cucumber crop is one of the most important parts of growing a healthy productive crop. The level of light, day and night temperatures, relative humidity, amount and frequency of irrigation, nutrition and air quality all influence crop growth. Controlling these factors is important. Large variations in growing conditions can also reduce plant productivity and increase pest and disease problems. Pests are attracted to stressed plants. For more information refer to the *Greenhouse design and technology* section.

Knowing the pest

Effective management of pests is dependent on knowing the pest. Not only is correct identification critical, but you need to understand the life cycle of the pest, at what stages they are most vulnerable to various control options and what specific management strategies are available. Integrated Pest Management is about using the most effective and lowest impact combination of strategies to control crop pests.

Useful tools for identifying pests are a 10x hand lens and yellow sticky traps and ribbons. There are many ute guides and apps for vegetable crops with pictures of the most common pests in them. To help you start an IPM programme it can be worth employing a crop consultant with IPM experience who can help you become confident with pest and beneficial insect identification.



Yellow sticky ribbon in cucumber crop.

Biological control agents/ beneficials

Some key pests of cucumbers, including western flower thrips, silverleaf whitefly and certain mites, have developed resistance to many pesticides. Even if alternatives are available, the withholding periods may be too long for use on cucumber crops.

Beneficials, or biological control agents, are natural enemies of crop pests. They do not harm the crop itself. Beneficials may occur naturally in and around the farm. They are also bred in commercial production facilities, so large numbers can be purchased and released into the crop to control specific pests. Using commercially supplied beneficials is increasingly accepted as normal practice at many greenhouse facilities.

Predatory insects eat the eggs and/or larvae and grubs of the pest. Parasitoid insects lay their eggs in the eggs or larvae of the pest. Pathogenic beneficials are diseases which affect pests.

All beneficials need to be recognised and encouraged on your farm and in your greenhouse. Beneficial organisms which occur naturally on your farm are a free method of pest control.

It is important to note that certain pesticides can harm beneficials. Always look for pesticides compatible with biological controls **before** you spray.

Using biological controls requires good production and management skills. As part of an integrated pest management program, biological controls can significantly reduce the need for and reliance on toxic pesticides. Go to www.goodbugs.org.au or www.koppert.com/side-effects/ for more details on pesticides safe to use with beneficials.

Recognising key biological controls

Note that all of the following beneficials are available commercially in Australia.

Encarsia wasp

(Encarsia formosa)

Encarsia is a tiny wasp which parasitises the eggs of greenhouse whitefly. It is available commercially and comes on small cards (from which they hatch). The cards are hung on plants throughout the greenhouse.



Encarsia parasiting white fly nymphs.



Releasing *Encarsia* into a young cucumber crop.

Entomopathogenic nematode

(*Steinernema*)

Steinernema is a nematode which attacks the larvae of fungus gnats and some caterpillars. It is available commercially as a powder that is mixed with water and added to the substrate.



Parasitic nematodes as seen through a microscope at 80x magnification.

Hypoaspis mite

(*Hypoaspis miles* and *Hypoaspis aculeifer*)

Hypoaspis are predatory mites that feed on the larvae of fungus gnats, thrips pupae and some other soil dwelling pests. They are available commercially and are supplied in a bran mix, which is added directly to the substrate.



Adult *hypoaspis* mites.

Montdorensis mite

(*Typhlodromips montdorensis*)

Montdorensis is a predatory mite that feeds on the larvae of thrips and whitefly and on some pest mites. It is proving effective against western flower thrips in cucumbers, especially when provided with a supplementary pollen source. 'Montys' are supplied mixed with vermiculite and can be sprinkled evenly onto leaves throughout the crop.



Montdorensis attacking thrips larvae.

Cucumeris mite

(*Neoseiulus cucumeris*)

This predatory mite is used to control thrips. It is very effective against western flower thrips in cucumber crops when used alongside *Orius*. It is supplied mixed in vermiculite which is sprinkled onto crop foliage.



Adult *Neoseiulus* predatory mite attacking thrips larvae.

Persimilis mite

(*Phytoseiulus persimilis*)

Persimilis is a predatory mite, which feeds on two-spotted mites and bean spider mite. It is very effective in cucumber crops. It is supplied in bottles in a vermiculite carrier and should be sprinkled onto the leaves in and around spider mite 'hot spots' as they are identified.



Adult *Persimilis* mite.

Typhlodromalus mite

(*Typhlodromalus lailae*)

T. lailae is closely related to *T. limonicus*, which is used extensively in Europe for control of thrips and whitefly in greenhouses. A predator of certain mites as well as thrips and whitefly, this native Australian predatory mite is found naturally in humid, coastal areas with mild climates. Optimum temperatures range from 15 to 30°C, but the mite can continue breeding down to 7°C and tolerate even lower temperatures for short periods. Although recognised as a predator for more than 20 years, new breeding techniques have recently enabled commercial production of this beneficial mite.



Typhlodromalus feeding on a thrips larvae.

Trichogramma wasp

(*Trichogramma pretiosum*)

Trichogramma is a tiny parasitic wasp which attacks some species of caterpillar such as *Heliothis*. It is purchased inside small cards which are placed in the crop. The wasp emerges from the cards.



Adult female *Trichogramma* wasp on a *Heliothis* egg.

Eretmocerus wasp

(*Eretmocerus warrae* and *Eretmocerus hayati*)

Eretmocerus wasps are parasitoid wasps, which attack whiteflies. There are two species of *Eretmocerus* commercially available.

E. warrae is very effective against greenhouse whitefly (*Trialeurodes vaporariorum*).

E. warrae **does not** attack silverleaf whitefly (*Bemisia tabaci*).

E. hayati **does** attack silverleaf whitefly. This is why correct identification of pests is so important.



Eretmocerus warrae, a parasitic wasp of greenhouse whitefly.



Eretmocerus hayati, a parasitic wasp of silverleaf whitefly.

Eretmocerus wasps are tolerant of a wide range of temperatures and relative humidity, and particularly useful in summer when very hot conditions are experienced. They are also more tolerant to some pesticides than many other parasites.

Eretmocerus are sent as loose pupae in plastic vials. They can be sprinkled over the top of the foliage.

If ants are present, try to control them with baits prior to and during release periods. *Eretmocerus* should be concentrated into known hotspots and distributed around the extremities of the crop. They are strong flyers so do not need to be placed evenly like *Encarsia* which can only fly short distances.



Basil banker plant for *Orius* in a cucumber crop.



Orius feeding on a juvenile thrip.

Orius bug (*Orius tantillus*)

Orius is a predator of various species of thrips, especially western flower thrips (*Frankliniella occidentalis*) and onion thrips (*Thrips tabaci*). Both adult and juvenile *Orius* feed on all stages of thrips including adults. They are a very effective biological control of thrips when used alongside predatory mites.

Orius need a suitable pollen source to establish in a crop. As cucumbers are not suitable, banker plants, such as flowering basil, will ensure they breed up and become very effective (Biological Services who sell *Orius* have detailed information sheets on how to establish and manage banker plants www.biologicalservices.com.au).

Orius are supplied in bottles containing adults and nymphs in buckwheat husks. To apply, gently rotate the bottle several times to mix the contents evenly, and then sprinkle over the plant heads, near the flowers. Try to ensure most of the buckwheat stays on the leaves. Each bottle should give about 50 release points to cover an area of 500-1000m².

Ladybird beetle

(*Harmonia octomaculata*, *Harmonia conformis*, *Hippodamia variegata* and *Coccinella transversalis*)

These ladybirds are a recent addition to the commercial biological control menu. They may be useful in controlling aphids in cucumber crops. The suppliers can advise on which are most suitable for individual situations. They are supplied as eggs on cards or as adults.

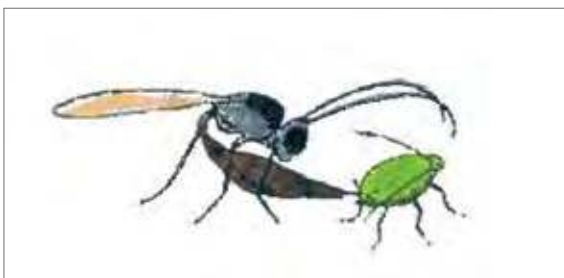


Adult ladybird.

Aphidius wasp

(*Aphidius colemani*)

Aphidius is a small wasp which is a parasite of many aphid species including green peach, cotton and melon aphids. It lays an egg into the body of an aphid which then hatches and feeds on the aphid before it emerges to find more aphids. It comes in small vials that contain about 500 mummified aphids with young *Aphidius* inside them. The mummies can be sprinkled onto the leaves of the crop, or the vials left strategically throughout the crop for the wasps to emerge over a few days.



Adult female parasitic *Aphidius* wasp laying eggs into green aphid.



Aphidius wasp and mummy.

Biorationals

Biorationals are substances used to control pests (or diseases) which have very limited or no effect on non-target organisms. These pesticides are safe for the user and are compatible with biological controls due to their selective nature or short residual activity. Biorationals are almost the ideal pesticide.

Biorational products include oils, soaps, insect growth regulators and insect-specific pathogens. Many of the new chemistries as well as microbially-derived products and living microbes such as fungi and bacteria are classed as biorationals.

There is on-going research in Australia, including at the National Centre for Greenhouse Horticulture, Ourimbah, to identify and develop biorational pesticides.

Table 31. Beneficial insects, mites and nematodes available in Australia and their suppliers			
Common name	Scientific name	Target pests	Supplier
Aphelinus	<i>Aphelinus abdominalis</i>	Larger aphid species including foxglove aphid and potato aphid.	BS
Aphidius	<i>Aphidius colemani</i>	Various species of aphid including green peach aphid and melon or cotton aphid	BS
Aphytis	<i>Aphytis lingnanensis</i> <i>Aphytis melinus</i>	Red scale	BB, BS
Chilocorus	<i>Chilocorus spp.</i>	Armoured scale insects, including oriental and oleander scales	BB
Cryptolaemus beetle	<i>Cryptolaemus montrouzieri</i>	Mealybug (various species)	BB
Californicus	<i>Neoseiulus californicus</i>	Bean spider mite, broad mite, two-spotted spider mite	BS, BB
Cucumeris	<i>Neoseiulus cucumeris</i>	Thrips (various species)	BS
Dalotia	<i>Dalotia coriaria</i>	Fungus gnats, shore fly, thrips pupae	
Eretmoceris	<i>Eretmoceris hayati</i> <i>Eretmoceris warrae</i>	Silverleaf whitefly, greenhouse whitefly	BB
Encarsia	<i>Encarsia formosa</i>	Greenhouse whitefly, tobacco whitefly, cotton whitefly, poinsettia whitefly	BS
Entomopathogenic Nematodes	<i>Heterorhabditis bacteriophora</i> <i>Heterorhabditis zealandica</i> <i>Steinernema feltiae</i> <i>Steinernema carpocapsae</i>	Black vine weevil, African black beetle, Argentine scarab, fungus gnats, shore fly, armyworm, cutworm Note: Other insect-killing nematodes (ENs) are available as well as pest treatments that are unrelated to cucumber crop production.	EG
Hypoaspis	<i>Hypoaspis miles</i> & <i>H. aculeifer</i>	Fungus gnats, thrips pupae	BS, BW
Ladybirds	Various species	Aphids	BS, BB
Montdorensis	<i>Typhlodromips montdorensis</i>	Thrips, whitefly, spider mites, broad mites, russet mites	BB
Orius	<i>Orius tantillus</i>	Western flower thrips, onion thrips & plague thrips	BS
Persimilis	<i>Phytoseiulus persimilis</i>	Two-spotted mite, bean spider mite	BB, BS, BW
Trichogramma	<i>Trichogramma pretiosum</i>	Heliothis moth eggs	BB
Typhlodromus	<i>Typhlodromus occidentalis</i>	Two-spotted spider mite, spider mites	BS

BB	Bugs for Bugs, Toowoomba, QLD. Phone: (07) 4646 2628 info@bugsforbugs.com.au
BS	Biological Services, Loxton, SA. Phone: (08) 8584 6977 info@biologicalservices.com.au
BW	Bioworks, Utungan, NSW. Phone: (02)6569 6228 info@bioworksonline.com.au
EG	Ecogrow Environment, Queanbeyan, NSW. Phone: (02) 6284 3844 info@ecogrow.com.au

Table 31 supplied courtesy of Australian Biological Control. Go to www.goodbugs.org.au for more details.

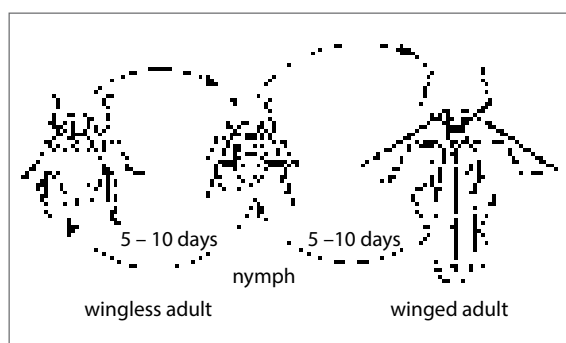
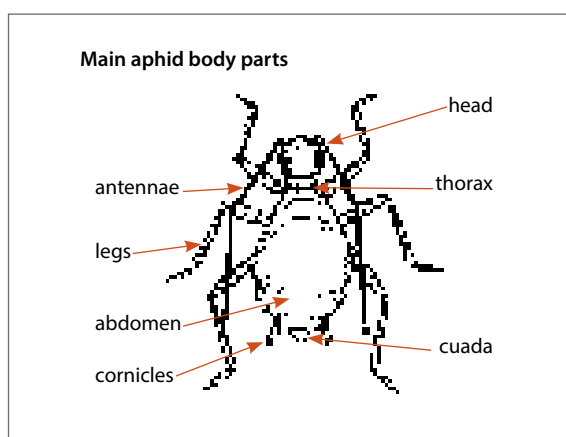
Table 32. Common pests and biocontrols for cucumbers, commercially available 2019

Protected Crops: Greenhouse vegetables and ornamentals & nurseries		
Insect pests	Biocontrol agents available	Naturally occurring beneficials
Aphids	Aphidius	Hover fly, brown & green lacewings
	Aphelinus	
	Ladybirds, various species	
Fungus gnats	Hypoaspis	
	Nematodes	
Heliothis caterpillars	Trichogramma	Predatory bugs and beetles, NPV
Thrips	Cucumberis	Entomopathogenic fungi
	Montdorensis	
	Orius	
Bean spider mite Two-spotted spider mite	Persimilis	Local predatory mites, Stethorus beetles, hover fly
	Typhlodromus	
	Montdorensis	
	Californicus	
White fly	Encarsia	Other parasitoids
	Eretmocerus	
	Typhlodromips	

Recognising key pests

Aphids

Aphids are pear shaped insects. They have soft bodies ranging from 1.5 to 3.5 mm in length. Adult aphids may be winged or wingless. Aphids produce live young (nymphs). There are several different aphid species that are pests on cucumbers. Aphids can be introduced on seedlings so always check seedlings before taking them into the greenhouse.



Generalised diagram of aphid stages and life cycle.

Winged adults can be carried in on the wind. They are a high risk problem if not detected and controlled.

Aphids are sap suckers. In large numbers, they physically damage plants, causing malformations in new growth. When aphids feed they produce honeydew which encourages the growth of sooty mould on foliage and fruit. This black mould reduces plant growth and marketability of fruit. Aphids can also transmit plant viruses.

Aphids are usually found at the growing tips of young leaves and flower buds but may also be on the underside of mature leaves and on stems. Ants can be an indicator that aphids are present because



Sooty mould on cucumber leaves.



Wingless green peach aphid adult.

they feed on the honeydew deposited on the plant foliage.

Aphids prefer warm, humid conditions.

The green peach aphid (*Myzus persicae*) is a key pest in the eastern states. This species transmits over 100 plant viruses including cucumber mosaic virus (CMV). This aphid has developed resistance to several commonly used insecticides. The wingless adults and nymphs are light green to pink with red eyes. The cornicles (a distinctive pair of protrusions at the insect's rear) have dark tips. Winged females have a black patch on the upper surface of the abdomen and a dark head and thorax.



Cotton aphids are yellow-green with black spiracles (Photo: L. Wilson).



Typical symptoms of cotton aphid damage on cucumber plant.



Wingless adult potato aphid.

The cotton aphid (*Aphis gossypii*) is another key pest in the eastern states and can also transmit several plant viruses including CMV. The small wingless adults and nymphs of this species vary from light yellow to greenish black. They have long black cornicles. Winged females are black.

The potato aphid (*Macrosiphum euphorbiae*) is a less significant pest but it can also transmit several plant viruses including CMV. The wingless adults and nymphs vary from pink to green. They have long cornicles. Winged adult females are black.

Management

Routinely monitor pest populations. Use physical barriers to exclude pests where feasible. Remove all plant material from the greenhouse between crops and control weeds in and around the greenhouse. Inspect all new plant material for pests before moving it into the greenhouse. Control ants that protect aphids from natural enemies.

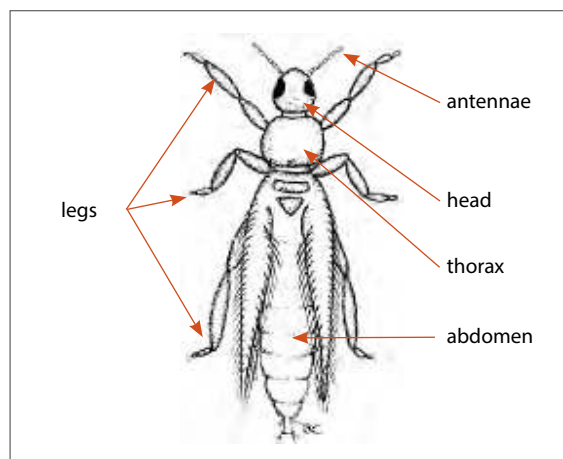
Manage plant balance – avoid excessive, lush vegetative growth.

To find which pesticides are currently registered for aphids in cucumbers and which are safe to use with beneficials, check with your IPM consultant, pesticide supplier, InfoPest® or the APVMA website (www.apvma.gov.au) which has more information on what is registered, or has a current off-label permit, in your state or territory.

Thrips

Thrips are small slender insects. They have soft bodies ranging from 1 to 2 mm in length. Adult thrips have two pairs of narrow wings fringed with long hairs. Immature thrips are pale yellow to white in colour. Adults can be pale to dark. Eggs are laid in leaves or petals. The larval stages and adults can be found in flowers and buds as well as on leaves.

Thrips are sap suckers. They physically damage plants causing malformations in new growth and bronzing and scarring of leaves, flowers and fruit from their feeding.



Main thrips body parts.

There are several species that can transmit tomato spotted wilt virus (TSWV). This virus is symptomless in cucumbers.

Western flower thrips (*Frankliniella occidentalis*) are a key pest in Australia. Adult females are yellowish on the head and thorax and brown on the upper abdomen. They can be darker in winter. Adult males are smaller and pale yellow. Immature stages are wingless and have bright red eyes. Adults are found in flowers and both adults and larvae are found on the undersides of leaves, on fruit and in the growing tips of the plant. When western flower thrips' (WFT) larvae feed on small developing fruit, they cause small scars. As the fruit grows, the scars cause the fruit to curl.



Western flower thrips adults (top) are larger and more two-toned than onion thrips (below).



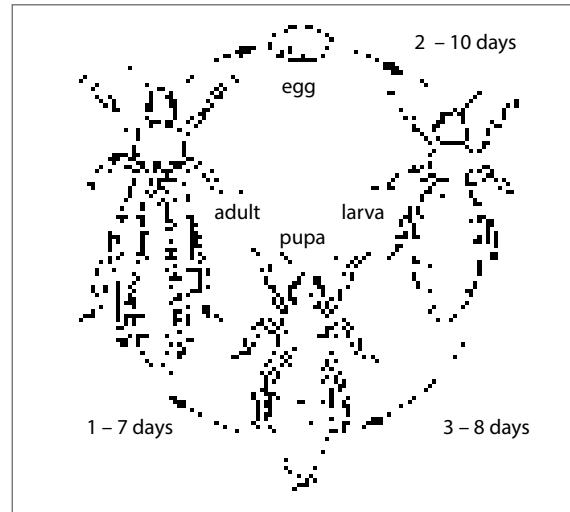
Young curved fruit due to western flower thrips feeding damage.



Western flower thrips feeding damage causes small scars which lengthen as the fruit develops, resulting in curved fruit.



Close-up of western flower thrips feeding damage on mature cucumber leaf.



Generalised diagram of the thrips stages and life cycle.

WFT have high levels of resistance to many insecticides. This makes them very difficult to control using chemicals. This species is the main carrier of TSWV.

Onion thrips (*Thrips tabaci*) are a key pest in the eastern states. Adults are smaller than WFT, pale yellow to dark brown – not as two-toned. Immature stages are yellowish and do not have wings. This species transmits TSWV. Adults and larvae are mostly found on the lower leaves, though they may also be in flowers, on fruit and leaves and in the growing tips of the plant.

Melon thrips (*Thrips palmi*) are a key cucumber pest in Queensland. These are small, yellow-orange thrips with dark fringed wings. Immature stages are yellowish. Melon thrips can transmit TSWV. This species of thrips are usually on the underside of leaves and in the growing tips.

Plague thrips (*Thrips imaginis*) are an occasional pest of greenhouse cucumbers. They are found feeding on flowers and young leaves.

Management

Routinely monitor pest populations visually and with sticky traps. Use physical barriers and screens to exclude pests where feasible. Remove all plant material from the greenhouse between crops and control weeds in and around the greenhouse. Inspect all new plant material for pests before moving it into the greenhouse.

In an IPM program the predatory mites *Typhlodromips montdorensis* and *Neoseiulus cucumeris* can provide effective biological control of thrips in greenhouse cucumbers. They are especially



Yellowish-orange Melon thrip adult.



Western flower thrips on cucumber flower.

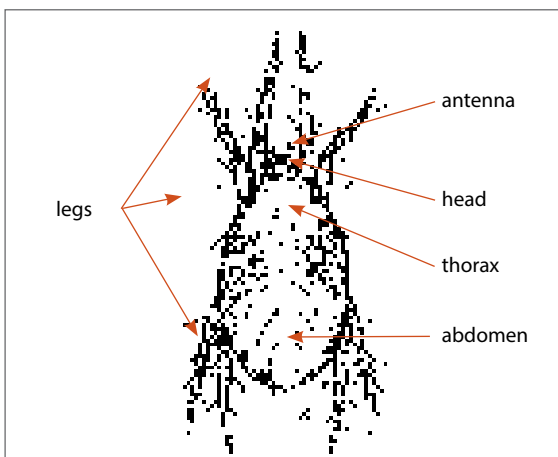
effective where western flower thrips are the key pest. The predatory mite *Stratiolaelaps (Hypoaspis) miles* also feeds on the pupae of WFT. There are also some naturally occurring predatory mites and bugs, parasitoid wasps and pathogenic fungi.

Due to insecticide resistance problems and the need for very short withholding periods in cucumbers there are limited effective insecticides available. To find which pesticides are currently registered for thrips in cucumbers and which are safe to use with beneficials, check with your IPM consultant, pesticide supplier, InfoPest® or the APVMA website (www.apvma.gov.au) which has more information on what is registered, or has a current off-label permit, in your state or territory.

Mites

Mites are sap suckers that cause leaf yellowing and mottling and reduced plant vigour. Adults are small, oval shaped pests. They are up to about 0.5 mm in length. The males tend to become narrower towards the rear end of their body.

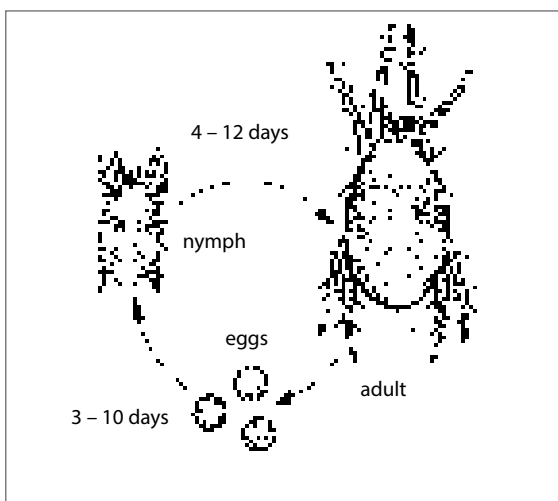
There are several species which are key pests in cucumbers.



Two-spotted spider mite body parts - note 8 not 6 legs.



Two-spotted spider mite male, female and egg (left) and heavy two-spotted spider mite damage and webbing on cucumber plant (right).



Two-spotted spider mite stages and life cycle.



Close-up of adult two-spotted spider mite.



Two spotted mites are a common pest of cucumbers in all regions (Photo: G. San Martin).

The two-spotted spider mite (*Tetranychus urticae*) is a key pest in all areas. It feeds on the underside of leaves and causes leaf cells to die resulting in a speckled pattern. Heavier infestations cause a yellowing of interveinal leaf area with prominent green veins and a lot of webbing. The two-spotted spider mite (TSM) has a

very broad host range including cucumbers and has increasing resistance to several insecticides/miticides. Adults and nymphs are yellowish-green with two dark green or black spots on their backs. In winter the female loses its spots and turns an orange colour. Eggs are small, round and white. TSM thrives in hot dry conditions. Infested leaves can rapidly become bronzed, shrivel and may drop, causing the plant to die.

The bean spider mite (*Tetranychus ludeni*) is a common pest of cucumbers in New South Wales and Western Australia. Life cycle stages are similar to two-spotted spider mite. Adult females are about 0.5 mm long and dark red. Nymphs can be a light greenish colour with dark patches on their backs. Eggs are small and round with a reddish tinge. Bean spider mites (BSM) mainly feed on the underside of i.e. leaves, but can be found on the upper side. When BSM feed, the damage causes leaves to become mottled and bleached. These symptoms are similar to some nutritional disorders such as magnesium



Bean spider mites (Photo J. Lovatt).



Typical spider mite damage on cucumber leaf.

deficiency or zinc toxicity so monitoring for this pest is critical to avoid misdiagnosis.

Broad mites (*Polyphagotarsonemus latus*) are a key cucumber pest in all the Eastern states. They are very small (0.25 mm) and pale white to yellow-green. The nymphs are pale and have a white stripe along the top of their back. Broad mites prefer warm, humid conditions and are found in the growing tips of plants. This species feeds on both the upper and lower surfaces of newly emerged leaves and flowers. Leaves become bronzed, russeted and distorted with downward curling leaves. The symptoms can be mistaken for viral or herbicide damage so monitoring for this pest is critical. Typically you need a microscope to correctly identify broad mites.



Broad mites are tiny and semi-transparent, so very difficult to see (Photo B Watt Bugwood.org)

Management

Routinely monitor pest populations. Use physical barriers to exclude pests where feasible. Remove all plant material from the greenhouse between crops and control weeds in and around the greenhouse. Inspect all new plant material for pests before moving it into the greenhouse.

Manage irrigation to avoid water stress as stressed plants are more prone to mite outbreaks.

Most mite populations have developed resistance to many miticides. There are commercially available predatory mites (*Phytoseiulus persimilis* and *Typhlodromus occidentalis*) that can provide effective biological control of two-spotted spider mite and bean spider mite. *P. persimilis* is more effective against two-spotted spider mite than against bean spider mite. There are also some naturally occurring predatory mites, predatory thrips, ladybird beetles, midges and pathogenic fungi.

Mite problems are very often caused by the improper use of broad-spectrum insecticides that have removed all the naturally occurring beneficials. Organophosphate and synthetic pyrethroid pesticides are the most problematic.

To find which pesticides are currently registered for mites in cucumbers and which are safe to use with beneficials, check with your IPM consultant, pesticide supplier, InfoPest® or the APVMA website (www.apvma.gov.au) which has more information on what is registered, or has a current off-label permit, in your state or territory.

Flies – Fungus gnats, Shore flies and Queensland fruit flies

Fungus gnats (*Bradysia* spp. (*Sciaridae*)) are a major pest in all areas. These pests are small black flies with long legs and antennae. They have a single pair of dusky wings and can look like a small mosquito. The veins on the wings make a Y-pattern at the end of the wing. Eggs are laid in the hydroponic substrate around the roots of the plant. The larvae are legless and white to clear in colour. They have a worm-like body (5 to 8 mm long) and a small black head.

Adults are weak fliers and are usually seen running about on the substrate surface. Adult fungus gnats



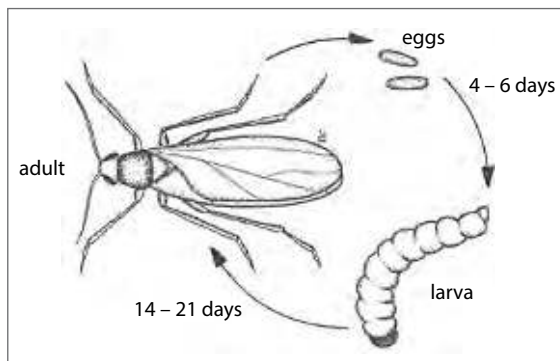
Various larval stages and a puparium (bottom) of shore fly.



Adult shore fly (Photo: Tony D).

do not feed on plants. The larvae feed on root hairs, roots, organic matter and the base of the stem. Algae is also a food source. Feeding damage can cause loss of plant vigour, wilting and collapse, particularly in young plants. Large larvae can enter the stem just below the substrate surface. Adults and larvae can spread a number of plant pathogens such as *Pythium*, *Rhizoctonia* and *Fusarium*. Adult fungus gnats can spread *Botrytis*.

Shore flies (*Scatella australiae*) are only minor pests. They can be mistaken for fungus gnats. The adults are



Fungus gnat stages and life cycle.



Fungus gnat larvae.



Adult fungus gnats can spread diseases like *Botrytis*.



Adult female Queensland fruit fly.



Male cucumber fly (Photo: M Tattersall).

brown-black and have five pale spots on their smoky coloured wings. They can look like a very small house fly or fruit fly. Shore flies do not hover. They have a typical short flight which makes them look like they are jumping. The larvae are small white maggots with no distinct head. They are found in the top layer of substrate. Algae is also a host on which they feed. Adults cause 'fly spotting' damage by leaving excrement on foliage and fruit. Adults and larvae are suspected of spreading some key plant pathogens such as *Pythium* and *Phytophthora*.

Queensland fruit fly (*Bactrocera tryoni*) and Cucumber fly (*Bactrocera cucumis*) are both pests of cucurbit crops in eastern Australia. While potentially very destructive, they rarely enter greenhouses, especially those with high sidewalls. To confirm the greenhouse is free of this pest, Queensland fruit fly can be monitored using traps baited with cue-lure. No lure is available for cucumber fly.

Adult flies are brown, 5-8mm long with yellow markings. The torpedo shaped maggots are creamy white with a black feeding hook. Infested fruit often starts to rot and may detach from the vine.

NB *Bactrocera tryoni* and *Bactrocera cucumis* are both italicised.

Management

Routinely monitor pest populations. Use physical barriers to exclude pests where feasible. Remove all plant material from the greenhouse between crops and control weeds in and around the greenhouse. Inspect all new plant material for pests before moving it into the greenhouse.

Use hydroponic substrates that have good drainage. Inorganic substrates harbour fewer fungus gnats than organic substrates. Manage irrigation to avoid excess watering. Keep the greenhouse floor dry and drainage channels clean. Minimise algal growth.

There are biological controls available commercially that can provide effective biological control of fungus gnats. The entomopathogenic nematode, *Steinernema feltiae*, parasitises the larvae of fungus gnats. The predatory mites, *Hypoaspis miles* and *Hypoaspis aculeifer*, feed on the larvae. The predatory beetle *Dalotia coriaria* will feed on both fungus gnat and shore fly larvae. Some naturally occurring predatory mites, beetles and parasitoid wasps attack the larvae of fungus gnats. There are also some naturally occurring parasitoid wasps that prey on Queensland fruit flies. Currently there is also a commercially available biological active for controlling fungus gnats on cucumbers.

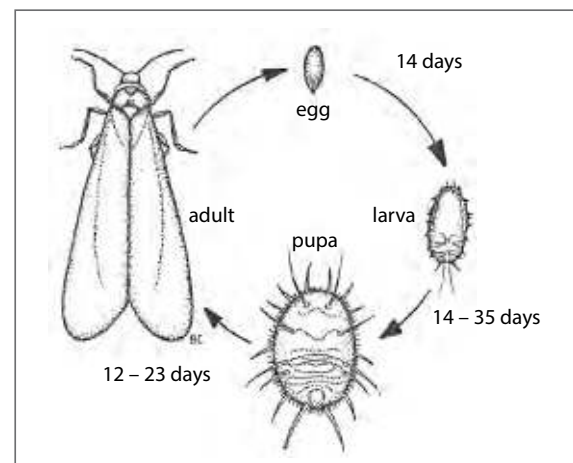
To find which pesticides are currently registered for fungus gnats in cucumbers and which are safe to use with beneficials, check with your IPM consultant, pesticide supplier, InfoPest® or the APVMA website (www.apvma.gov.au) which has more information on what is registered, or has a current off-label permit, in your state or territory.

Whiteflies

Whiteflies are major and common pests of cucumbers.

Greenhouse whitefly (*Trialeurodes vaporariorum*) is an important pest in most production areas.

Greenhouse whitefly (GWF) are tiny white insects 1.5 to 2 mm in length. When disturbed, they tend to flutter near the plant and resetttle quickly on leaves. Heavy infestations give the appearance of white clouds when they are disturbed and flutter about. Adults are usually on the underside of leaves, towards the top of the plant. Eggs are found on the underside of new foliage. Immature whiteflies (nymphs and pupae) are scale-like and generally found on older foliage. Whiteflies also suck plant sap as they feed.



Greenhouse whitefly stages and life cycle.



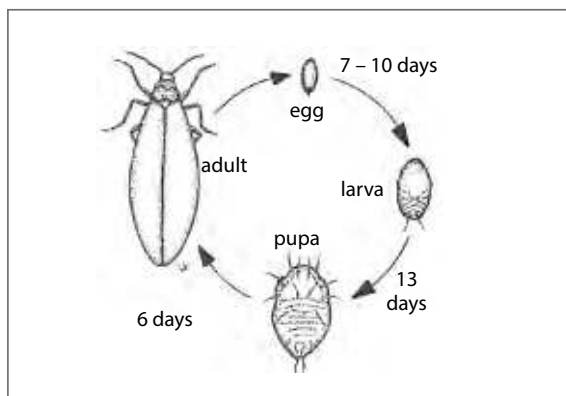
Adult greenhouse whitefly (left), unparasitised white nymphs (centre top), parasitised nymphs (black) and encarsia parasitoid (right).



Adult whitefly.



Whitefly nymphs (Photo: P. DeBarro).



Silverleaf whitefly stages and life cycle.

Direct feeding damage by adults and immature stages causes leaves to yellow and die prematurely. Heavy infestations reduce plant vigour. Adults have the potential to transmit viruses. They also excrete honeydew which encourages the growth of sooty mould on leaves and fruit. Weeds such as sow thistle, verbena and mallow are hosts.

Silverleaf whitefly (*Bemisia argentifolii*) is a key field problem in tropical zones of Western Australia,

Queensland and northern NSW and is becoming a significant pest of greenhouse crops in most areas – it has been positively identified in greenhouse vegetable crops in the Sydney basin. The adult has a smaller body than GWF and holds its wings at a steeper angle – more tent-like than GWF. Silver leaf whitefly has a yellowish body that is visible between its wings. It also sucks sap resulting in a loss of plant vigour, poor growth, leaf yellowing and leaf drop. It also transmits viruses including gemini virus complex. Milk thistle is a host.

Management

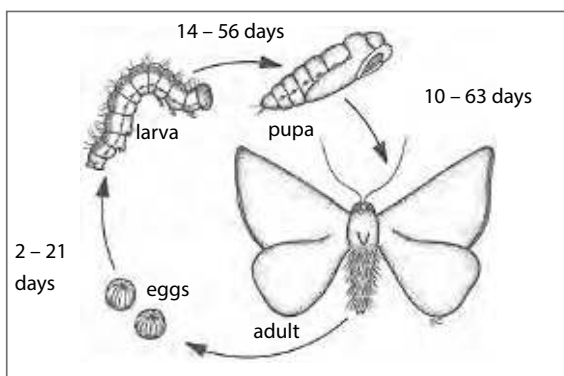
Routinely monitor pest populations visually and with sticky traps. Use physical barriers and screens to exclude pests where feasible. Remove all plant material from the greenhouse between crops and control weeds in and around the greenhouse. Inspect all new plant material for pests before moving it into the greenhouse.

There are commercially available parasitoid wasps that can provide effective biological control of whiteflies: *Encarsia formosa*, *Eretmocerus warrae* (Greenhouse whitefly), *Eretmocerus hayati* (Silverleaf whitefly). The predatory mite *Montdorensis* will also feed on whitefly scales. There are also some naturally occurring parasitoid wasps and pathogenic fungi.

There are pesticide resistant populations of whitefly, especially the silverleaf whitefly. To find which pesticides are currently registered for whitefly in cucumbers and which are safe to use with beneficials, check with your IPM consultant, pesticide supplier, InfoPest® or the APVMA website (www.apvma.gov.au), which has more information on what is registered, or has a current off-label permit, in your state or territory.

Caterpillars

A number of caterpillar, larvae or grub life stages of adult moths are pests in cucumber crops. Caterpillars cause damage by feeding directly on leaves, young stems, buds and flowers.



Generalised caterpillar stages and life cycle.



Typical caterpillar damage on a cucumber plant.

Budworms (*Helicoverpa punctigera* and *H. armigera*) are key cucumber pests in New South Wales and Victoria. These species were previously known as *Heliothis*. Young caterpillars or larvae are pale with a dark brown head. Older caterpillars grow to 40 to 50 mm long and are yellow-green to red-brown in colour. They have yellowish stripes along the side of their bodies and a darker one along their back. Besides destroying plant foliage, buds and flowers, *Helicoverpa* also chews holes in fruit.

The adult moths are grey to reddish brown, have a 40 mm wingspan and feed only on nectar. They are active at night and fly towards lights.

The cluster caterpillar (*Spodoptera litura*) is also a key cucumber pest in New South Wales and Victoria. Young caterpillars feed in clusters on the underside of leaves and skeletonise leaves. Older larvae are solitary. They feed on flowers, leaves and growing points of the plant. Caterpillars grow to 40 to 50 mm

long. They are commonly brownish purple in colour, though can be green. The cluster caterpillar has a row of dark triangles and a distinctive yellow line along either side of the body. Adult moths have dark forewings and light hind wings.

Looper caterpillars (*Chrysodeixis* spp.) are another cucumber pest in New South Wales and Victoria. These caterpillars grow to 30 to 40 mm long and are usually green, but can be brown, and are smooth and slender. They feed on the underside of leaves and can skeletonise or chew holes in them. Large populations can defoliate plants. Loopers move in a looping motion. The adult moths are active at night and fly towards lights.

Management

Routinely monitor pest populations. For small infestations, remove insects by hand. Use physical barriers and screens to exclude pests where feasible. Remove all plant material from the greenhouse between crops and control weeds in and around the greenhouse. Inspect all new plant material for pests before moving it into the greenhouse. As with most larvae, insecticides are most effective when used on small larvae that are about 5 mm long.



Budworm caterpillar.



Cluster caterpillar.



Looper caterpillar.

There is a commercially available bacterium (*Bacillus thuringiensis*) that provides effective biological control of most species of caterpillar. *B. thuringiensis* kills early larval stages of caterpillars. Some naturally occurring predatory bugs and ladybird beetles attack eggs and larvae while parasitoid wasps and parasitoid flies prey on eggs, larvae and pupae. There are also some pathogenic fungi.

To find which pesticides are currently registered for caterpillars in cucumbers and which are safe to use with beneficials check with your IPM consultant, pesticide supplier, InfoPest® or the APVMA website (www.apvma.gov.au) which has more information on what is registered, or has a current off-label permit, in your state or territory.

Hints for successful use of biocontrol agents (BCAs) in greenhouse cucumbers

- Start the crop in a clean greenhouse with pest-free plants. Contact seedling propagator to ensure harmful residues to beneficials are not used during propagation.
- Never use pyrethroids or other toxic pesticides with long residual action.
- Be familiar with side-effects of all chemicals you intend to use, whether insecticides, miticides, or fungicides. Mixtures may be more toxic than single products; addition of spreaders/adjuvants may make a 'safe' chemical unsafe. Side-effects may be very subtle – a reduction in egg laying, poor dispersal rate, loss of appetite. No chemical use is the safest option, but spot application is next best.
- BCAs work best in greenhouses with good environmental management. Most need a warm, humid environment to increase faster than their target pest. Hot, dry conditions strongly favour spider mites, and broad mites. Increase humidity by use of foggers to avoid leaf wetness, or water walkways. New crops are a hostile environment for biocontrol agents as lack of leaf cover means low humidity, limited food and reduced mobility between plants. Repeat introductions may be necessary. BCAs will not survive in very high or very low temperatures.
- Install screening where possible to exclude constant incursions of flying pests.
- Practice good sanitation and weed control inside and outside the greenhouse to reduce spread and carryover of pests and diseases.
- Monitor regularly (at least weekly) both visually and with sticky traps so that you pick up the first sign of pests. It is cheaper and far more effective to release low rates of BCAs regularly, than high rates when there is a problem. Spot treat with a compatible chemical if necessary. Have compatible chemicals on hand so that prompt action can be taken. Re-release BCAs if necessary after the recommended wait period.
- All pests need to be identified correctly to species as management may vary.
- Don't start a biocontrol program with high levels of pests – start when pests are barely detectable, even with careful monitoring. Use yellow sticky traps to detect first whitefly, WFT etc. If pest levels are high, reduce them to low levels with a short residual chemical first. Consider increasing BCAs rates during cooler weather.
- Encarsia benefits from increased light levels (>7300lux). During winter, consider addition of lights. Do not clump Encarsia cards in one spot. Spread them throughout the crop, but increase rates in problem areas. Hang cards low in the canopy in shade. In winter, hold cards in screened jar until day first adults emerge, then place through the crop.
- Control ants. They milk and protect aphids for their honeydew and eat Encarsia off cards. Use baits.
- Sulphur and some greenhouse gases (carbon monoxide from poorly operating CO2 burners) are detrimental to Encarsia, predatory mites and many other BCAs.
- Keep caterpillars out with good screening. Know when peak moth flights are due so that preventative Bt applications can be made. Xentari® formulation is needed for cluster caterpillar.
- For container-grown/bag grown plants, *Hypoaspis* mites must be added to each container/bag as they will not move much when food is readily available. Similarly with Montdorensis and Cucumeris predatory mites - initially you should release onto every plant and then apply to hot-spots as the crop develops.
- A commercially formulated, naturally occurring insect fungus *Beauveria bassiana* is expected to be registered and available in Australia in 2019. This and other entomopathogenic fungi have been available overseas for some time and will be useful for spot treatments in IPM glasshouse programs.



PESTICIDES, SPRAYS AND THEIR USE IN CUCUMBERS

Pesticides are defined as any substance that is used to control a pest. Pesticides may be made from synthetic chemicals, naturally occurring elements or even live organisms. They could be used to control mites, insects, or diseases in the crop, or weeds around the greenhouse.

THIS SECTION COVERS

- Transporting, storing, handling and applying pesticides
- Selecting pesticides
- Calibrating spray equipment
- Personal Protective Equipment
- Keeping pesticide use records

Transporting, storing and handling pesticides

Before opening and applying any pesticide, you must read the label, and understand the directions. The directions for use of the chemical must be followed. Workers handling pesticides are required by law to have completed chemical training (e.g. ChemCert). As the qualification varies by state, check your local state requirements.

Greenhouse growers who decide what pesticides to use (you, the owner or the manager) must make sure they are legal and safe to use for the specific greenhouse cucumber crop situation. All employees or anyone handling and using the chemicals or spray equipment must do so safely and with appropriate training. Spray equipment must be safe to use, regularly maintained and calibrated.

What is a pesticide?

A pesticide is any substance or mixture of substances used to kill or suppress a pest, disease or weed. A pesticide is derived from a natural product or manufactured synthetically. Many pesticides are toxic or poisonous and are also Hazardous Substances and Dangerous Goods (DGs). Dangerous Goods pose risks to people and the environment when transported, stored, prepared, applied, disposed of and immediately after application.

The safe transport, storage, handling, application and disposal of Hazardous Substances is written into the Acts of the different States. Pesticides should be locked away and not accessible to children. They must not contaminate the environment. Pesticide spills can cause harm to waterways, soil, wildlife, livestock and people. Not only are many pesticides lethal to pests, diseases and weeds, many are also poisonous to other living things, including humans, marine life, bees and birds. Carbamates and organophosphates are particularly problematic. You must always take care when using pesticides to ensure your long-term health and safety and that of your family, workers, the environment, the community and consumers.

Pesticide use hazards in greenhouses

There are many pesticide labels and permits that have safety directions specific to greenhouses. If these are not provided, it is essential to be aware of the differences in environment inside a greenhouse compared to that in a field environment. For example, issues relating to some pesticides' hazards and safety have not been determined for greenhouse production systems. This is currently of concern to the Australian Pesticides and Veterinary Chemicals Authority (APVMA) and the Office of Chemical Safety and Environmental Health (OCSEH) in Canberra. There are a couple of unique situations that occur when spraying pesticides inside an enclosed or semi-enclosed greenhouse. Firstly, the person spraying is often enveloped in spray mist. Secondly, a person hand spraying has to brush past a large surface area of wetted foliage. This significantly increases potential skin and breathing exposure risks associated with using pesticides in greenhouses. Make sure you wear all the recommended Personal Protective Equipment (PPE) when applying a pesticide with a label or permit use pattern for greenhouses. Ensure that the correct respirator cartridges are used for inside an enclosed, misty greenhouse.

Any pesticide that is a Hazardous Substance will have a Hazchem rating displayed on the pesticide label. Any pesticide classified as a Dangerous Good will have a diamond shape displayed on the pesticide label. These products have special transport and storage requirements. This information is provided to help you protect your short-term and long-term health and safety when dealing with Hazardous Substances and Dangerous Goods.

Safety Data Sheets

A Safety Data Sheet (SDS) is a record of information about a Hazardous Substance or Dangerous Good. The SDS gives valuable information on how to safely transport, store, prepare and handle the chemical. It also lists the chemical properties of the product and contains First Aid information. The SDS for the pesticide contains a statement of hazardous nature, a Hazchem Code and a Dangerous Goods Class. It also specifies the chemical type or group and the formulation type. You should have a copy of the SDS for all Hazardous Substances and Dangerous Good on your farm (including acids and alkalis).

When buying a pesticide or other chemical, make sure you get a copy of the SDS for that product from

the person who sells you the product. Alternatively, telephone the 1800 number under the Safety Data Sheet heading on the label or go to the manufacturer's website where product and SDS information is provided.

Maximise safety, minimise hazards and risks

All pesticides must be registered with the APVMA. Registered pesticides carry an approved label that gives instructions designed to minimise impacts on health, the environment and trade. You must read all the Safety Directions before opening and using any pesticide and follow those directions carefully.

The best way to avoid the hazards and risks associated with pesticides when transporting, storing, preparing, applying, and post application is not to use them. By adopting good agricultural practices and using an integrated approach to pest and disease management (IPM), you can minimise pesticide use.

Screening the greenhouse against insects is a physical control strategy. When combined with good hygiene, screens can significantly reduce the need for pesticides. Relying on the use of Dangerous Poisons (S7 scheduled poisons) to control pests and diseases is fraught with hazards and risks. For effective control, increase the number of options that you have available. This gives you greater flexibility to manage the problem and more opportunity to reduce or

eliminate the hazards and risks associated with pesticides. This concept is known as the hierarchy of control and is applicable to both WHS and IPM. It is inherent in good agricultural practices.

Transport

Never accept damaged or leaking containers or packaging. When transporting chemicals it is important to make sure that they are kept separated from food, water, animal feed, seeds and fertilisers. Whenever possible have the reseller deliver pesticides to your farm so the risks associated with transporting are eliminated for you. A ute is the preferred vehicle for transporting pesticides yourself. Make sure the load is tied down and covered properly. Never transport pesticides in the cabin of the family car. Have all the right protective equipment for the chemical(s) being transported. Keep a written record of the chemical(s) you are transporting.

Storage

Always follow the manufacturer's instructions for storing pesticides – there is a Storage and Disposal section on the label plus Storage, Transport and Disposal sections on the SDS. Keep pesticides in their original containers and never remove the labels from containers. Do not pour any pesticides into smaller containers or drink bottles for storing. Some products, including biologically derived pesticides such as BT, have expiry dates. If present, the expiry date will be on the label. Check the section on the label that contains the Batch Number and Date of Manufacture to be sure. Do not use any pesticides that have passed their expiry date.

Store chemicals in a well ventilated shed below 30°C. Keep the shed locked. Lockers and cabinets as well as modified shipping containers are available to store pesticides. The floor should be made of material that will not let the chemicals leak into the ground if they are accidentally spilt. Make sure you always have a bucket of 'mop-up' or absorbent materials such as



Pesticides must be stored properly and the facility appropriately signed.

sand or vermiculite or other appropriate materials near the chemical storage area.

Store pesticides in metal or plastic trays (to contain any leaks) on wooden shelves. If possible put a layer of sand or vermiculite or another non-combustible absorbent material in the tray. Disused, triple rinsed, metal or plastic 205 litre drums cut in half and partially filled with sand can be used to house and store 20 litre pesticide drums. Place dry formulations above liquid formulations. Don't use drums that previously contained fuel or other flammable liquid, even if they have been washed out. Store different classes of chemicals separately and never store feed, seeds or fertilisers near pesticides. If fresh, running water is not available near the pesticide store, make sure a bucket or tub of fresh water is kept near the storage area, in case somebody is accidentally splashed or clouded by pesticide concentrate.

Residual contaminated spill debris needs to be collected by a Hazardous Waste Collector and NOT put in domestic garbage. Contact your local council for advice on waste disposal.



Various types of lockable pesticide storage cabinets are available.



Metal or plastic trays can be used to store and contain any leaks from smaller pesticide containers. It is good practice to add an appropriate absorbent material to the containers.



Chemical stores must be kept locked and have appropriate signage.

Handling

Always take care when handling pesticides. Absorption through the skin (dermal) is the most common way in which chemicals enter the body, followed by breathing in vapours or dusts. Use safety clothing, and equipment or PPE whenever you are handling containers, preparing or mixing and applying pesticides. Use PPE even after chemicals are applied – follow the re-entry period on the label. Protective equipment minimises the risks of immediate (acute) and long-term (chronic) poisoning.

Hand operated pumps, taps and spouts are available to help reduce splash and spill risks associated with manually lifting and pouring from pesticide containers. It is recommended that these devices are used on all pesticide containers of 10 L or more. Cradles are another tool designed to minimise splash and spill risks associated with handling of pesticide.



Personal Protective Equipment (PPE) needs to be used whenever you handle chemicals.



Top and below: There are various designs of taps, pumps and spouts that can be fitted to pesticide containers to reduce splash and spill risks when handling them.



Dedicated equipment should be used to accurately measure and mix chemicals. Never use cups or drink bottles to measure out chemicals.

Applying pesticides

Always make sure that the area in which a pesticide is applied is well ventilated. Follow the manufacturer's instructions on the label and always wear the specified personal protective clothing when using pesticides in greenhouses. A list of PPE will always be written on the label and the SDS specifying use when preparing or mixing the pesticide, applying it and after it's applied (re-entry period). Using the recommended PPE will significantly reduce the risk of immediate or long-term injury or poisoning. Stick to the label and/or SDS PPE recommendations.

When pesticides are applied inside a greenhouse, there is usually spray mist surrounding the person who is hand-spraying. There will also be a large wet surface area of cucumber plant foliage which the person spraying often has to move past.



Always aim to minimise your exposure to spray mist when applying pesticides inside the greenhouse. Strategies that can help achieve this are:

- As far as practical, minimise time spent in the greenhouse spraying.
- As far as practical, consider sharing or rotating spraying duties to limit any one person's exposure to pesticides and reduce the load on their body from wearing uncomfortable PPE in the greenhouse environment.
- Use PPE that will reduce the amount of body heat generated and thus reduce stress on the operator's respiratory (lungs) and cardiac (heart) systems.
- Whenever possible, apply the least toxic product option to reduce hazards and the burden of the PPE you need to wear.
- Select pesticides that are IPM compatible and also reduce the risk of pesticide resistance developing in plants. Old chemistry, broad spectrum pesticides usually have resistance problems and their residues are often hard to manage in a continuously harvested crop such as greenhouse cucumbers.
- Whenever possible, improve ventilation in the greenhouse during spraying to improve the rate of vapour dispersal and reduce inhalation risk. In some circumstances this may allow use of lighter duty PPE e.g. a half face respirator instead of full face shield.
- Consider improving spraying equipment to reduce spraying times and hence operator exposure, as well as improving product efficacy or results.



Above: Different makes of remote or unmanned sprayers are available that reduce exposure risks when spraying pesticides in greenhouses.



Various types of motorised sprayers can be used on greenhouse crops.



Another type of robot sprayer.

Wearing impermeable PPE clothing, such as a two piece protective waterproof trousers and jacket set may offer greater dermal protection than Tyvek® hooded coveralls (depending on the product sprayed). However, both of these spray suits greatly increase the heat load generated by the operator to an uncomfortable level when hand-spraying, compared to a Breathalon® suit. Again, depending on the toxicity of the product being sprayed and the recommended PPE, it is preferable to wear cotton coveralls to minimise dermal exposure if the time spent spraying inside the greenhouse can be limited or minimised, particularly if products with low dermal toxicity are used. If the spray time is lengthy, then choose a breathable impermeable PPE clothing fabric such as a Breathalon® suit. However, even so-called breathable fabrics eventually cause the spray operator to feel hotter and sweat more, so it is important to limit the time spent spraying and get as much air vented into the greenhouse as possible. Better still, whenever possible, select a pesticide that doesn't require high level PPE.

Again it depends on the product used, but in general terms a half-face respirator is usually sufficient to minimise inhalation and exposure risks. There are disposable types that are more comfortable than the conventional ones. The respirator must fit properly to be effective; beards can be an issue with these devices. However, half-face respirator's cartridges have a very limited effective operational life when used in a greenhouse environment, particularly when spraying a volatile pesticide. If greater inhalation protection is needed, use a battery powered, air-assisted helmet respirator. Compared to half-face respirators, such PPE significantly reduce the stress load on the respiratory and cardiac systems. They also

offer greater flexibility with the choice and comfort level of PPE clothing worn.

Air-assisted units pump air which passes through a carbon filter attached to a waist belt or in the helmet itself into the breathing zone beneath the hood or helmet. The air stream creates a positive pressure beneath the helmet which excludes any pesticide vapours. The air stream also cools the face. Because the air is pumped into the breathing zone from a small battery powered unit there is no additional load placed on the lungs or heart (unlike unpowered respirators) hence breathing is much easier. The helmets are also very light.

Air-assisted units have colour codes indicating when the cartridge needs replacement. Half-face respirator cartridges are worked hard inside greenhouses, particularly when using newer chemistry fungicides that create a lot of finer droplets.

It is not obvious when these cartridges have expired, which is probably after only a few hours use. If the respirator fits snugly and you can smell or taste the spray odour, then the cartridges have probably expired. Replace with cartridges rated as specified for agricultural chemical use.

Although remote greenhouse sprayers may significantly reduce the risk to people when spraying inside a greenhouse, they may not produce sufficient turbulence, droplet size and penetration of the crop foliage. This can lead to poor pest and disease control. Using the correct nozzles to suit the crop, chemical and target organism is very important for effective pesticide coverage. Seek advice from the sprayer manufacturer.

The time required to complete the spraying with unmanned equipment is often a lot longer than if applied by hand. This needs to be factored into management decisions.

Make sure the pesticide does not drift outside the greenhouse and cause harm or injury to non-target sensitive areas including soil, water, animals or plants. It is important to make sure that your spray equipment is well maintained and correctly calibrated so it delivers the correct amount of pesticide to the crop.

Always follow the Insecticide and Fungicide Resistance Management directions on the product label. This will help make sure good control is achieved without reducing the effective life of the product.

Avoid mixing pesticides together unless there is clear information about their compatibility. Do not

mix more than two pesticides together in a spray tank because the risk of physical and chemical incompatibility increases. This can result in one or all the products not performing properly. Crop burn may occur. Mixing multiple pesticides can even turn the spray mix to jelly making it useless and a big disposal problem. Always check the directions under the compatibility heading on the pesticide label.

When you have finished a chemical application, clean your PPE as per the manufacturer's instructions. Wash the spray tank, the hoses and nozzles with water or a commercial tank cleaning product. Use a cleaning product straight after use, especially if applying a suspension concentrate. Cloudy ammonia can also be used. If suspension concentrate residues are not washed-out of the sprayer straight after use, a thick plug will block nozzles, lines and pumps. Dispose of the rinsate in a fenced-off and appropriately signposted disposal pit.

Disposal

When disposing of empty pesticide containers always follow the manufacturer's instructions as per the directions under the Storage and Disposal heading on the label and SDS. Triple rinse (add this rinsate to the spray tank) and puncture the base of all empty containers with a crowbar. Most current Australian pesticide labels display the drumMUSTER logo which means that triple rinsed and punctured containers can be delivered to participating Local Government Council tips. For more information contact drumMUSTER National Office on 1800 008 707.

Unwanted or out-of-date pesticides can be collected by Hazardous Waste Collectors and some states offer periodic specific collection campaigns for such pesticides. ChemClear has an Australia-wide campaign for such chemicals. Contact their National



Identify your nearest drumMUSTER collection compound.

Office on (02) 6206 6868 or make a collection booking on 1800 008 182.

Re-entry period

Most pesticide labels state a re-entry period. The re-entry period is the amount of time that must pass after spraying the chemical, before anyone goes back into (re-enters) the crop without the PPE that was worn when spraying the pesticide. The re-entry time varies depending upon the toxicity of the pesticide. It may be only until the spray has dried for a pesticide with a Caution Signal Heading but can be 48 hours or more for a Dangerous Poison product.

When spraying volatile pesticides, i.e. ones that require a respirator, make sure the greenhouse is well ventilated before re-entry.

Withholding period (WHP)

The withholding period is the time that must elapse after spraying and before produce is picked. For glasshouse cucumber production the WHP of a particular insecticide is very important. Once harvesting begins only pesticides with a one-day WHP are suitable. Breaches or violations of the maximum residue limit (MRL) can occur when a crop is picked before the WHP has passed, re-treatment intervals are not observed or when too much pesticide is added to the spray tank.

Legislation

The use of pesticides is governed by laws in each state. For example, in NSW, the Environment Protection Authority administers the *Pesticides Act of 1999*. There are heavy penalties for users in all states if pesticides are found to have been misused. There is currently a review taking place to investigate the potential for national harmonisation.

Under current NSW legislation, it is illegal to use a pesticide on any crop or weed that is not mentioned on the label. The APVMA can approve Minor Use Pesticide Permits that legally allow the use of a pesticide on a crop or in a situation that is not mentioned on the label. If you think there is a need for a Minor Use Permit for greenhouse cucumbers in your state, contact the AUSVEG project coordinator for Agrichemical Pest Management Needs and Priorities (03) 9882 0277.

State legislation requires you to keep records of the pesticides you transport and store (WHS) and the details of application (chemical control of use,

e.g. Pesticides Act in NSW). Quality Assurance (QA) schemes also require these records. If you don't record data or information then you are not able to objectively assess or evaluate your pesticide management practices and performance. It is good agricultural practice etc to keep detailed records so that risks can be minimised and properly managed. Performance of chemicals can be evaluated and any necessary corrective measures introduced.

Selecting pesticides

Before using any pesticide, you need to know what problem is affecting your crop. You also need to know how you can best manage it. This means considering all available options.

What is the crop situation? What pest or disease is present? Making a mistake when identifying a pest or disease can cost a lot of money. Some greenhouse cucumber growers have confused nutrient disorders with diseases, treating them with fungicides without success. Making a mistake about pesticide use on cucumbers can damage or even kill the crop or worse, the wrong pesticide can leave chemical residues in your product that goes to market. Always be sure. If you are unsure, get a professional diagnosis immediately.

When you are clear about what the problem is and determined that a biological option is not suitable and a chemical control is necessary, you need to find out what pesticides are registered or have Minor Use Permits for use against the specific pest or disease in greenhouse cucumbers.

Your IPM consultant or chemical supplier can provide a list of registered products, but for any pesticide always check the 'Directions for Use' section on the label yourself. You are ultimately responsible if something goes wrong or the pesticide is not registered or permitted. The reseller is not responsible for what you use. **Always check the label to make sure that the pesticide is allowed in your State for the specific purpose for which you want to use it.** Check the APVMA website for products registered for specific pests, as well as off-label permits current for greenhouse cucumbers. Information is also available from state departments and AUSVEG.

Carefully check the 'Restrictions' above the 'Directions for Use', 'Precautions' and 'Critical Comments' statements on the label. Often specific information relating to greenhouses is provided in one or all of these parts of the label. Some newer pesticides

specifically prohibit use in 'protected cropping' or 'Hydroponics'.

When selecting from a number of registered products, rotate chemical groups and other controls to prevent or delay development of resistance. It is also good practice to select the least toxic, preferably IPM compatible, product available. Remember this step will reduce the burden of the PPE you have to wear and reduce the build-up of pesticide resistance. Old chemistry, broad spectrum pesticides usually have resistance problems and their residues are often hard to manage in a continuously harvested crop like greenhouse cucumbers.

See: www.goodbugs.org.au/chemicals.html or www.koppert.com/side-effects/ for the most recent information on biologicals and chemical compatibility.

InfoPest®

InfoPest is a commercially available online database of registered agricultural chemicals. It is used to look up what products are registered or have off-label permits for control of specific pests, diseases and weeds in different crops for each state. It is updated three times per year. For more information on InfoPest®.

Telephone 1300 367 911

Email: admin@infopest.com.au

website: www.infopest.com.au

Calibrating spray equipment

Correct calibration of spray equipment is essential to ensure that the correct pesticide rate is applied to the crop. If not enough chemical active is applied, poor control may result. If too much chemical active is applied, it can lead to residue problems and perhaps crop burn.

Whether you are using a knapsack sprayer, a hand-held wand connected to a tank with its own pump or power take-off (PTO) connection on a tractor, all hand-held spray equipment can be calibrated by the same method. There are three basic measurements needed:

1. nozzle output in litres per minute
2. spray width
3. metres covered in 1 minute of spraying

An example of a calibration worksheet for a handheld sprayer which takes into consideration the time it takes to spray a three dimensional (3-D) volumetric area such as a greenhouse cucumber crop canopy is included on page 202.

Beneath the calibration calculations, there is an example of how to double check the amount of chemical you worked out that needs to be added to the sprayer.

There are other methods for calibration of spray equipment. The method used can vary with personal preference and the type of equipment used. For more information on calibration of spray equipment, refer to your farm chemical user training course reference manual.



Step 1: Using water, measure how many litres are emitted into a measuring jug from the sprayer in one minute. This is the nozzle output.



Step 2: Using water, on a dry surface, measure in metres the width of the spray pattern of the nozzle.



Step 3: Using water, measure in metres, how far you walk in one minute while spraying. Note a hedgerow is shown here as it is similar to spraying a row of greenhouse cucumbers, that is up and down the plants as you walk along the row.

Backpack/knapsack & hand held sprayer calibration

(Area extrapolation method considering nozzle output, spray width and distance walked)

Pesticide name =

Step	What to do	Answer
1	Measure how much you can spray into a measuring jug for 1 minute. This is your <i>nozzle output</i> .	L/min
2	Measure the <i>spray width</i> of the nozzle on a dry surface.	metres
3	Measure <i>how far you walked</i> as you sprayed for 1 minute.	metres
4•	If provided, from the product label, what is the <i>water application rate</i> ?	(A) should be close to 4 L/ha
5	From the product label, what is the <i>chemical application rate</i> ?	L or kg/ha
6	What is the <i>size or volume</i> of the spray tank?	litres

(A) How much spray mix will I apply per hectare? (Application rate)

nozzle output (1) x 10,000^Δ ÷ $\frac{\text{Spray width (2) x distance walked (3)}}{= ?}$ = Application rate (L/ha)

(1) x 10,000 = ÷ ? $\frac{(2) \times (3)}{= ?}$ = (A) L/ha

•Test: If your calculated water application rate is not the same as the water application rate on the label (4), what can you change to get the right rate?

(B) How much chemical product to put in the tank? (litres or kilograms)

Product or chemical into the tank (B) = label rate (5) x tank size (6) ÷ Application rate (A)

(5) x (6) = ÷ (A) L/ha = (B) L or kg

(^Δbecause 1 ha = 10,000 m²)

How to check if the total amount of chemical to put in each knapsack or tank matches the product application rate per hectare chosen from the label?

1. Application rate (A) ÷ size or volume of the knapsack or tank = the number of knapsacks or tanks needed to spray one hectare (C).

(A) L/ha ÷ Volume L = (C) Number of tanks/ha

2. The amount of chemical put into each tank (B) multiplied (x) by the number of knapsacks or tanks needed to spray one hectare (C), should equal or be fairly close to the chemical application rate per hectare on the label.

(B) L or kg x (C) = Chosen label rate per hectare

It is important to note that many pesticide labels recommend a minimum amount of spray mix be applied per hectare. This is commonly in the range of 500 to 1000 litres per hectare (L/ha). If your calibration calculations show that you are below this volume, there are several strategies that you could use to increase the spray volume. These include walking more slowly, using a swirl plate to produce a larger droplet size, using a hollow cone tip with a larger opening or using a double/twin nozzle attachment.

There are useful videos on YouTube on how to calibrate spray equipment.

Personal Protective Equipment

The right Personal Protective Equipment (PPE) must be worn whenever a pesticide is used. The PPE you must wear for the chemical you are using when both preparing, measuring and mixing it as well as when applying the pesticide is always written on the product label and the SDS. All employees must be provided with the necessary protective equipment and be trained in how to use and maintain it. Remember, if supplying an employee with a respirator, it has to be suitably fitted and they have to be shown how to do a fit test – not all respirators fit all people, an individual fit is required, just like with shoes. Additionally, employees must have a pre-employment medical to ensure they don't have underlying respiratory (lung) or cardiac (heart) conditions that will be made worse by wearing a respirator.

Always wear the PPE listed on the label or SDS as a minimum when preparing and mixing pesticides. When measuring and mixing pesticide concentrates there is a high splash risk. Labels for Dangerous Poisons usually recommend wearing elbow length



The pesticide label and MSDS will specify the appropriate PPE to wear when measuring, mixing and loading, concentrate. The amount and type of PPE recommended varies according to the pesticide's toxicity. The pesticide on the left has a lower toxicity than the one on the right.



Always wear the PPE specified or recommended on the pesticide label and its SDS. There is a range of options for respirators and coveralls/spray suits. The two-piece protective waterproof suit in 'A' and 'C' (opposite) gives better dermal protection than coveralls in 'B'. A full-face respirator, as in 'B' should be worn if recommended. In most situations a half-face respirator, as in 'A' will suffice when the correct cartridges are used. However, the air-assisted helmet respirator in 'D' (opposite), which has a battery pack in the back of it, is recommended because it is less stressful on the heart and lungs of the user than the half-face respirators. The breathable spray suit shown in 'D' (opposite) is also less stressful on the user than the suits in 'A' and 'B' because body heat does not build up as much when hand-spraying.



Elbow length gloves should fit snugly at the elbow so pesticide spray can not enter them and contact the hands. If gloves are worn outside the sleeve, fold the cuffs back to form a crease or gutter to prevent pesticide spray getting inside the gloves when spraying overhead by hand. Gloves can be worn inside the sleeve if the cuff is elasticised and a tight fit.

PVC gloves, a face shield and a chemically resistant apron. The use of pumps, taps and spouts on pesticide containers minimises the splash and spill risks associated with lifting them to pour and measure.

The PPE requirements vary depending upon the level of the pesticide's toxicity. There is a minimum standard of PPE, because a person applying pesticides in the greenhouse may be exposed to greater risks. Remember to wear the PPE recommended on the label and SDS.

Typically recommended PPE for use in greenhouses includes:

- impermeable coveralls or 2-piece protective waterproof long sleeved jacket and long trousers
- at least PVC or nitrile gloves
- gum boots or nitrile boots (trouser legs outside boots)
- air assisted respirator helmet.

Make sure that all PPE is cleaned according to the manufacturer's instructions after use and placed in a sealed container. Use disposable nitrile gloves when washing PPE and for some handling procedures as you can grasp small parts more easily compared the thicker gloves used to spray. Do not wash coveralls with the family washing – wash them separately.



Keeping pesticide use records

Good record keeping is an important part of reducing the risks of using chemicals as well as transporting and storing them. While laws may be different between states, if records are not kept, then objective evaluation of management practices and performance is not possible. Good record keeping is a good agricultural practice from both a business and horticultural sense.

In NSW it has been law under the *Pesticides Act, 1999*, to keep spray application records since July 2002. It is mandatory that a record of use be made in English within 24 hours of using a pesticide and that the record is kept for at least 3 years. On-the-spot fines may apply to first time offenders.

You need to record the following information:

- date of use and the start and finish times
- name and contact details of the person who uses the chemical
- the actual place that the chemical was applied, for example, which greenhouse
- the type of equipment used or how the chemical was applied
- the name of the pesticide used
- how much pesticide was used
- total amount of anything else you used like water, oil or adjuvant that you mixed with the pesticide
- the size of the area that was treated
- the weather conditions while the pesticide was being used, such as wind speed and direction and air temperature
- the pest or disease that was being controlled.

Good pesticide record keeping is both a good agricultural practice and a legal requirement under most state legislation.



POSTHARVEST MANAGEMENT AND MARKETING

Today's growers need to plan the sale of their crop before they plant it. Marketing options include the central markets (consigned to an agent or sold directly at the growers' market), direct sales to retailers, export markets and farmers' markets. Niche markets and direct sales to local outlets should be exploited by smaller growers.

THIS SECTION INCLUDES

- Postharvest handling
- Cool chain management
- Grading and packing
- Basics of marketing
- Quality Assurance

Postharvest handling

Greenhouse cucumbers, are a highly perishable commodity. The expected shelf life is 10 to 14 days. This means that you must get your product to the market quickly and efficiently to avoid postharvest losses.

Losses may be due to one or more of the following:

- mechanical damage
- chemical damage
- physiological breakdown
- pests and diseases
- physical environment
- over-supply or not what the consumer wants.

Good practice in the greenhouse needs to be preceded by planning (before planting) and followed by effective postharvest management, in order to avoid losses.

Cucumbers are still alive after harvest, so physiological processes continue. These processes use up water and stored food. Cucumbers may begin to shrivel or discolour. Quality is reduced. Once this happens, they cannot be restored to their original condition.

This process cannot be stopped. All you can do is slow it down.

Conditions which affect how fast cucumbers breakdown include:

- temperature
- physical damage
- relative humidity
- infection by pathogens.

Cool chain management

After putting money and time into growing top quality produce, it is important not to let that hard work go to waste. Keep cucumbers cool to preserve their quality. Properly cooled produce keeps longer, in better condition. A high level of humidity should also be maintained.

Cucumbers should be cooled as soon as possible after picking. Cucumbers have what is called 'field' heat when they are picked. It is critical that this heat is removed as soon as possible to maintain quality and shelf-life. Picking in the early morning is a good strategy as fruit are relatively cool, but cooling as soon as possible after harvest is still needed.

Transfer harvested fruit out of the greenhouse and into a cooled area as quickly as possible. Avoid leaving picked fruit in the sun. If possible, keep picking containers in shaded positions while harvesting. Move them out of the greenhouse as soon as they are full.

Cooling produce

There are several systems for cooling fresh produce. Passive cooling is where produce is stacked in containers that enable air to flow around the produce. Cold air circulates between the containers. This system is slow and allows condensation to form, potentially increasing disease.

Forced air cooling can be up to ten times faster than room cooling, and avoids condensation forming on the cucumbers. Forced air systems pull air through crates or cartons stacked against a plenum. The air is prevented from 'short circuiting' using tarpaulins, which force it through the entire batch. The warm air is cooled then returned to the room.

Hydro-cooling is a more expensive system but is fast at removing heat from the cucumbers. This system uses cold water to cool the produce. The cold water needs to move over as much of the surface of the cucumbers as possible. The most common systems use a submerged conveyor belt to move produce through the cold water.

Once cooled, cucumbers should be kept cool during packing, grading, storage, transport and ideally while being sold. After harvest cucumbers should be kept at between 7–10°C and at 90 – 95% relative humidity. Under these conditions, your cucumbers will maintain their quality for at least 14 days.

Cucumbers can suffer 'chilling injury' if kept too cold. Chilling injury may present as dark coloured water soaked areas. Chilling injury may occur if cucumbers are stored below 7°C.



If using room cooling, ensure pallets are well spaced to allow plenty of air circulation.



Rack systems allow efficient use of cold room space as well as good air circulation around stacked produce.



Cold rooms should be set at 7–10°C. Lower temperatures can cause chilling damage to cucumbers, while higher temperatures allow increased moisture loss, disease and yellowing.

Grading and packing

Grading is a critical step in marketing your cucumbers. It is important that all the fruit in a container is uniform. Never mix grades. This simply reduces the overall value of your product and gives you a poor reputation in the marketplace.

Remove defective and damaged fruit before packing. Cucumbers should be packed to meet the specifications that you have agreed with the buyer. Specifications will include grade standards, packing weights and tolerance levels for blemishes or other problems. The size of cucumbers is an important part of grading and specifications. Know what your buyer wants and clearly and correctly label packaging.



Packaging

Packaging is an important part of marketing. In particular, continental cucumbers are normally individually shrink wrapped to maximise their shelf-life. Packaging needs to hold the produce and enable transportation to the consumer. Packaging must protect your cucumbers by minimising any of the conditions that might reduce quality, such as physical injury. Often the markets recommend or require specific packaging.

There is a strong trend towards recyclable and/or reusable packaging and this should always be considered. Avoid single use plastics.

Packaging indicates what is inside and should include your brand name and a logo. Logos enable you to develop a reputation and help buyers find



Grading and packaging practices are important facets of marketing cucumbers.

your product. They should be used on all your packaging.

The most common type of individual fruit branding is with adhesive PLU (Price Look Up) stickers but these are difficult to stick to cucumbers. Laser etching of fruit is possible, but has not been commercialised in Australia. Another fruit branding practice involves a clear plastic sleeve in which individual fruits grow and develop. A logo is embossed inside the plastic sleeve so as the fruit develops and expands the logo is pressed onto the fruit.



Novel branding and packaging of Korean hybrid Oriental cucumbers.



Mini cucumbers are usually packed in overwrapped or clamshell punnets.



Laser branding on cucumber.

Basics of marketing

Marketing is an extremely important part of your business. Marketing is everything you do to put your cucumbers in the hands of your customer. Marketing is not just selling, it also includes:

- production planning (when, what and how you will produce your cucumbers)
- handling and transport during harvest
- loading and unloading of cucumbers
- specifications and grading
- packaging, branding and promotion, and
- storage and delivery of cucumbers through the markets to the consumers.

Before you start any production, you must research the market. You need to look at the level of supply, the prices and whether the market trend is increasing or decreasing. You need to know or have a reasonable idea of what the quality of your cucumbers will be. You need to know how much produce you will have for sale and when it will be ready. Greenhouse hydroponic production is a lot more predictable than other production systems so you should be able to have reasonably reliable estimates.

A key part of marketing is identifying your buyer and how you will supply them with what they want. This includes both domestic and export markets.

A lot of growers strive for higher yields but without good marketing, this often leads to low prices. Yield is very important but as a business person, you also need to focus on the financial return that you are making.

Planning goes well beyond deciding to plant a particular variety of cucumber. Planning includes how you are going to grow the crop. Previous sections of this manual have addressed irrigation and nutrition, planting density, pruning and training, pest and disease management and of course, growing conditions. All of these contribute to the financial return that you will achieve.

It is important to be aware that markets only ever accept a limited quantity of cucumbers at any particular time. To optimise your production and get the best return, plan your crop and your marketing. Develop a range of markets. Produce what your buyers want.

Quality Assurance

Quality Assurance (QA) is about managing quality to guarantee consistent product and the ability meet the quality specifications of your buyer the same way every time. QA systems greatly improve the way you run your farm and business and will generally lead to better financial returns through better production and business practices.

QA systems involve:

1. writing down what you do and how you do it
2. identifying hazards and assessing risks
3. following your production procedures
4. monitoring and recording the results – tracing back production processes
5. making sure that the results are what you expected
6. implementing corrective actions
7. training staff to make sure that product specifications are met.



WASTE MANAGEMENT

Good agricultural practice is about managing the whole farm system and includes a Duty of Care, or responsibility, towards the environment. Waste management is a very important aspect of good agricultural practice. Not only does effective waste management prevent negative impacts of the business on the environment, but it will significantly reduce pest and disease problems on the farm. Significant cost savings can be attained by planning and carrying out good waste management.

The planning, design, operation and management of the farm should make the most efficient use of resources, recycle and reuse waste where possible and dispose of waste materials regularly and appropriately.

THIS SECTION INCLUDES

- Plastics
- Crop residues
- Used substrates
- Waste water

Plastics

Plastics are commonly used in most industries. In controlled environment horticulture, polythene coverings, crop support strings, bags for substrate, tray liners, weed matting and redundant irrigation tubing are the main sources of plastic waste.

The performance of plastic coverings declines over time, reducing crop yields. The useful life of coverings depends on type and quality. The manufacturer's specifications and warranty should be used as a guide to useful life expectancy. Replace all plastic covering materials before they visibly start to break down, such as when discolouration is apparent.

Contract a waste collection service to remove plastic waste regularly from the farm. Do not burn or bury plastic waste on the farm – some plastics release toxic fumes if burnt. Between collections, store waste materials neatly and out of sight or in a lidded bin. Prevent fragments such as pieces of covering materials from blowing away. Do not try to remove old greenhouse covering materials during strong winds.

Crop residues

A significant volume of crop residues are generated in a greenhouse cucumber operation. This is particularly the case when hydroponic systems are used, because plant residues are not incorporated into the soil. Pruned leaves and stems as well as rejected produce, such as unsaleable and damaged fruit, are all waste products. Keep green waste in a lidded bin or suitable container away from the cropping area to minimise the potential spread of pests and diseases into crops.

Shred plant material to reduce the volume. Contract a waste collection service to remove green waste regularly. It may be more appropriate to compost green waste on-site for use elsewhere on the farm or later removal. If doing this, do not store or compost green waste upwind from the greenhouse because of the risk of pests and disease blowing into the new crop. Avoid locating crop residue near or upwind of neighbouring houses as odour can be generated.

If stockpiling or composting green waste and substrate, prevent nutrients from leaching into the soil. Make sure that nutrients are not washed away in surface run-off during storms.

Used substrates

Used substrate is also a waste product. Depending on the type of substrate used, it may be replaced with each new crop or used for several crops before disposal. Organic substrates can be incorporated with crop residues for management and disposal. Inorganic substrates derived from minerals can also be shredded and managed with crop residues. Other substrates, such as foam needs managing in a similar manner to plastic and packaging waste.

Store waste materials neatly and out of sight or in a lidded bin until disposal. Do not store used substrates near the greenhouse as it can make it easier for pests and diseases to get into the new crop.

Be aware that used substrates will contain significant amounts of nutrients so when storing them, you need to ensure nutrients are leached out and washed into water courses or ground water.



Waste water should be contained and treated on farm.

Waste water

Waste water or 'run-off' from intensive horticulture usually contains a high level of nutrients, particularly phosphorus and nitrogen, some sediments and possibly plant pathogens. This water must be managed.

Solid matter and sediment in waste water can include organic matter such as algae, leaf and root tissue as well as substrate particles. Run-off water from hydroponics also contains nutrients. In the natural water systems, total nitrogen levels of 0.1– 0.75 mg/L contribute to algal blooms, though the level of phosphorus in water is often the key factor causing algal blooms. Total phosphorus levels of 0.01– 0.1 mg/L contribute to algal blooms. Growth of algae in irrigation systems can also clog drippers and filters.

Contain waste water on-farm so that nutrients, sediments and diseases (if planning to reuse the water) can be removed from the water. Cleaning the waste water means removing

or reducing pollutants to a satisfactory level. A number of methods can be used to stop nutrients and sediments being carried into water courses including bio-filtration (wetlands and reed beds), filtration, evaporation and reverse osmosis. Pathogen treatments before reusing the water include chlorination, iodine sterilisation, ultra violet radiation, ozonation, chloro-bromination, ultra (micro)-filtration, chlorine dioxide and slow sand filtration.

Any system used to treat waste water must be checked routinely to make sure it is working properly. Take water samples routinely and test for nutrient levels. If reusing the water, also test for pathogens.

If your irrigation water source is town or mains supply, it may be a legal obligation to install a backflow prevention containment device. Check your requirements with your water utility.



Many councils require a waste water management plan before development consent is granted. Reed beds and wetlands are a convenient method to fulfil this requirement.



HEALTH AND SAFETY IN THE GREENHOUSE

Health and safety in the greenhouse is an extremely important consideration during horticultural production. Good agricultural practice is about managing the whole farm system, including health and safety of workers and visitors, especially children.

Every greenhouse grower must make sure their greenhouse and farm area is a safe working environment. This is called a Duty of Care. It is the law that every business must be a safe workplace.

Everyone who works on or visits your farm, including family members, has a legal right to protection from any hazards and associated risks.

Be prepared and stop problems from happening.

THIS SECTION INCLUDES

- Heat related illness
- Air quality in the greenhouse
- Lifting, carrying and working at heights
- Risk management
- Risk assessments

Risk assessments are an important part of running a good business. Never take chances. When you find something is a risk it should be recorded as well as what you need to do to fix it, in other words, corrective action.

Never assume that someone knows how to do a task. Always check that they fully understand the task before leaving them alone to do it – implement regular introductory and refresher staff training.

Check your farm and greenhouse regularly for problems. Set a date every few months on your farm calendar or in the farm diary to spend time checking everything is in good working order. Record if items need immediate or imminent replacement.

Sometimes it is hard to see all the problems on a farm when you are there all the time. To make sure you don't miss anything you could get a consultant to look over the farm on a regular basis. Or if you have a friend who is also a greenhouse grower, have them check your farm while you check theirs.

Make sure that your employees are aware of on-farm health and safety issues – work health and safety (WHS). Staff can be the best people to identify problems, so ask them regularly about the workplace. They should be able to help make decisions that affect their health, safety and welfare.

If something looks like it will be a problem, do something about it straight away.

As a greenhouse business owner and/or manager, it is your legal responsibility to make sure that the greenhouse is a safe and healthy workplace.

Heat related illness

The greenhouse environment can be a difficult place to work. It is often hot and quite humid, particularly in low technology systems. Heat related illness is one of the most important health and safety issues for people working in greenhouses. Heat illness is more likely to happen if you are involved in anything that:

- produces body heat (physical work, overexertion)
- increases heat in the environment (strong sunlight, heat generated from machinery)
- interferes with heat loss from the body (high humidity, lack of air movement).

Working in a hot and humid environment makes it harder for your body to cool itself. Heat cramps and muscle spasms can occur in a person's arms, legs and abdomen after several hot hours of work. Another problem is heat exhaustion. Heat exhaustion means you can not keep working and you may even collapse. People who are not used to heat and humidity will get heat exhaustion much sooner than people who are used to these conditions. This means their bodies have adapted to the heat and humidity so they are not affected as much. When you are heat stressed, less blood flows to your brain as well. This can make it hard for you to think clearly.

Heatstroke is the most dangerous heat related illness. When someone gets heatstroke, their core body temperature is very high and they cannot think clearly. It can cause permanent damage or even kill.

Heatstroke is an emergency. Treatment must happen right away.

*Some signs of heat stress:
dizziness, nausea, cramps, muscle
spasms, high body temperature,
disorientation & collapse.*

Workers need to acclimatise to working in a hot and humid greenhouse. This usually takes about five to seven days for a healthy, fit person. During this time, their body makes changes so it can deal with the heat. For example, they will not lose as much salt in their sweat so are less likely to get cramps.

Another way to avoid heat illnesses is to take rests outside the greenhouse. Short work periods followed

by rest periods will keep employees healthy and productive in a hot and humid environment.

Showing the temperature and relative humidity all the time in each greenhouse lets employees know their working conditions. Clocks in each greenhouse help employees follow short work then rest periods.

Greenhouse workers should not drink only when they are thirsty. To stop your body from losing too much water you should keep taking small drinks throughout the day. As a guide, drink 140 – 200 ml of water every 15 – 20 minutes.

Healthy and fit people will cope much better with the hot and humid conditions of a greenhouse.

Air quality in the greenhouse

There are two main things about air quality that greenhouse growers need to know. The level of carbon dioxide in the greenhouse is an important part of air quality in the industry overseas. Air pollutants are another issue. Air pollutants are airborne substances that can cause problems for the health and safety of people working in the greenhouse.

Carbon dioxide

Internationally, carbon dioxide is used a lot as a supplement in greenhouses and is increasingly being adopted for some crops in Australia. In the natural atmosphere, nitrogen gas makes up 78% of the air we breathe. Approximately 21% is oxygen and is now around 400 ppm or 0.004%.

Higher levels of carbon dioxide can increase plant growth and yield. Carbon dioxide gas can be pumped into the greenhouse creates these higher levels, and the closed environment holds it around the crop. Knowing how much carbon dioxide to pump into your greenhouse will depend on how much you can afford. But even very small increases of carbon dioxide have been shown to increase crop growth and yield. Carbon dioxide is used by the plant for photosynthesis so adding the gas to the greenhouse needs to be done during daylight hours.

However, carbon dioxide levels above 3,000 ppm can cause problems for the health and safety of people working in a greenhouse. Some people may have problems at levels of only 1,000 ppm. Moderately high levels of carbon dioxide can make people sleepy, give them bad judgement and also make their muscles too relaxed. These problems can cause accidents. Very high levels of carbon dioxide can kill a person.

If carbon dioxide is added to a greenhouse it must be monitored at all times and alarms installed to detect levels above 800 ppm.

Air pollutants

Air pollutants include dusts, fibres, fumes, mists, smokes, vapours, gases and biological agents. Air pollutants are more of a problem when there is inadequate ventilation. Greenhouses can either be confined spaces or ventilated areas depending on what is happening inside and outside the greenhouse at different times. Because conditions change all the time it can be hard to know what the best safety measures are to put into place. Many jobs done in a greenhouse can cause air pollutants.

Common air pollutants include chlorine (from cleaning products), carbon monoxide (from machinery), sulphur dioxide (sometimes used as a fungicide), dust (from outside, some substrate and from manures if growing in soil), pesticides (with every application), biological agents (such as fungal spores in the crop) and ozone (from water disinfection).

Be aware of all of these potential hazards and make sure they do not cause problems. As mentioned previously, all hazardous materials and dangerous goods have a Safety Data Sheet (SDS), so make sure you have one on site for all such substances. One of the best ways to manage air quality problems is to stop pollutants from getting into the greenhouse. There are different ways to do this. For example, when pruning crops, put the cut pieces into a bag or bin not on the floor to be swept up later. This will mean less dust and fungal spores in the air of the greenhouse. Working this way makes a healthier environment for people and reduces the spread of diseases in the crop.

Ventilation is a very important part of greenhouse management. Ventilation makes the best environment for a crop and is a very good way to make air quality suitable for people working in a greenhouse. Always ventilate the greenhouse early in the morning so air pollutants built up overnight are cleared out before employees start work. Early morning ventilation also helps crop growth and production.

When a greenhouse is unsafe to go into it should have information signs up and structures that stop people from going inside. Keep information about pesticide applications and re-entry times up-to-date and clearly presented at the entrance of the greenhouse. Locks on greenhouses that have just had pesticide applied will stop employees accidentally going in.

Lifting, carrying and working at heights

A lot of work in the greenhouse is manual. Equipment is moved, plants are pruned and harvested and fresh produce needs removal. This means employees do a lot of lifting and carrying every day in a greenhouse.

When lifting a heavy item, bending over can damage your back. The right way to lift is to bend at the knees and try to keep your back straight. An employee should never be expected to lift more than they can comfortably carry.

Trolley rail systems and conveyors can significantly reduce labour costs in a greenhouse and improve the health and safety of employees.



Providing picking trolleys and other aids for workers can improve their health and safety as well as increase their productivity in the greenhouse.

Working at height

Modern greenhouses are taller as this provides a better growing environment; this means employees may need to work at heights to keep them maintained. Ladders, platforms and picking trolleys are used more often, which can cause a safety problem with them toppling over or a worker falling from them.

Develop, and make sure employees follow, a clear guide about working from ladders, platforms and trolleys. Provide information and training to staff about safety when working at heights. Make sure all employees are properly supervised.



Although personal elevating implements are available, there are safety issues when working at heights and safe work practices need to be developed and followed.



Risk management

Risk management is the process of looking for hazardous situations in the greenhouse and around the farm that could cause harm to people, then fixing the problems so they are no longer a risk. It is the law under OH&S legislation that all employers and business owners must identify and fix risks in the workplace.

There are specific steps involved in risk management:

1. Identify the problem.
2. Decide how serious the problem is. This is called a **risk assessment**.
3. Decide what can be done to fix the problem to stop accidents. The more options, the better. This is called a Hierarchy of Control.
4. Check regularly that the risk assessments you have done are still suitable.

Risk assessments

A risk assessment is made for each activity on the farm. The risk assessment identifies the activity and each of the steps needed to complete it. Find any problems or dangers that are possible with each step. Next, put the dangers in order of how bad they are. Use the priority chart, Table 33, to work this out.

Once you have ranked the dangers in order, the table is used to decide the priority for fixing each danger. Then list all the things you will do to fix the danger. Record all of this information.

These records are a way for you to clearly think about the problems and come up with ways to fix them. The priority table makes it easier to work out what should be done first.

In many situations a range of control methods is needed to control hazards. It is best to control a hazard at the source. There is a hierarchy of hazard controls – engineering, administrative and personal protection. Engineering controls are strategies less subject to human failure as well as being less disruptive and uncomfortable for people working in the area. They should generally be used if possible.

Engineering controls

(Adapted from *Managing hazards and risks*, SafeWork NSW)

- Design or eliminate. Try to ensure that hazards are 'designed out' when new materials, equipment and work systems are planned for the workplace. Adequate ventilation in a confined workplace is an example.
- Remove the hazard or substitute less hazardous materials, equipment or substances.
- Adopt a safer process. Follow safe work practices, such as adopting an IPM approach. Alterations to tools, equipment or work systems can often make them much safer.
- Enclose or isolate the hazard, using guards or remote techniques such as barriers or pesticide sprayers.

Administrative controls

Establish appropriate administrative procedures such as:

- job rotation to reduce exposure or boredom, or timing the job so that fewer workers are exposed, such as when applying pesticides and following re-entry periods
- routine maintenance and housekeeping procedures
- training on hazards and correct work procedures such as the safety, mixing and application directions on a pesticide label and/or SDS.

Personal Protective Equipment

Provide suitable and properly maintained PPE and training in its use as per product labels and/or the SDS.

Whichever methods you use, remember in each case their effectiveness should be monitored regularly.

Table 33. Risk management					
		How likely is it that the hazard could occur?			
		Very likely (could happen any time) A	Likely (could happen some time) B	Unlikely (could happen but rarely) C	Very unlikely (could happen but probably never will) D
How severe are the consequences if the hazard occurred?	Kill or cause permanent disability or ill health A	1	1	2	3
	Cause long-term illness or serious injury B	1	2	3	4
	Requires medical attention and several days off work C	2	3	4	5
	Requires first aid D	3	4	5	6



**National Vegetable
Extension Network**
NEW SOUTH WALES