HORTICULTURAL RESEARCH & DEVELOPMENT CORPORATION

The Research Arm of the Australian Horticultural Industries

Carrot yield decline

Know-how for Horticulture™

VG036

Alan McKay
WA Department of Agriculture

FINAL REPORT

VG036

This report is published by the Horticultural Research and Development Corporation to pass on information concerning horticultural research and development undertaken for the vegetable industry.

The research contained in this report was funded by the Horticultural Research and Development Corporation with the financial support of the Sumich Group.

Cover Price $20.00

HRDC ISBN 1 86423 307 9

Published and Distributed by:

Horticultural Research and Development Corporation
Level 6
7 Merriwa Street
Gordon NSW 2072

Telephone: (02) 9418 2200
Fax: (02) 9418 1352

CARROT YIELD DECLINE

CONTENTS

1. Project Executive Summary

This 3 year project began in 1990 at the request of the Sumich Group Ltd. The CEO at the time, Jack Sumich, believed that while carrot production was on the increase and overseas demand was strong for high quality carrots, the ability of the Western Australian industry to provide high yield and quality from the existing intensive cropping base was declining. Western Australia had been producing about 90 % of Australia's export carrots.

The initial approach was to survey the whole industry to identify areas which influenced yield, quality and industry efficiency. The findings of the survey were used to develop research and extension programs to improve industry yields and sustainability.

In 1990-91, a survey of 202 commercial carrot crops, growing on the sandy soils of the Swan Coastal Plain to the north and south of Perth, Western Australia, was conducted to quantify the major causes of marketable yield loss in carrots. Important areas requiring research and extension activities were as follows; crop establishment and plant densities, crop wind protection, blight control, cavity spot disease, root scab, nitrogen nutrition of Nantes carrots, varietal yield and disease tolerance. Cavity spot was considered by many producers to be on the increase and was a disease which threatened the long-term viability of the Western Australian export carrot industry.

Cavity spot (see Figs. 1 and 2, attached Farmnote 74/95 for symptoms) was found in 48% of crop surveyed and reduced marketable yield by an average of over 10% in all crops surveyed. Fungal isolates from cavity spots capable of causing lesions in the laboratory most often resembled *Pythium sulcatum.*

Metham sodium soil fumigant did not control cavity spot in field experiments and metalaxyl (Ridomil 50G ®/Apron ®) failed to give satisfactory control at most field sites. The approach was therefore to pursue development of an integrated disease control strategy. The most promising approach to cavity spot management was with the combination of soil liming and tolerant varieties (see Farmnote 74/95). However further work is needed on cavity spot, including identifying commercially suitable cavity spot tolerant varieties and gaining an understanding of the long-term effects of soil liming on carrot and other vegetable cropping systems.

From the crop survey, it appeared that standard protectant fungicides (such as mancozeb, chlorothalonil and cupric hydroxide were failing to control leaf blight diseases of carrots. Leaf blights became considerably more severe in commercial crops with the adoption of Nantes varieties by the export industry in 1991. Field experiments showed that the combination of chlorothalonil and mancozeb provided excellent control of blight when spray programs commenced at the first signs of disease. The triazole fungicide difenaconazole (Score®) also provided an excellent level of disease control and trial data from this project has been used to support registration of Score on carrots in Australia. Under severe blight pressure the best control programs increased export yields from 24 t/ha (unsprayed crop) to 64 t/ha (chlorothalonil alternated with mancozeb).

Carrot scab (see Fig. 3 in attached Farmnote 73/95) was an important disease or disorder of Western Red carrots and appeared to be transmitted by seed and/or related to severe blight outbreaks. Scab development was still not fully understood, however with the adoption of Nantes varieties, scab became less of a problem.

Nitrogen recommendations had been developed for Western Red carrots and were usually based on restricting top growth in order to allow machine harvesting. The export carrot industry change to Nantes carrot was completed by late 1991 in response to importer demands for these varieties. The smaller-tops of the Nantes varieties offered the opportunity to optimise root yield. Field experiments showed that near maximum yields could be obtained with 250 kg N/ha for a summer-sown (15 week) crop and 350 kg N/ha for a winter sown (20 week) crop. Highest yields with least root forking and highest fertiliser efficiencies were obtained by applying only 10 kg N/ha/week during the early stages of the crop (up to week 6) and then applying 25 kg N/ha/week up until 1 or 2 weeks prior to harvest. Refinement of irrigation scheduling guidelines for carrots growing on sandy soils would hold the key to improved fertiliser use efficiency.

Carrot yields were not sustainable under a continuous cropping regime when compared to yields on new land over 6 crop cycles. The soil fumigant metham sodium did little to improve yield and quality of carrots from continuously cropped areas. Export grade yields in continuously cropped carrots declined to 60 % of new land yields by the 6th crop possibly due to declining phosphorus status on continually cropped areas. Disease was not important at this site with only 4 % of total yield developing severe cavity spot symptoms by the 6th crop.

Two field experiments grown under centre pivot-irrigation studied the effects of plant density and harvest time on the yield and quality of Nantes carrots. Optimum plant density (for export yield) depended on yield level and changed with time of harvest as yields increased with later harvest. Across the six harvests (2 sites x 3 harvests), the plant density for optimising export yield increased from 44 to 70 plants/m^2 as optimum export yields increased from 14 to 83 t/ha. Cavity spot disease could not effectively be avoided by planting at low density to permit earlier crop harvest. Growers were encouraged to use windbreaks and nursery crops, such as cereal rye, with the aim of reducing wind damage to young crops.

The main aim of variety evaluation work was to identify high yielding genotypes of high quality which possessed disease tolerance and which were suitable for export production. Varieties with cavity spot tolerance were identified. There was further industry evaluation and subsequent adoption of some of these varieties. However shortcomings in either yield or quality meant that further disease tolerance screening is needed in close liaison with industry and carrot breeding companies.

Seed priming by the 'drum' priming method commercialised in the U.K. was evaluated in 3 small field experiments. Primed carrot seed emerged only 1 to 2 days earlier than unprimed seed when sown in late winter. No differences in yield or quality were measured however consideration of the potential yield benefit of even 1 to 2 days earlier crop emergence showed that an economic advantage could result from adoption of primed seed. (High yielding carrot crops can increase in yield by 1 t/ha/day close to harvest time).

The W.A. carrot industry was highly supportive of this project and in 1992 formed the Carrot Association for Research and Development (inc.)[CARD] to ensure that export carrot research and development continued. The CARD committee together with the Horticultural Produce Commission (HPC) introduced of a carrot grower 'fee for service' under state HPC legislation to fund future industry research and development.

In the decade prior to this project commencing (1980-1990) the average yield of carrots in W.A. was 38.5 t/ha (ABS) with the highest average annual yield in this period of 43 t/ha. In 1992/93 and 1993/94 average carrot yields in W.A. were 51 and 52.5 t/ha respectively, the highest carrot yields in Australia.

Note: A summary of each chapter of this report is included at the start of the chapter.

2. Project staff and collaborators:

Allan McKay - Project supervisor and research officer

Angie Galati - Project contract research officer

Kris Gajda - Project contract technical officer

Margaret Graham - Vegetable extension specialist

Dr Ian McPharlin - Research officer, plant nutrition

Eleanor Melvin-Carter - former plant pathologist

Dennis Pitman - technical officer, Medina Research Centre

Dr Geof Proudfoot, CSBP and Farmers, analytical services

Staff of Medina Research Centre

Staff of the Chemistry Centre of Western Australia

Farmnote
No. 74/95
Agriculture Western Australia

Agdex 267/633
Root crops/diseases

Cavity spot disease of carrots

By Angie Galati and Allan McKay, Research Officers, Horticulture, South Perth

Cavity spot disease of carrots is caused by soil borne *Pythium* fungi. It appears as small elliptical lesions (usually less than 10 mm across) often surrounded by a yellow halo (Figure 1). Infection can take place anywhere along the carrot root and lesions start as pinhead-size spots. In most cases visible symptoms develop in the month before harvest maturity and develop rapidly if conditions are favourable.

Cavity spot reduces the quality of carrots so that they become unacceptable for the local and export fresh markets.

Cavity spot has resulted in severe losses and has been difficult to control.

An extensive survey of commercial carrot crops showed that cavity spot was:

- more prevalent in late summer and autumn harvested carrot crops;
- more serious on soils with a pH less than 7 than on soils with a higher pH;
- not reduced with the use of the soil fumigant metham sodium; and
- more severe in carrots following another carrot crop.

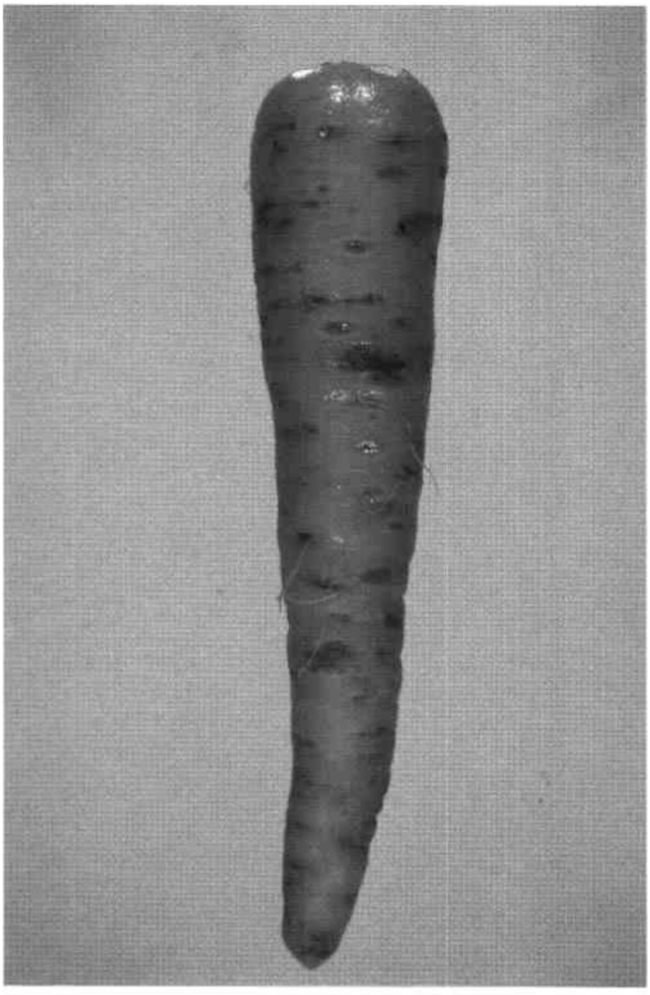
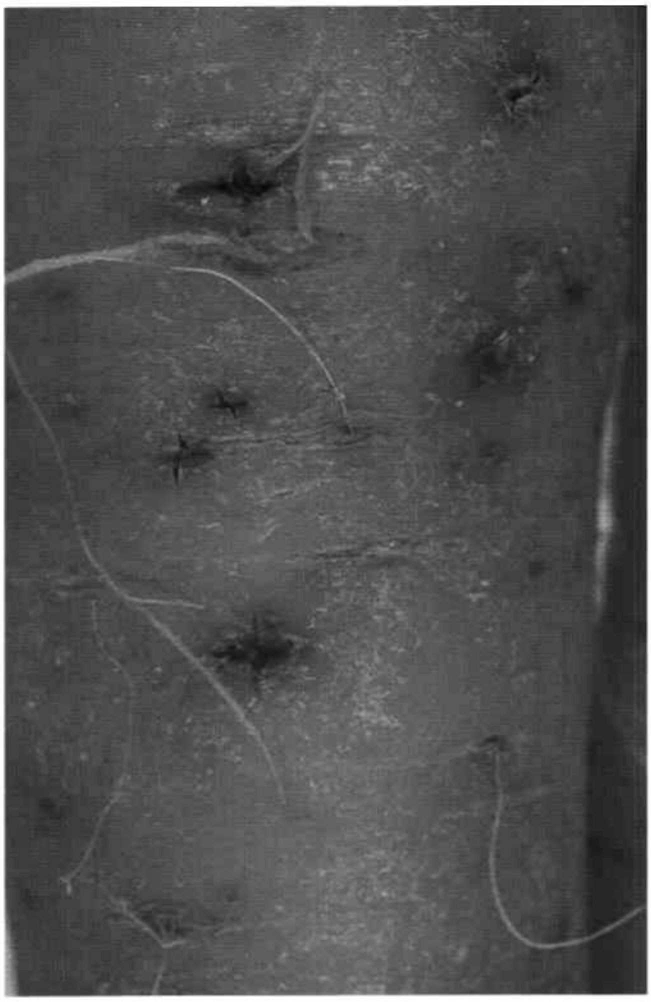


Figure 1. Cavity spot disease of carrots.



Close up: Severe cavity spot symptoms.

Continued overleaf ...

Control

Metham sodium application before cropping has failed to control the disease and the fungicide metalaxyl (Ridomil 50G®) has given some control at some trial sites but has failed to reduce disease at many sites. Where there is a history of use of fungicides that contain metalaxyl (such as Ridomil 720®) on other crops such as onions, resistance may have developed in the soil-borne *Pythium* fungi that cause cavity spot. Note that Ridomil 50G is not currently registered for use on carrots in Western Australia.

By following integrated management guidelines, carrot growers can reduce the severity of disease.

- Harvest carrots as soon as they reach marketable size, since over-mature carrots develop more cavity spot. On sites with a history of cavity spot, monitor disease development over the life of the crop. In the month before the normal harvest date, sample and wash carrots regularly to monitor disease levels. This will help you make decisions on when to harvest.

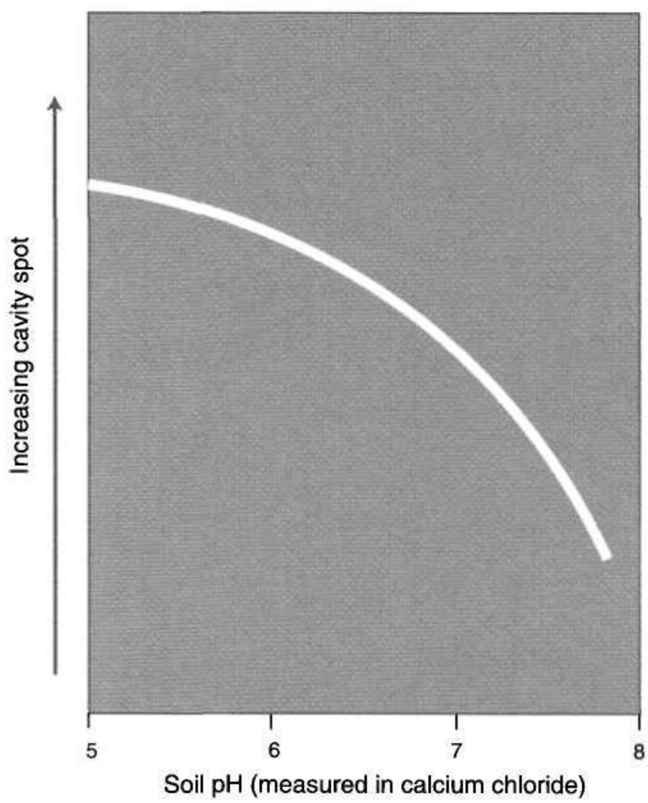


Figure 2. The relationship between soil pH and the incidence of cavity spot in carrots at harvest. The soil pH is measured in a 1 : 5 ratio of soil to calcium chloride solution (0.01 M $CaCl_2$).

- Rotate your crops. Avoid growing carrots continuously on the same ground, which leads to disease problems and general yield decline.
- Grow carrots when cavity spot is least likely to occur. Avoid summer and autumn harvested crops on areas where previous crops have been affected by cavity spot.
- Liming acid soil to increase soil pH reduces the incidence and severity of cavity spot (Figure 2). The amount of lime to apply depends on soil type and soil pH. The target pH for suppression of cavity spot is 7.2 or higher (measured in calcium chloride). The pH of 7.2 in calcium chloride equals about pH 8 measured in water. As an example - on a yellow Karrakatta sand of pH 5.6 (calcium chloride), 8 t/ha of limesand reduced cavity spot incidence from 65 per cent to 32 per cent. The pH 18 months after incorporating the lime was 7.2. The long term effect of lime on cavity spot is unknown.
- The amount of lime to apply also depends on the future cropping program. For instance, potatoes prefer lower soil pH than carrots; liming may affect the yield and quality of the crop. In addition, liming may induce deficiencies of trace elements such as zinc, manganese and iron. Growers are advised to test soil before adding lime. Contact Development Officers of Agriculture Western Australia for advice on lime rates for cavity spot control.
- Some varieties are more susceptible to cavity spot than others. Varietal tolerance can form part of an integrated disease management program along with crop rotation and the use of lime. Most of the commonly grown varieties, such as Top Pak, Nandor and Crusader, have moderate cavity spot susceptibility. Primo is a highly susceptible variety. Agriculture Western Australia is evaluating varieties for cavity spot tolerance. Contact Development Officers of Agriculture Western Australia for the latest information on varieties.

Acknowledgments

Recommendations in this Farmnote are based on research by Agriculture Western Australia sponsored by the Sumich Group Limited and the Horticultural Research and Development Corporation.

Note: Mention of trade names does not imply endorsement or preference of any company's product by Agriculture Western Australia, and any omission of a trade name is unintentional. Recommendations are current at the time of preparation of this publication.

12/95167 - 3 500
Print Post Approved
PP 665002/00031

 Edited and published by Information and Media Services, Agriculture Western Australia, 3 Baron-Hay Court, South Perth, W.A. 6151

ISSN 0726-934X

Farmnote
No. 73/95
Agriculture Western Australia

Agdex 267/633
Root crops/diseases

Leaf blight diseases of carrots

By Angie Galati and Allan McKay, Research Officers, Horticulture, South Perth

Carrot leaf blight is a disease commonly found in carrot crops in Western Australia. Carrot leaf blight is usually caused by the fungus *Alternaria dauci* and occasionally by *A. radicina*. Another fungus, *Cercospora carotae*, causes a leaf spotting of carrots. Both *Alternaria* and *Cercospora* can weaken leaves and in severe cases can defoliate crops. Mechanical harvesting is difficult when leaves are weakened by blight.

Alternaria dauci is more common in autumn and winter and *Cercospora carotae* is more common in summer. It is possible for both types of fungi to be present at the same time in a crop.

Symptoms

Alternaria dauci appears on leaves as small variously-sized dark brown to black lesions. The lesions often appear on the edges or margins of the carrot leaf. In severe cases, the lesions expand, causing the leaflets to turn brown, shrivel and die. The leaf may have a scorched appearance (Figure 1). The petiole or leaf stems can also become infected and develop brown irregular-shaped lesions.

Generally, the older, lowest leaves of a carrot are affected before the upper younger leaves. The disease will first be obvious in carrot crops as irregular patches or 'hotspots' of diseased leaves.

Cercospora carotae appears as small, almost circular, brown spots that are often surrounded by a yellow border. Generally the upper, younger leaves are affected first (Figure 2). *C. carotae* is not as prevalent as *Alternaria dauci*.

Recently, outbreaks of *Cercospora* had symptoms that were indistinguishable from those caused by *Alternaria*.

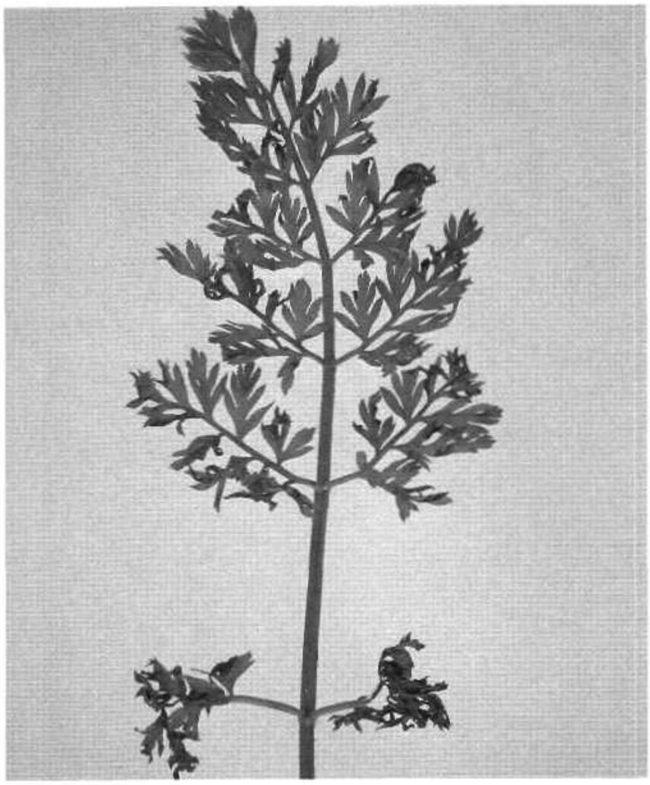


Figure 1. Alternaria leaf blight. Leaf symptoms (above). In the field (below).

Figure 2. Cercospora leaf spot.

Continued overleaf ...

Although symptoms of bacterial blight (*Xanthomonas campetris* pv. *carotae*) can be confused easily with those of alternaria leaf blight, the lesions of bacterial blight are smaller, with a characteristic yellow border. However, bacterial blight has only occasionally been observed in Western Australia.

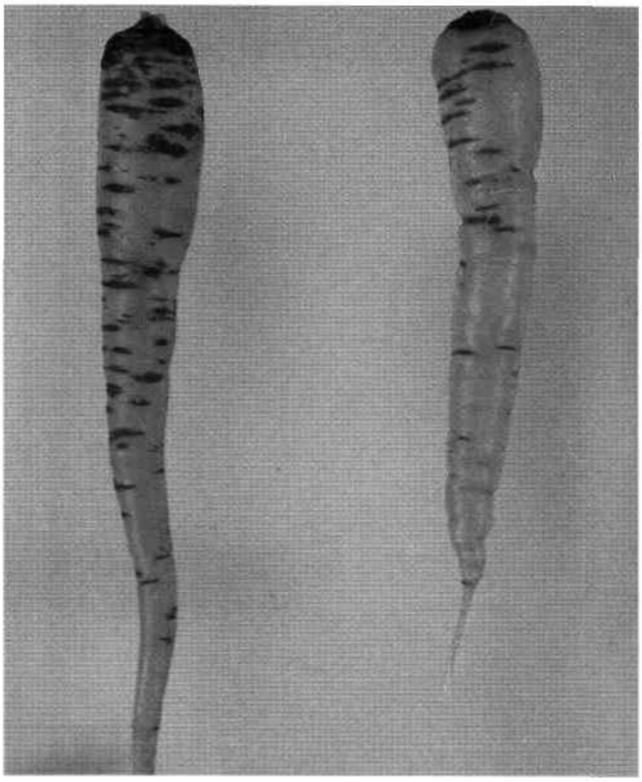


Figure 3. Root scab complex or carrot scab.

Root scab complex or carrot scab may be caused by seed borne *Alternaria* or severe blight outbreaks in the field. This disorder is characterised by thin corky black lesions arising on the secondary root nodes on the carrot (Figure 3). *Fusarium* species can usually be isolated from scab lesions on carrots taken from the field, but evidence suggests that the *Fusarium* may be a secondary invader.

Spread

Leaf blight spores are spread by water, wind and machinery. The spores may come from other diseased fields or from debris of decomposing carrot leaves. *Alternaria dauci* can be introduced on infested carrot seed. Spores produced on infected plants are spread rapidly during wet, windy weather.

Control

- Control seed-borne *Alternaria* by treating seed with hot water (50°C) for 20 minutes (see Farmnote 90/90 'Vegetable seed treatments'), or soaking seed in a 0.2 per cent suspension of thiram for 24 hours at 30°C.
- Carrot seed can be dusted with thiram (5 g/kg of seed). Dusting is not as effective as soaking. Most seed companies take precautions against seed-borne disease. Check the seed tin label or with your seed company representatives.
- Rotary hoe the harvested leaves from old crops, since these contain fungal spores that can spread the disease to neighbouring, younger crops.
- Good crop nutrition will help limit leaf blight. Avoid excessive nitrogen fertiliser use, since very lush tops make blight difficult to control.
- Some carrot varieties are more tolerant of leaf blight than others. Agriculture Western Australia is evaluating varieties for disease tolerance. Contact your local Development Officer for the latest information.
- Fungicide sprays can play an important part in an integrated blight control program.
- All the currently registered fungicides act as *protectants*, not *eradicants*, by interfering with spore germination. Once the disease is present, fungicides will not kill the fungus.
- The effectiveness of a spray program improves if the first spray is applied at the first sign of disease. Check lower leaves for signs of spotting.
- Field trials have shown that under high disease pressure, alternating weekly chlorothalonil and mancozeb gives excellent blight control (Table 1). Cupric hydroxide can also be alternated with chlorothalonil. The spray program must begin at the first sign of disease, particularly in autumn when blight develops rapidly.
- Iprodione (Rovral®), vinclozolin (Ronilan®) and procymidone (Sumisclex®) failed to control leaf blight in trial work because these fungicides are ineffective against *Cercospora*.

Acknowledgments

The results presented in this Farmnote are from work sponsored by the Sumich Group Limited and the Horticulture Research and Development Corporation.

Table 1. Fungicides to control leaf blight

Common name of chemical	Trade names	Spray interval (days)	Withholding period (days)
chlorothalonil	Bravo®, Rover®	14	7
copper as cupric hydroxide	Kocide®, Spectrum®, Blue Mantel®	14	1
mancozeb	Mancozeb®, Dithane M-44®, Manzate®	7-10	7
metiram	Polyram®	7-10	7

Note: Mention of trade names does not imply endorsement or preference of any company's product by Agriculture Western Australia, and any omission of a trade name is unintentional. Recommendations were current at the time of preparation of this publication.

Print Post Approved PP 665002/00031 11/95166—3500

ISSN 0726-934X

3. Publications arising from Carrot Yield Decline project

Seminar/Conference proceedings

Galati, A., McKay, A. G., Melvin-Carter, E., and Gajda, K. (1991). Roots 'aint roots (Carrot survey 1990-91). Conference Proceedings, Horticulture research and extension update, June 13-14, Mandurah, Department of Agriculture.

Galati, A., McKay. A. G., and Gajda, K. (1992) Carrot yield decline- the survey. Proceedings from the Carrot Industry Seminar, Department of Agriculture March 6 1992.

McKay A. G., Galati, A., Melvin-Carter, E., and Gajda, K. (1991). Carrot yield decline.Conference Proceedings, Horticulture research and extension update, June 13-14, Mandurah, Department of Agriculture.

McKay, A. G, Galati, A., and Gajda, K. (1992) Carrot yield decline- research update. Proceedings from the Carrot Industry Seminar, Department of Agriculture, March 6 1992.

Phillips, D. (1992). Carrot yield decline- the importance of plant spacing and harvest time. Proceedings from the Carrot Industry Seminar, Department of Agriculture, March 6 1992.

Industry newsletter articles

Galati, A., and McKay, A. G. (1992). Metham sodium and carrots. *Carrot Association for Research and Development Newsletter* **1**(1), 1.

Galati, A. (1992). Wind and carrots. *Carrot Association for Research and Development Newsletter,* **1**(1), 3.

Galati, A. (1992). Carrot leaves need attention. *Carrot Association for Research and Development Newsletter,* **1**(1), 3.

McKay, A. (1992). Carrot exports grow. *Carrot Association for Research and Development Newsletter*l **1** (1), 2.

McKay, A. (1992). The search for the perfect carrot variety continues. *Carrot Association for Research and Development Newsletter* **1**(1), 3.

Galati, A., and McKay, A. G. (1993). Nutrient deficiencies in carrot survey (boron). *Carrot Association for Research and Development Newsletter* **1**(2), 3.

McKay, A. G., and Galati, A. (1993). Primed seed -is it worth it? *Carrot Association for Research and Development Newsletter* **1**(2), 4.

McKay, A. (1993). Registration update-Ridomil 50G®. *Carrot Association for Research and Development Newsletter*, **1**(2), 5.

Graham, M. (1993). Mycoplasma found in diseased carrots. *Carrot Association for Research and Development Newsletter* **1**(2), 2.

McKay, A. G., and Galati, A. (1993). Nutrient deficiencies in carrot survey (magnesium). *Carrot Association for Research and Development Newsletter* **1**(3),1

Galati, A., and McKay, A. G. (1993). Varieties tolerant to cavity spot. *Carrot Association for Research and Development Newsletter* **1**(3),2.

McKay, A. (1993). Health benefits of carrots. *Carrot Association for Research and Development Newsletter* **1**(3),4.

McKay, A. (1993). New herbicide registration for carrots. *Carrot Association for Research and Development Newsletter* **1**(3), 5.

McKay, A. G., Galati, A., and Graham, M. (1993). Plant densities for carrots. *Carrot Association for Research and Development Newsletter* **1**(3), 3.

Graham, M. (1994). Local experience with liming. *West Coast Vegetables* **1**(1), 9.

McKay, A., Galati, A., and McPharlin, I. (1995). Nitrogen rates for Nantes carrots need fine tuning *West Coast Vegetables* **1**(2), 4.

Journal and magazine articles

McKay, A. G., and Galati, A. (1992). Survey looks at cause of carrot yield decline. *Good Fruit and Vegetables* **3**(5),24-5.

Galati, A., and McKay, A. G. (1993). The export carrot industry. *WA Journal of Agriculture* **34**, 48-51.

McKay, A.G. and Galati, A. (1994). Research shows new techniques for control of cavity spot. *Horticulture Today*, **8** (87), 12-13.

Galati, A., and McKay, A. G. (1997?). Comparison of fungicides for controlling carrot leaf blight (prepared for *Australian Journal of Experimental Agriculture*).

Galati, A., and McKay, A. G. (1997?). A survey of marketable yield losses in carrot crops in Western Australia (prepared for *Australian Journal of Experimental Agriculture*).

Galati, A., and McKay, A. G. (1997?). The effects of lime and variety on cavity spot disease of carrots (prepared)

Farmnotes

Galati, A., McKay, A, and Tan, S. C. (1995). Minimising post-harvest losses of carrots. Agriculture Western Australia Farmnote 75/95.

Galati, A., and McKay, A. G. (1995). Leaf blight diseases of carrots. Agriculture Western Australia Farmnote 73/95.

Galati, A., and McKay, A. G. (1995). Cavity spot disease of carrots. Agriculture Western Australia Farmnote 74/95.

Radio Interviews

ABC Regional radio interviews on *The Country Hour,* March 1992 and June 1993.

Newspaper Articles

Exports rise but yields fall. The Countryman April 1992 p 8

Carrot growers urges to control output and size. The Countryman April 1992 p 7

Seminar will hear about carrot yield research. Horticulture 2001 Jan- Feb 1992

Leaf blight in carrots. Horticulture Today, 5 No 5 1991

Leaf blight warning for carrot growers. Good Fruit and Vegetables July 1991

Disease clouds WA export carrot drive. Countryman May 1991

Carrot Scab. Horticulture 2001, v. 3 no 4 Jan/March 1991

What's up in the carrot industry? Horticulture Today, v. 6 no. 9 Nov/Dec 1992

An overwhelming 'yes' to improve carrot outlook. Better Growing, March 1994

Carrot growers vote for levy. The Countryman, March 1994

---

4. A SURVEY OF COMMERCIAL CARROT CROPS IN WESTERN AUSTRALIA

A. Galati and A. G. McKay

A SURVEY OF COMMERCIAL CARROT CROPS IN WESTERN AUSTRALIA

Summary

In 1990-91, a survey of 202 commercial carrot crops grown on the sandy soils of the Western Australian Swan coastal plain, was conducted to determine major causes of carrot yield loss and to determine recommendations for future carrot industry research, development and extension.

The survey identified several areas requiring extensive research and a concentrated extension effort. Research is needed into the control of cavity spot disease, 'scab' and leaf blights. The effect of metham sodium fumigation on carrot yield and quality also needs quantification. In addition, crop nutrition and plant densities for Nantes carrots require more research as recommendations are based on the Autumn King variety Western Red. The effect of crop rotation on disease incidence requires further research as the intensity of carrot cropping was often high. The survey data also indicated the need for extension programs on the control of leaf blight and achieving optimum plant densities.

Major results

- The predominant variety at the start of the survey was the open pollinated variety Western Red. However, during the survey period the industry first swung to Imperator and then hybrid Nantes varieties such as Top Pak and Nandor.
- Total yields ranged from 16-102 t/ha, with an average of 64.7 t/ha. The marketable yield ranged from 3 to 93 t/ha with an average of 39.4 t/ha.
- The average density of crops in the survey was 67 plants/m^2. However plant densities ranged from 16-152 plants/m^2. Wind damage was the major cause of poor crop density, while some low densities resulted from poor seed germination or seed bed preparation.
- Nearly 40 % of the carrot crops surveyed were following another carrot crop.
- Leaf diseases caused by the fungi Alternaria and Cercospora were found in many of the crops surveyed.
- Nutritional problems were detected in some crops. For instance, phosphorus deficiency was detected on the grey leaching sands. Boron deficiency was found in several crops, as evident by the 5 o'clock shadow symptoms.
- The most prevalent causes of marketable yield loss (ie greater than 10 % yield loss) were:

  Cavity spot (16 % of crops),
  Scab (9 % of crops),
  Forking (13 % of crops),
  Nodal enlargement (13 % of crops), and,
  Poor size distribution-oversize/undersize (17 % of crops).

Recommendations

(a) Extension/adoption by industry

A summary of results from each crop (including soil and leaf analysis) was sent to the respective grower with suggestions for the improvement of future crops. This was followed by a summary of results from all crops surveyed which was extended to the industry at the first carrot industry seminar held in March 1991. Several extension issues were identified for Development officers including the improvement in some agronomic practices which could improve marketable yields.

(b) Directions for future research

The survey identified several areas requiring long term research, which formed the basis of the research phase of this project. These included integrated management of the cavity spot, leaf blight and scab, nitrogen nutrition of Nantes carrots and optimal plant densities for Nantes carrots

(c) Financial/commercial benefits

The survey identified areas where yield improvement could be made thus potentially improving grower returns. It also identified research areas which when resolved and extended to the industry could further improve production efficiency and grower returns.

Experiment 90PE8 - A survey of commercial carrot crops in Western Australia

Introduction

Carrots were one of Australia's ten most valuable horticulture exports in 1990-91 valued at $A10.5 million (FOB). About 30,000 tonnes of carrots were produced in Western Australia in 1990/91 of which 20,400 tonnes were exported to south east Asia, accounting for 97 % of Australian carrot exports. By 1992/93, carrot exports from WA had increased to 26,800 tonnes. Singapore, Malaysia and Hong Kong are the major markets for Australian carrots.

Carrots grown in Western Australia are produced on sandy soils on the Swan coastal plain, from Gingin to Myalup (100 km north and south of Perth). The sandy soils and mild climate make possible for the year round production of high quality carrots.

Typical grower practice is to alternate carrots with other vegetable crops in a close rotation or to grow a sequence of carrot crops before planting a rotation crop. Growers are constantly striving to increase their production efficiency in order to remain viable. Grower observations suggested that unspecified diseases and disorders were reducing marketable yields and threatening the viability of several major carrot producers.

A survey of commercial carrot crops commenced in early 1990 with the objectives of investigating the extent and causes of carrot yield loss and defining strategies which would allow growers to produce economically and sustainably higher yields. The survey results would also help identification of areas for future research and development for the carrot industry.

Materials and Methods

Cultural methods

The survey commenced in March 1990 and was completed in April 1991. Growers were approached via contacts made with exporters, other growers or Department of Agriculture development officers. Fifteen questions were asked of growers about the management of the crop to be surveyed (see appendix). Information provided by individual growers remained confidential. Sixty growers participated in the survey. All of the 202 crops surveyed were sampled at harvest maturity. Leaf and soil analysis, details about yield and crop loss were sent to growers along with recommendations for future crops. Many smaller growers kept only poor crop records or in a number of cases none, so that in some instances, crop information such as fertiliser use was incomplete.

Crop assessment

Five small quadrats (1 m length) were sampled from each crop at maturity to estimate total yield, marketable yield and the major categories of marketable yield loss. Roots were washed, weighed individually and examined for root diseases or disorders. Tops were also weighed and 20 youngest mature leaves (YML) was taken for nutrient analysis. The leaves were dried and then forwarded to a commercial laboratory. Soil samples (30 cores to 15 cm) were collected from each crop at harvest to determine concentrations of extractable phosphorus (Colwell 1963) and potassium, organic carbon (Walkley and Black 1934), reactive iron, ammonium, nitrate, conductivity and pH (1:5 water). In 30 crops, measurements of soil compaction were undertaken with a soil penetrometer at harvest.

Carrot roots were categorised according to the following grade specifications :
export: 25 to 50 mm crown diameter and greater than 150 mm length;
marketable short: 25 to 50 mm crown diameter and 100-150 mm length;
undersized: less than 25 mm crown diameter and less than 100 mm length;
oversized: more than 50 mm crown diameter;
small: crown diameter less than 25 mm, length more than 150 mm and
short: crown diameter more than 25 mm, length less than 100 mm.

Rejected carrots were also categorised according to the disease or disorder which rendered them unmarketable. Occasionally more than one disease or disorder was present on an individual carrot. In these instances, priority in grading was given to the most obvious disease or disorder. Each category was weighed. Leaf and root diseases were confirmed by isolations and identifications in the laboratory. All information was recorded on a database program.

Statistical analysis of data

Data for cultural methods are presented as number of crops and as a percentage of the total number of crops in each category. Diseases and disorders are presented as incidence (ie percentage of crops where that disease or disorder was observed) and percentage of crops with greater than 5 % and greater than 10 % of the total yield affected by that disease or disorder. Where appropriate, the percentage of crops with greater than 10 % marketable yield loss caused by a particular reject category was analysed by Chi-square test using GENSTAT software.

Results

Cultural methods

Crop variety. Nine varieties each accounted for more than 5 % of the crops surveyed (Table 1). When the survey commenced in March 1990, the predominant variety was Western Red, but by 1991- 92, the export carrot industry was based solely on Nantes varieties such as Top Pak and Nandor. Western Red was still grown by growers on small hectarage supplying the local market.

Table 1. Carrot varieties grown in 202 surveyed carrot crops

Varieties	Number of crops	% of crops
Western Red	60	29.7
Red Hot	20	9.9
Top Pak	19	9.4
Red Sabre	17	8.4
Majestic Red	17	8.4
F1	15	7.4
Nandor	14	6.9
Cellobunch	10	5.0
Hero	9	5.0
Red Rocket	4	2.0
Tip Top	4	2.0
Growers own variety	3	1.5
Celloking	2	1.0
Other	8	4.0

Sowing. About 62 % of the crops surveyed were sown with an Agricola Italia® air seeder and 13 and 16 % of crops were sown with a Stanhay® belt seeder or Coles® seeder, respectively. The remaining 9 % of crops were sown with an Earthway® seeder.

Carrot seed was available to growers in raw or pelleted form. Pelleted seed was used in 44 % of the crops surveyed compared with 56 % of crops surveyed that were sown with raw seed.

Cereal rye was used by many growers to protect young seedlings from wind. The cereal was planted between the carrot rows a few days prior to sowing the carrots and then killed with a grass specific herbicide after carrot seedlings had established. Forty two percent of the crops in the survey were sown with a nursery crop, such as cereal rye.

Fumigant and nematicide use. Soil was treated with the general purpose fumigant metham sodium in 33 % of crops surveyed. A nematicide, commonly Nemacur®, was applied to soil in 35 % of crops. Five percent of crops were treated with both Nemacur® and metham sodium before planting.

Herbicide and fungicide use. Growers applied pre-emergent herbicides to 60 % of crops surveyed and post-emergent herbicides to 80 % of crops. The herbicides used included linuron (Linuron®), chlorthal dimethyl (Dacthal®), prometryne (Gesagard®), fluazifop (Fusilade®) and metoxuron (Carrotex®).

Sixty two percent of the crops were treated with fungicide. The most common fungicides were: chlorothalonil (Bravo®, Rover®), mancozeb (Dithane 45®, Manzate ®, Mancozeb®), benomyl (Benlate®) and copper based fungicides (eg Kocide®).

Fertiliser use. Poultry manure was rarely used for carrots, but was often applied to other crops grown in rotation with carrots. Superphosphate or double superphosphate was applied as a pre-planting source of phosphorus in 63 % of crops surveyed. Growers were using post-planting applications of ammonium nitrate or Urea in combination with either muriate or sulphate of potash (33 % of surveyed crops). Many growers were using NPK compound fertilisers after planting (62 % of surveyed crops). Table 2 shows the median and the range of N, P and K rates applied to crops.

Table 2. Range and median (kg/ha) of N, P and K rates applied to 202 surveyed carrot crops

Nutrient	Median (kg/ha)	Range (kg/ha)
N	150	28 - 1125
P	75	0 - 230
K	200	45 - 880

Cropping history. Nearly 40 % of the carrot crops surveyed were immediately preceded by another carrot crop (Table 3). Potatoes and brassica vegetables (cauliflower, cabbage, broccoli and Chinese cabbage) were the preceding crop for 22 % and 14 % of crops respectively. Lettuce and onion were the next most important rotation crops (Table 3).

Table 3. Vegetables grown immediately before the surveyed carrot crop expressed as number and % of surveyed crops

Vegetable	Number of crops	% of crops
Carrot	79	39.9
Potato	44	22.0
Lettuce	14	7.1
Onion	12	6.1
Cauliflower	12	6.1
Parsnip, Turnip, Beetroot	11	5.6
Cabbage	7	3.5
Broccoli	7	3.5
Fallow/New land	5	2.5
Capsicum	3	1.5
Chinese cabbage	1	0.5
Zucchini	1	0.5
Cucumber	2	1.0

Intensity of carrot cropping. Over 80 % of the land growing surveyed crops had produced a carrot crop in the previous 12 months. Only 6.5 % of crops in the survey were grown on land which had more than a two year break from carrots (Table 4).

Table 4. Time since harvest of previous carrot crop on land used for 202 survey crops expressed as % of surveyed crops

Time since last carrot crop	% of crops
Less than 12 months ago	86.0
More than 12 months, less than 2 years	3.5
More than 2 years	6.5
New land	2.5

Crop assessment

Yield. Total yield ranged from 16 to 102 t/ha while 65 % of crops produced yields between 50 and 80 t/ha (Fig. 1). Only 1 % of crops produced total yields of more than 100 t/ha. The average total yield was 64.7 t/ha. Average total yields were slightly lower in winter harvested crops (63 t/ha) than in spring, summer and autumn harvested crops (65-67 t/ha).

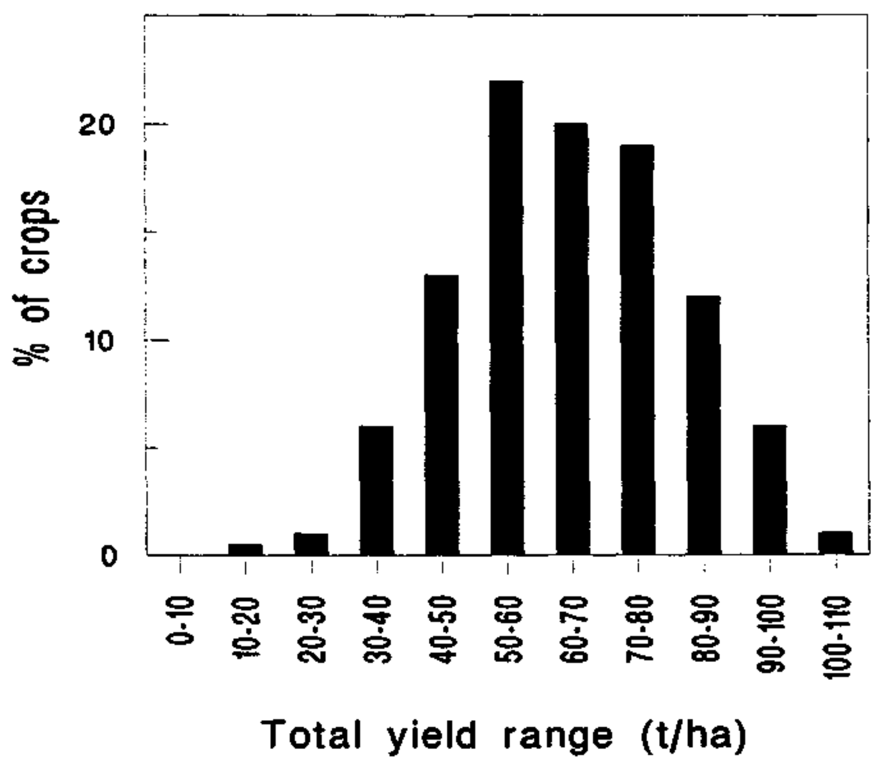


Fig. 1 The distribution of total yields (t/ha) of carrot crops surveyed during 1990/91. Average total yield = 64.7 t/ha, n = 202

Export yield ranged from 3 to 93 t/ha, with an average of 39.4 t/ha (Fig. 2). While 71 % of the crops had marketable yields in the range from 20 to 60 t/ha, only 1 % of crops produced marketable yield greater than 90 t/ha.

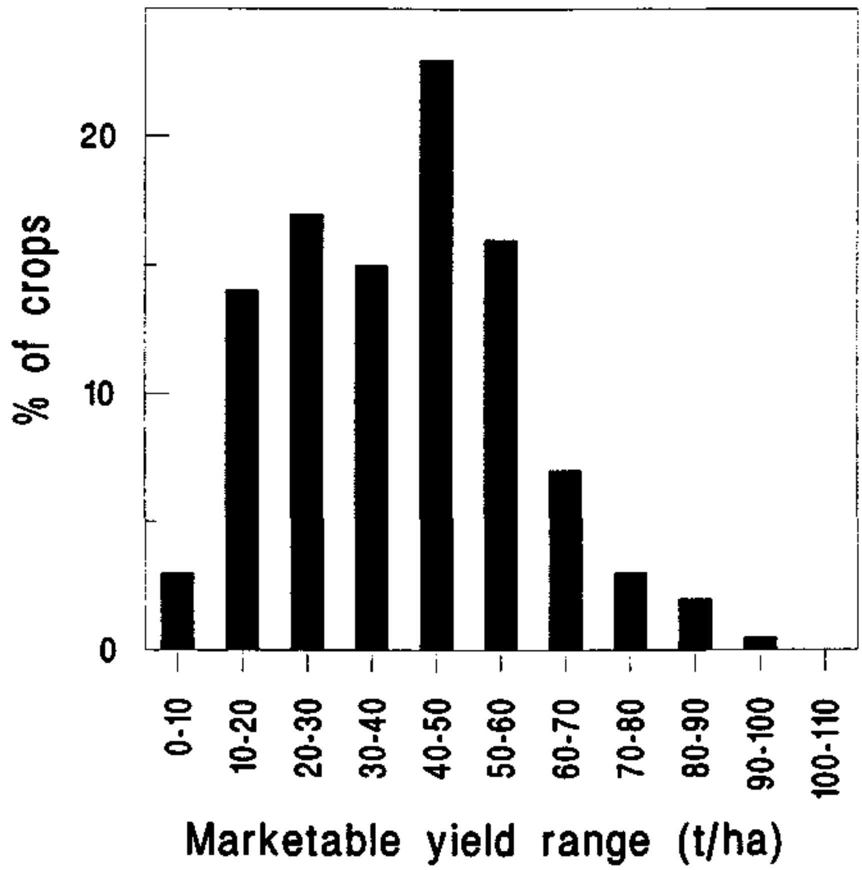


Fig. 2 The distribution of export yields (t/ha) of carrot crops surveyed during 1990/91. Average export yield = 39.4 t/ha, n = 202

Average export yields was nearly 61 % of average total yield. A further 8 % (5 t/ha) of the roots were classed as marketable short, that is, too short for export, but able to be sold on the domestic market. Table 5 lists the average yield for the major variety groups. Nantes carrots produce a higher total yield but a larger percentage of marketable short roots (19 %) compared with other variety groups.

Table 5. verage total, export and marketable short yield of the major variety groups in 202 surveyed carrot crops

Variety group	Main varieties	% crops in survey	Average total yield (t/ha)	Average export yield t/ha (%)	Average marketable short yield t/ha (%)
Western Red	Western Red	30	60.6	31.9 (52.6)	2.8 (4.6)
Western Red related hybrids	Majestic Red, Western Red F1	16	62.9	41.9 (66.7)	4.6 (2.5)
Imperator	Red Hot, Cellobunch	28	64.8	44.6 (67.7)	1.6 (2.5)
Nantes	Top Pak, Nandor	20	75.2	44.8 (60.0)	14.1 (18.8)
All varieties		100	64.7	39.4 (60.9)	5.1 (7.9)

Rejects. Table 6 lists the incidence of all causes of rejection for carrots in the survey. Severity of the disease or disorder is reflected in the percentage of crops with greater than 5 and 10 % of the total yield affected by the disease or disorder. The major causes of marketable yield loss were: cavity spot, 'scab', forking and nodal enlargement. Poor size distribution (undersize and oversize roots) also caused reduction in marketable yields (Table 6).

Table 6. Incidence of reject categories (disorders, diseases and poor size distribution) in 202 carrot crops surveyed during 1990-91 expressed as a percentage of crops surveyed

Reject category	Incidence	% of crops >5 % markeable yield loss	>10 % marketable yield loss
Undersized	98.0	22.8	9.9
Oversized	39.6	16.3	6.9
Short	27.7	2.0	1.5
Smalls	69.8	15.8	4.5
Forking	85.6	30.2	13.4
Misshapen	89.1	33.2	9.9
Nodal enlargement	27.7	24.8	13.4
Cavity spot	47.5	30.2	15.8
Scab	22.8	12.9	8.9
Nematodes	8.9	5.9	4.0
Hairy roots	15.3	1.0	0.5
Root splitting	40.6	3.0	1.0
Bolting	16.3	5.9	3.0
Rotting	11.9	0.5	-
Boron deficiency	5.9	1.5	0.5
Crown rot	11.9	0.5	0.5
Crown discolouration	5.9	-	-
Pale and albino	14.8	3.5	1.5
Insect damage	2.0	-	-
Broom rape damage[A]	1.5	1.0	1.0
Unknown	4.5	-	-

[A]Parasitic plant (*Orobanche australiana*)

Cavity spot. Cavity spot which appears as small elliptical brown lesions on the root, was found in nearly 48 % of the crops surveyed and resulted in an average reduction in marketable yield of 10.9 % over all crops surveyed. Cavity spot was classed as severe (greater than 10 % loss in marketable yield) in 16 % of these crops (Table 6). Cavity spot was found to be more severe (P=0.041) with more intensive carrot cropping (Table 7). When another carrot crop was harvested less than 12 months before harvest of this crop, 34 % of crops had more than 10 % loss in marketable yield due to cavity spot, compared with only 10 % of crops where carrots were harvested more than 12 months ago (Table 7).

Table 7. The effect of cropping history, previous rotation crop, soil pH, variety and fumigant use on the incidence of cavity spot (% of crops) and % crops with greater than 10 % marketable yield loss from cavity spot in 202 surveyed carrot crops

	% of crops	
	Incidence of cavity spot	>10 % marketable yield loss to cavity spot
Last time carrots were harvested on this site		
1 to 12 months ago	49	34
More than 12 months ago	40	10
Significance		P=0.041
Previous crop		
Carrots	58	19
Other vegetables	41	15
Significance		P=0.064
Soil pH		
less than 7	55	21
greater than 7	39	11
Significance		P=0.081
Variety group		
Nantes	60	20
Western Red	40	12
Imperator	51	21
Western Red hybrids	44	13
Significance		P>0.1
Fumigant		
+ metham sodium	51	18
- metham sodium	64	15
Significance		P>0.1

Cavity spot was less severe (P=0.081) in carrots growing on soils with a pH greater than 7 compared to soil of pH less than 7 (Table 7). There was a trend for Nantes and Imperator types to have more severe cavity spot than other variety groups though the result was not significant (P>0.1). The use of metham sodium fumigant did not reduce cavity spot (Table 7).

Cavity spot was found to develop in crops throughout the year (Fig. 3), however autumn harvest crops had higher losses due to cavity spot.

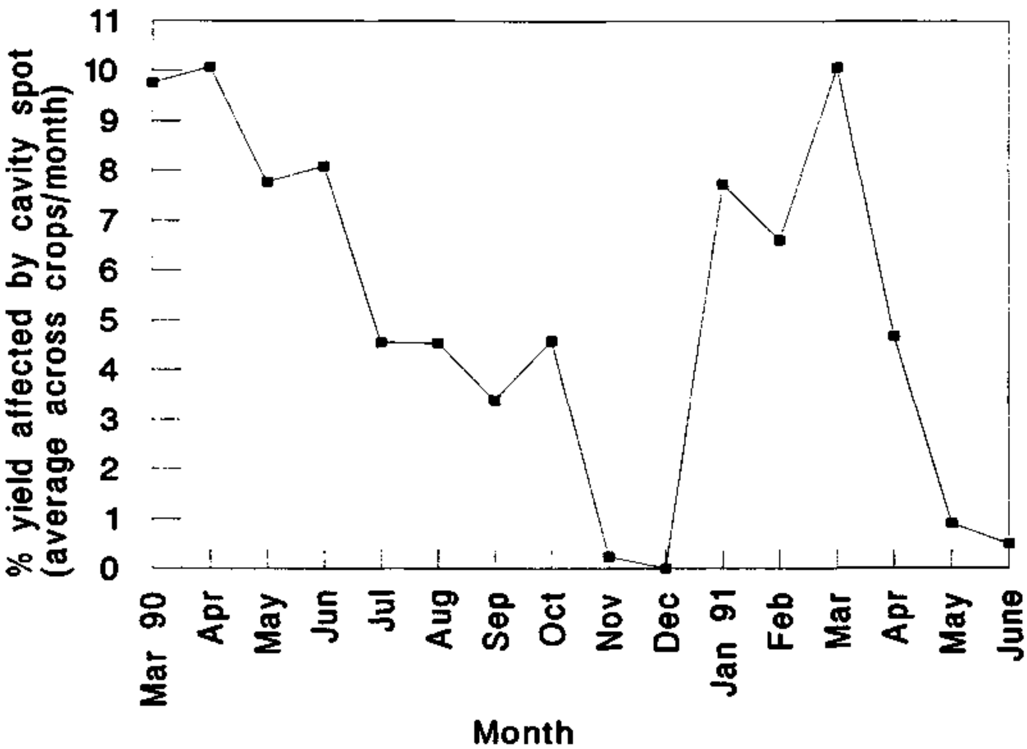


Fig. 3. The seasonal severity of cavity spot disease in carrot crops surveyed during 1990/91.

Scab. The symptom known locally as 'scab' appears as thin black corky lesions where the secondary roots arise on the carrot. Scab was found in 23 % of the crops surveyed (Table 6). Western Red suffered particularly large marketable yield losses from scab (Table 8). One seed source of Western Red had a significantly higher incidence (P=0.033) of scab at harvest than other seed sources (Table 9). There was no difference in the incidence of scab between fumigated and non-fumigated crops, or between soils of high and low pH. However, scab was more likely (P=0.013) to occur if carrots had been harvested from the area in the previous 12 months (Table 8).

Table 8. The effect of variety and cropping history on the incidence (% of crops) and % crops with greater than 10 % marketable yield loss from scab in 202 surveyed carrot crops

	% of crops	
	Incidence	>10% marketable yield loss
Variety group		
Nantes	18	0
Imperator	12	6
Western Red	21	21
Western Red related hybrids	12	0
Significance		*P*=0.006
Last time carrots were harvested on this site		
1-12 months ago	20	16
More than 12 months ago	8	3
Significance		*P*=0.013

Table 9. The effect of seed source on the incidence (% of crops) and % of crops with greater than 10% marketable yield loss due to scab in the variety Western Red

		% of crops	
Seed source	Number of crops	Incidence	>10% marketable yield loss due to scab
1	32	50	38
2	3	0	0
3	8	25	12
4	9	22	11
Significance			*P*=0.033

Plant density and root size distribution. The plant density of crops in the survey ranged from 16 to 152 plants/m^2. The average plant density was 67 plants/m^2. Low densities resulted in low total yields. For example, the average total yield was 49 t/ha when the plant density was less than 50 plants/m^2. However when densities were more than 50 plants/m^2 the average total yield was 68 t/ha. Problems of poor size distribution were also related to plant density.

When the density was more than 70 plants/m^2 only 1 % of crops had significant marketable yield loss due to oversize roots. When the density was less than 40 plants/m^2, 57 % of crops had a greater than 10 % marketable yield loss due to oversized roots (Table 10). There was no significant effect of plant density on the incidence of undersize or forked carrots. However, there were trends for forking to be more severe at less than 40 plants/m^2 (31 % versus 13 %) and for undersize to reduce marketable yields more at densities greater than 70 plants/m^2 (Table 10).

Table 10. The effect of plant density on the incidence of oversize, forked and undersize carrots in 202 surveyed carrot crops. Data shown as incidence (% of crops) and % crops with greater than 10 % of marketable yield loss

	Oversize (% of crops)		Forked (% of crops)		Undersize (% of crops)	
Density (plants/m^2)	Incidence	> 10% marketable yield loss	Incidence	>10% marketable yield loss	Incidence	>10% marketable yield loss
less than 40	71	57	79	31	93	23
41 to 70	43	5	85	14	100	18
more than 70	31	1	86	13	100	31
Significance		$P<0.001$		ns		ns

Forking and nematodes. Forking of carrot roots can be caused by any abiotic or biotic action that kills or damages the developing tap root. Forking was detected in nearly all crops (86%) however forking associated with root knot nematode (*Meloidogyne* spp.) was only found in a 9% of crops. Thus in the majority of cases, root forking was not caused by nematodes. Root forking was most severe in spring and summer harvested carrots (Table 11).

There was no obvious hardpan development in any of the crops in which penetrometer readings were taken (results not shown). Growers were conscious of the possibility of soil compaction and regularly used deep tine implements or mouldboard plough cultivation.

Nantes varieties were less affected by forking than other variety groups (Table 11).

Table 11. The relationships between forking and season of harvest and variety group in 202 surveyed carrot crops. Data shown as incidence (% of crops) and % of crops with greater than 10 % marketable yield loss

	% of crops	
	Incidence	>10 % marketable yield loss
Season of harvest		
Autumn	80	8
Winter	84	11
Spring	93	25
Summer	97	24
Significance		P<0.001
Variety group		
Nantes type	87	8
Western Red	84	18
Imperator type	72	14
Western Red hybrids	94	16
Significance		P<0.001

Other causes of rejection

Crown and root rots. Crown and root rots were each detected at low levels in 12 % of crops. There were no severe losses due to rots (Table 6). Isolations from these lesions yielded various fungi such as, *Sclerotinia* spp., *Fusarium* spp. *and Rhizoctonia* spp.

Paleness and albinos. Paleness and albinos were found in 15 % of the surveyed crops (Table 6). They are caused by a lack of carotene in the roots and probably as a result of pollen from wild carrots fertilising female parents in hybrid seed crops.

Insect damage. Insect damage was rarely a problem in carrots (2 % incidence in crops) (Table 6). In affected crops, weevil larvae had caused feeding tunnels in the upper one third of the root and crown.

Hairy roots. Hairiness or excessive secondary root growth was detected in 15 % of crops but only resulted in rejection of greater than 10 % of yield in 0.5 % of crops surveyed (Table 6). Hairiness is a symptom of Aster yellows disease, motley dwarf and carrot red leaf virus. Roots infected by Aster yellows are hairy and stunted and leaves are yellow. It is caused by a mycoplasma which is usually spread by leaf hoppers (Stevenson 1981; Sherf and MacNab 1986). The carrot viruses are spread by aphids and cause reddening of old leaves.

Broom rape. Broom rape was detected in 3 % of crops (Table 6). Broom rape (*Orobanche australiana*) is a native species which parasitises a host plant to obtain its carbohydrate requirements (Anon 1984). The crops affected were often on new land or land which had only been in production for a few years. Roots become misshapen and pale once the broom rape plant parasitised the root.

Crown discolouration. Discolouration of the crown, usually green or red, occurs when the crown is exposed to sunlight. About 6 % of crops in the survey had roots which were affected by crown discolouration (Table 6). It may have been caused by shallow sowing depth although some blunt ended varieties also tend to 'push' themselves out of the ground. Erosion of soil, often on the outer rows and edge of beds can also lead to crown discolouration. This defect can be reduced by hilling soil over the roots using shallow tynes and by maintaining full leaf cover in the crop.

Boron deficiency. The common symptom of boron deficiency, '5 o'clock shadow', is characterised by the appearance of many small brown spots imparting a dull appearance to the root (Scaife and Turner 1983). Symptoms of boron deficiency were found in 6 % of crops (Table 6). Leaf analysis of these crops detected low concentrations (less than 20 mg/kg) of boron in the youngest mature leaves at harvest.

Bolting. The presence of bolters (carrots that have developed seed stalks) also caused carrots to be rejected because the roots tend to become woody and distorted. Carrots bolt in response to long days once their vernalization requirement is satisfied. Bolting was detected in 16 % of crops (Table 6). Certain varieties were more susceptible to bolting. Western Red had a significantly (P<0.001) higher incidence of bolting than Nantes varieties (5 % vs. 0 % of crops with greater than 10 % yield loss). Although a low incidence of bolting occurred during autumn and winter a significantly (P<0.001) higher incidence of bolting occurred during spring and summer (13 % vs. 0 % of crops with greater than 10 % marketable yield loss).

Nodal enlargement. Enlargement of nodes caused greater than 10 % reduction in marketable yields in 13 % of the crops (Table 6). Nodal enlargement is caused when the secondary root scars or 'eyes' on the carrot enlarge causing bulging outgrowths. This was more common in overmature carrots, in low density crops and in certain varieties.

Root splitting. Root splitting (in this case splitting occurring in the field before harvest rather than splitting occurring during harvesting or grading) occurred in 40 % of the crops surveyed, but only caused greater than 10 % marketable yield loss in 1 % of crops (Table 6).

Leaf blight

Leaf diseases in surveyed crops were associated with the fungi *Alternaria dauci* and *Cercospora carotae*. In general, *A. dauci* was predominantly isolated from leaves in autumn and winter, whereas *C. carotae* was isolated in spring and summer. These diseases weaken the tops and make mechanical harvesting difficult. Many growers were spraying protectant fungicides infrequently and then only when blight had become severe. There appeared to be some varietal differences in blight susceptibility with the Nantes varieties possibly more susceptible than Western Red. Under some intensive cropping systems, disease pressure was so great that applications of protectant fungicides failed to control blight.

Crop nutrition

The nutritional status of most crops was adequate, but in many cases there were luxurious concentrations of some nutrients such as potassium. Few growers soil tested and fewer still were using leaf analysis to monitor crop fertiliser requirements. In one instance, one major carrot producing property had widespread problems with manganese toxicity, as a consequence of repeatedly applying manganese sulphate in response to 'soil test' results.

We observed visual symptoms of magnesium deficiency associated with YML concentrations of less than 0.2 %. About 5 % of crops had marginal or deficient magnesium concentrations (<0.2 % in dried leaves) (Table 12). Among the trace elements, manganese was often marginal on the high pH Spearwood sands. As reported under disorders, boron deficiency was found in 6 % of crops and these crops showed evidence of the characteristic 'five o'clock shadow' symptoms.

Table 12. Average concentration, range in concentration, adequate range (as reported by Piggott 1986) and the percentage of crops from survey with deficient or luxury concentrations of nutrients in the youngest mature leaf at harvest

( ) figures in brackets and italics are critical or excessive concentrations of nutrient in YML at harvest from Piggott (1986). [A]Adequate concentrations at harvest maturity, except those [B]denoted concentrations measured at midgrowth. [C]McPharlin (unpublished data).

Nutrient	Reported adequate range[A]	Average concentration in surveyed crops	Nutrient range in surveyed crops	Deficient (% of crops)	Luxury (% of crops)
(%)					
Nitrogen	1.6-1.7	2.27	1.13-4.26	5 *(< 1.5)*	84 *(>1.7)*
Phosphorus	0.3-0.4	0.316	0.16-0.57	4 *(< 0.2)*[C] 17 *(< 0.3)*	12 *(> 0.4)*
Potassium	1.3-1.5	2.94	0.38-6.04	5 *(< 1.0)*	90 *(> 1.5)*
Calcium	1.8-2.0	1.91	0.63-3.97		
Magnesium	0.35-0.40	0.30	0.139-0.68	5 *(< 0.20)*	10 *(> 0.4)*
Sodium	0.6-4.5[B]	1.79	0.57-5.52		
Chloride	3.0-3.6	3.48	1.68-6.31		
(mg/kg)					
Copper	10-25	12.2	3.8-109.5	1 *(< 4.0)*	6 *(> 25)*
Zinc	20-50[B]	48.9	13.4-208.7	7 *(< 18)*	
Manganese	50-200[B]	42.8	15.7-1408.7	8 *(< 25)*	8 *(> 350)*
Iron	120-350	407.7	50-4590		
Boron	30-100[B]	38.52	15-104.4	6 *(< 20)*	0.5 *(> 100)*

Four percent of crops had leaf P concentrations of less than 0.2 % which was suggested by McPharlin (unpublished data) as being the concentration of P in the YML of carrots at harvest necessary for 99 % maximum yield (Table 12).

Table 13 shows the average and range of soil P, K, NO^-_3, NH^+_4, organic carbon, reactive iron, electrical conductivity and pH (1:5 water) of surveyed crops. Soil pH ranged from 5.0 to 8.3 and averaged 6.9 (Table 13). Soil phosphorus concentrations ranged from 4 to 200 mg/kg. Some soil P concentrations would have exceeded 200 mg/kg as this was the upper limit of reporting by the laboratory.

Table 13. Soil (0-15 cm taken at harvest) test results shown as averages and range found in the crop survey

	Average	Range in survey
Phosphorus (mg/kg)	79.1	4-200
Potassium (mg/kg)	44.0	12-245
Nitrate (mg/kg)	3.3	1-30
Ammonium (mg/kg)	2.1	1-14
Organic carbon (%)	0.68	0.28-2.11
Reactive iron (mg/kg)	280.5	39-1292
Electrical conductivity (dS/m)	0.124	0.018-0.92
pH (1:5 water)	6.94	5.0-8.3

The sandy soils of the Swan Coastal Plain can be divided into 3 main groups. Close to the coast are the orange sands (Spearwood) of high pH (up to 8.5 when measured in water) with some (2%) clay content. The yellow and grey Karrakatta sands further from the coast range from slightly acidic to neutral and retain applied phosphorus reasonably well, while further inland are deep, coarse grey acidic sands which are the most infertile and from which phosphorus is easily leached (McPharlin *et al.* 1990).

Table 14 shows the average bicarbonate extractable P, reactive iron and soil pH (1:5 water) of the various soil types present in the survey. About 20 % of the crops surveyed were on Spearwood sands and 41 % were on grey phase Karrakatta and Bassendean sands ('grey sands') (Table 14). Soil phosphorus concentrations were low on the grey sands. That is, soil bicarbonate extractable phosphorus averaged 47 mg/kg in the grey sands compared to 134 mg/kg on the Spearwood sands.

Table 14. Major soil types on Swan coastal plain

Soil type	% of crops in survey	Average soil bicarbonate extractable P (mg/kg)	Average reactive iron (mg/kg)	Average soil pH (1:5 water)
Grey sands [A]	41	47.3	175	6.5
Karrakatta (Yellow phase)	36	82.3	321	7.0
Spearwood	20	133.8	453	7.5
Vasse (peaty sand)	6	133.8	218	7.2

[A]includes Bassendean sands and grey phase Karrakatta sand.

Discussion

Survey results have highlighted that root diseases were among the most important reasons for the reduction in marketable yields in carrot crops during then 1990/91 season and support grower observation. Nearly a quarter of crops surveyed had greater than 10 % yield loss due to cavity spot or scab disease.

Soil borne Pythium fungi are the cause of cavity spot disease of carrots (White 1986). As cavity spot was more prevalent in crops on land with a recent carrot history, crop rotation may be important for disease control. The indication that Nantes and Imperator varieties were particularly susceptible to cavity spot also means that it is important to screen varieties for disease tolerance before widescale commercial adoption.

The effect of soil pH on the incidence of cavity spot confirms observations in the United Kingdom where Scaife *et al.* (1983) and White (1988) found that the incidence of cavity spot was lower in high pH soils.

An integrated management program for cavity spot needs to be developed for the carrot export industry. This would involve examining the importance of crop rotation. The efficacy of various chemical control measures and the scope for introducing cavity spot tolerant varieties. Metham sodium was used extensively by industry. Its efficacy against cavity spot as well as other effects of fumigation need quantification.

Little information is available on the cause of 'scab' symptoms found on carrots. Symptoms are not consistent with those of bacterial scab (Ark and Gardner 1944), but are similar to those attributed to *Alternaria radicina* (Grogan and Snyder 1952). Laboratory isolations from lesions on carrots from the survey consistently produced *Fusarium* spp. Results from the survey suggest a link between seed source and scab development. Research into this disorder could begin with laboratory examination of potential pathogens present in commercial seed lines.

Growers were unclear as to which fungicides and their time of application needed to achieve control of blight. Fungicides, registered for blight control need to be further evaluated under high disease pressure because of their apparent failure to control blight in some instances. The relative tolerance of carrot varieties to leaf blights also needs to be assessed. The research program would aim to develop a package which would involve blight tolerant Nantes varieties and/or effective use of fungicides.

Possible causes of root forking (other than nematodes) reported previously include; fungal attack on young tap roots caused by Pythium fungi (Kalu *et al.* 1986; Liddell *et al.* 1989), wind damage (Taksdal 1986), waterlogging (Globerson and Feder 1986) and soil compaction (Strandberg and White 1979). It was not possible to establish the causes of taproot damage in the survey as roots were examined at harvest. For a proper assessment, roots need to be examined at early stages during the crop cycle. Attention to good crop management (nursery crops, windbreaks, site selection, uniform irrigation systems) would eliminate some of the causes of root forking. If further evaluation of young seedlings implicates Pythium species as causing tap root damage, then the evaluation of seed treatments and soil drenches would be warranted.

Attention to crop establishment and the use of nursery crops such as cereals and windbreaks is an area requiring extension effort to reduce yield losses caused by wind damage and poor plant density. A yield loss to unmarketable size grades means extra grading costs to the grower. Hybrid varieties have different optimal plant densities than Western Red. Planting Nantes varieties, which are characteristically shorter than Western Red, at high densities would lead to a higher proportion of short carrots. There is potential to improve total and marketable yields of Nantes carrots by defining the relationships between plant density, yield and root size distribution in relation to market requirements.

Enlargement of nodes was more common in older carrots, in low density crops and in certain varieties. No potential pathogens have been isolated from enlarged nodes, suggesting the disorder is physiological. Irregular water supply is reported to result in deep horizontal depressions in the root surface. When excessive moisture follows a period of water shortage, white corky outgrowths may occur at the points of side root emergence (Becker 1970). Improvement in crop management (ie uniform fertiliser and water use) might eliminate much of the marketable yield reduction caused by nodal enlargement.

Other diseases and disorders only played a minor part in the marketable yield losses in the crops surveyed, and research on these, at this stage, would have only minor benefit to industry.

Capital investment in irrigated vegetable land is high. Two to 3 vegetable crops a year are usually grown on the same area of ground and as economic pressure forces growers to keep their land in production. The effect of crop rotation on yield and quality of carrots needs to be evaluated because the intensity of carrot cropping was high. Some growers, who were attempting to crop carrots continuously to supply the export market are no longer in business because rising disease levels eroded returns. Research is required to monitor the sustainability of cropping carrots under various rotational regimes with and without the use of soil fumigants.

For many years, the carrot industry was based on the open pollinated variety Western Red. The nutritional requirements of hybrid varieties needs fine tuning.

Recommendations to date for crop nutrition are based on Western Red. Field observations of commercial crops suggest that a method for monitoring nitrogen nutrition of Nantes carrots would be beneficial to the industry. The survey identified some nutrient deficiencies and excesses in carrots and scope exists for development officers to work with individual growers to develop more efficient fertiliser programs. This is desirable as there are some concerns about excessive use of fertilisers on vegetable crops such as carrots grown on the Swan coastal plain.

The survey has identified a number of areas for research and extension which are considered to be of importance to the carrot industry in Western Australia. The survey also provides some baseline data to measure the success of future research and extension programs.

Acknowledgments

The growers who participated in the survey and provided positive support to the project are gratefully acknowledged for their assistance. E. Melvin-Carter and K. Gajda are thanked for their assistance during field sampling and with pathological isolations. M. Graham is thanked for assisting with industry liaison. We thank T. Boughton for his considerable effects in completing the dBase programming for the survey. J. Dhaliwal is thanked for assistance with statistical analysis. Dr. G. Proudfoot (CSBP) is kindly thanked for his assistance in leaf and soil analysis. The financial support of this project by the Sumich Group Ltd. and the Horticulture Research and Development Corporation is gratefully acknowledged.

References

Anon (1984). Australian broom-rape. WADA Farmnote No 18/84. Agdex 646.

Ark, P. A., and Gardner, M. W. (1944). Carrot bacterial blight as it affects the roots. *Phytopathology* **34**, 416-20.

Becker, R. F. (1970). The influence of environment on carrot quality. Cornell University Extension. *Cornell Miscellaneous Bulletin* No 85.

Colwell, J. D. (1963). The estimation of phosphorus fertiliser requirements of wheat in southern New South Wales by soil analysis. *Australian Journal of Experimental Agriculture and Animal Husbandry* **3**, 190-7.

Grogan, R. G., and Snyder, W. C. (1952). The occurrence and pathological effects of *Stemphylium radicinum* on carrots in California. *Phytopathology* **42**, 215-18.

Globerson, D., and Feder, Z. (1986). Carrot root forking. 22nd International Horticulture Congress, California, Abstract no. 1276.

Kalu, N. N., Sutton, J. C., and Vaartaja, O. (1976). *Pythium* spp. associated with root dieback of carrot in Ontario. *Canadian Journal of Plant Science* **56**, 555-61.

Liddell, C. M., Davis, R. M., Nunez, J. J., and Guerard, J. P. (1989). Association of *Pythium* spp. with carrot root dieback in the San Joaquin Valley of California. *Plant Disease* **73**, 246-49.

McPharlin, I. R., Delroy, N., Jeffery, R. C., Dellar, G., and Eales, M. (1990). Phosphorus retention of sandy horticultural soils on the Swan Coastal Plain. *Journal of Agriculture of Western Australia* **30**, 91-95.

Piggott, T. J. (1986). Vegetable crops. *In* 'Plant analysis. An Interpretation Manual' (Eds D.J. Reuter and J. B. Robinson). pp. 161-2. (Inkata Press: Melbourne.)

Scaife, A., and Turner, M. (1983). 'Diagnosis of Mineral Disorders in Plants.' Volume 2. Vegetables. (MAFF/ARC HMSO: London).

Scaife, M. A., Turner, M. K., Barnes, A., and Hunt, J. (1983). Cavity spot of carrots-observations on a commercial crop. *Annals of Applied Biology* **102**, 567-75.

Sherf, A. F., and MacNab, A. A. (1986). 'Vegetable Diseases and their Control.' Chapter 6. Carrot. pp. 119-156. (John Wiley & Sons Inc) 2nd edition.

Stevenson, A. B. (1981). Carrot insects. MAFF, Ontario. Factsheet agdex 258/605.

Strandberg, J. O., and White, J. M. (1979). Effect of soil compaction on carrot roots. *Journal of the American Society of Horticulture Science* **104**(3), 344-49.

Taksdal, G. (1986). Windbreak effects on the carrot crop. 22nd International Horticulture Congress, California. Abstract no. 1277.

Walkley, A., and Black, I. A. (1934). An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Science* **37**, 29-38.

White, J. G. (1986). The association of *Pythium* spp. with cavity spot and root dieback of carrots. *Annals of Applied Biology* **108**, 265-73.

White, J. G. (1988). Studies on the biology and control of cavity spot of carrots. *Annals of Applied Biology* **113**, 259-68.

Appendix

Table 15A. Range of rejects (diseases, disorders and size distribution) expressed in t/ha and percentage of total yield in the survey

	Range (t/ha)	Range (% of the total yield)
Undersize	0.02 - 2.0	0.02 - 28.1
Oversize	0.16 - 19.9	0.18 - 36.3
Short	0.16 - 19.9	0.17 - 21.9
Smalls	0.18 - 10.2	0.22 - 26.1
Forking	0.05 - 25.3	0.07 - 52.1
Misshapen	0.11 - 20.1	0.15 - 26.4
Nodal enlargement	1.11 - 42.6	1.32 - 60.7
Cavity spot	0.24 - 34.8	0.29 - 63.9
Scab	0.31 - 41.7	0.53 - 48.3
Nematodes	0.43 - 26.0	0.74 - 76.7
Hairy roots	0.11 - 8.9	0.16 - 12.4
Root splitting	0.19 - 7.1	0.24 - 11.0
Bolting	0.04 - 23.2	0.07 - 54.4
Rotting	0.03 - 4.0	0.07 - 8.1
Brown lesions	0.03 - 6.0	0.05 - 13.2
Crocodile skin	0.21 - 4.7	0.28 - 8.2
Boron deficiency	0.18 - 45.4	0.36 - 68.0
Crown rot	0.29 - 6.6	0.36 - 11.5
Crown discoloration	0.21 - 1.9	0.6 - 2.8
Pale and albino	0.05 - 6.5	0.09 - 8.5
Insect damage	0.1 - 1.4	0.17 - 2.0
Broom rape	0.38 - 15.2	0.73 - 22.1
Unknown	0.18 - 1.2	0.44 - 1.8

Table 16A. Proportion of surveyed carrot crops grown from a particular seed company and the major varieties supplied by seed companies in 1990/91

Seed company	% of crops	Major varieties
Lefroy Valley Seeds	24.5	Western Red, F1
South Pacific Seeds	18.0	Top Pak, Nandor
Henderson Seeds	26.0	Red Hot, Red Sabre, Western Red
Yates Seed	13.0	Majestic Red
Northrup King	1.5	Tip Top
WA Produce	4.5	Hero
Magnus Kahl	4.0	Western Red
New World Seed	6.0	Cellobunch, Celloking
Other sources	2.5	Growers own seed

Table 17A. Deficiency or toxicity symptoms observed in carrot crops in the survey

Nutrient	Deficiency or toxicity symptom noted in the survey
Nitrogen	Foliage uniformly pale green, older leaves yellow.
Phosphorus	Stunting of tops (purpling of tops NOT observed)
Magnesium	Yellowing of leaf margins of older leaves
Manganese	Toxicity- black spotting on margins of older leaves
Boron	5 o'clock shadow on roots only

18A. SURVEY QUESTIONNAIRE (90PE8)

Crop No :______

Sample date:_________ Sowing date:_______________

Grower :____

Address : ____

____

Site ID: ____

Preplant

1. How do you prepare ground for carrots? ______________________________

2. Do you apply fumigants/nematicides? _________________________________

3. Do you apply pre-emergence herbicides? ______________________________

Gesagard Linuron Other _______________

4. Do you apply fertiliser/amdendments prior to planting? _________________

Superphosphate Trace elements Lime

NPK Fowl manure Other

5. What is the carrot variety & company? _______________________________

6. Seed type : Raw Pellet

7. Seeder type: Agricola Coles Stanhay Earthway

8. Do you use cereal rye? Yes No.

9. What was the previous crop?

Lettuce	Onion	Carrots	Chinese cabbage
Potato	Cauliflower	Other______________	

10. When was your last carrot crop?________________________

11. What is your fertiliser schedule after planting?

____
____
____
____

12. Do you apply any pesticides after planting? _________________________

Herbicides	*Fungicides*	*Insecticides*
linuron	chlorothanonil	________
prometryne	mancozeb	
fluazifop	copper hydroxide	
metoxuron	benomyl	
other________	other_______	

13. What is the bed size (tractor wheel centre to centre)? ______________

14. How many rows per bed? _________________________________

15. Have you had any problems with your carrot crops? ___________________
____
____
____

5. INVESTIGATIONS INTO THE CONTROL OF CAVITY SPOT OF CARROTS

A. Galati and A. G. McKay

INVESTIGATIONS INTO THE CONTROL OF CAVITY SPOT OF CARROTS

Summary

Cavity spot is a disease caused by soil borne Pythium fungi. The brown, elliptical lesions affect the marketability and quality of export carrots. The commercial survey of carrot crops identified cavity spot as a cause of serious marketable yield losses in carrots.

Several field and laboratory experiments were carried out in the following areas:

- Preliminary taxonomic identification of *Pythium* spp. associated with cavity spot.
- The effect of fungicides on the incidence and severity of cavity spot.
- *In vitro* sensitivity of Pythium isolates to metalaxyl.
- The effect of solarisation and metham sodium fumigation on the incidence of cavity spot.
- Preliminary screening of materials with some known activity against *Pythium* spp.
- Prediction of field tolerance of varieties to cavity spot by *in vitro* testing.
- Effect of pH on growth of Pythium isolates *in vitro*.
- The effect of soil amendments on the incidence of cavity spot
- The effect of lime rate on the incidence of cavity spot

Major results

- Cavity spot disease was detected in 48% of 202 crops surveyed.
- The survey showed that the incidence of cavity spot was higher if the previous crop was carrots.
- Cavity spot was more severe in carrots harvested in the summer and autumn.
- Cavity spot was more serious on soils with pH (1:5 water) less than 7 compared with soils of higher pH.
- There were differences among varieties in their susceptibility to cavity spot.
- Cavity spot was detected by the third crop in continuouly cropped treatments in a rotation experiment.
- Metalaxyl reduced the incidence of cavity spot in only one field experiment out of 5. Phosphonic acid failed to reduce cavity spot at all 5 sites.
- Evaluation of Pythium isolates under laboratory conditions showed differences in susceptibility to metalaxyl.
- Increasing soil pH with lime reduced cavity spot in 2 field experiments.
- Growth of Pythium isolates *in vitro* was reduced on high pH media.
- Metham sodium and soil solarisation were ineffective against cavity spot.
- Materials with activity against Pythium *in vitro* in the literature had no effect under field conditions.
- Laboratory tolerance of carrot varieties to cavity spot correlated with field tolerance.
- Preliminary identification of Pythium isolates causing cavity spot showed that they were very similar to *P. sulcatum*.

Recommendations

(a) Extension/adoption by industry

The results from laboratory and field experiments were presented to the carrot industry at March 1991 and November 1992 seminars. Several publications were also produced. An article about varietal tolerance and integrated managment of cavity spot was published in the Carrot Association for Research and Development Newsletter and the local industry magazine 'Horticulture Today'.

In addition a farmnote on the integrated management of cavity spot was produced. Promising varieties found to be tolerant in field experiments were recommended for limited testing by industry. Lime evaluations could be conducted on a small scale on growers properties. The failure of metham sodium to control cavity spot control needs to be confirmed.

(b) Directions for future research

An integrated management approach to cavity spot is required. The work undertaken has provided some preliminary information, but further studies are required about the long term effects of lime use. For instance, the effect of lime on other crops grown in rotation with carrots needs to be assessed. Also, the effect of crop rotation and the lack of rotation on cavity spot incidence needs to be examined. Screening of Nantes lines *in vitro* for tolerance to cavity spot could fast track varieties suitable for the field. Pythium isolates will need to be tested for fungicide sesntivity *in vitro*. Promising fungicides will then be evaluated in the field. Metham sodium is used extensively by industry. Survey results and trial work showed it was ineffective in controlling cavity spot. Further data is needed to quantify the effects of metham sodium in vegetable cropping systems. Further work should be conducted on this fumigant (eg rate x application methods x timing?).

(c) Financial/ commercial benefits

The control of cavity spot remains high priority to the Australian export carrot industry because of widespread reductions in marketable yields caused by the disease. This work has provided the basis on which to build an integrated program for cavity spot control.

INVESTIGATIONS INTO THE CONTROL OF CAVITY SPOT OF CARROTS

Introduction

Cavity spot is a fungal disease which seriously affects the quality of carrots in Western Australia. The symptoms appear as small elliptical brown lesions (Groom and Perry 1985). A survey of commercial carrot crops found that 48% of all crops were affected by cavity spot disease and that 16% of surveyed crops had marketable yields reduced by more than 10% because of cavity spot (McKay and Galati 1992).

Many possible causes of cavity spot have been hypothesised in the past. Calcium deficiency (Maynard *et al.* 1961), anaerobic pectolytic bacteria (Perry and Harrison 1979), soil ammonification (Scaife *et al.* 1980) and fungal gnats (Hafdih and Kelly 1982) were all suggested as causes of cavity spot.

A significant breakthrough came when cavity spot was reduced with applications of the Phycomycete active fungicide metalaxyl (Lyshol *et al.* 1984). *Pythium* spp. were isolated from cavity spot lesions and healthy carrots inoculated with the Pythium developed cavity spot symptoms. Metalaxyl reduced cavity spot in field crops in the United Kingdom (Gladders and Crompton 1984; Wheatley *et al.* 1984).

The objectives of these investigations were to examine the effect of fungicides, amendments, fumigants and other products on the incidence and severity of cavity spot. In addition, preliminary laboratory work was undertaken to determine the effect of metalaxyl and pH *in vitro* to *Pythium* spp. Varietal tolerance to *Pythium* spp. *in vitro* was also assessed. Finally, attempts were made to identify Pythium isolates collected from the survey and field experiments to species level.

1. Experiment 91MO5 - Control of carrot root diseases - cavity spot and scab

Aim

The aim of this experiment was to determine whether seed fungicide treatment, soil amendments, fumigants and fungicides applied to the soil would control these diseases.

Materials and Methods

A site was selected on a commercial carrot grower property, 100 km north of Perth, where the last 3 crops were carrots and the previous crop had been infected with scab disease.

There were 18 treatments (Table 1) by 4 replicates arranged in a randomised block design.

Raw seed of the 3 varieties was sown with an Agricola Italia® air seeder on 20 March 1991 with 5 double rows per 1.92 m bed. Plots were 10 m long. The experiment was managed as part of a commercial carrot crop.

At harvest (8 October 1991, 202 days after sowing [DAS]), 3 metre lengths of row from the middle rows of each 10 m plot were harvested, washed and weighed for yield and disease assessment. Leaves were also weighed and checked for disease. Leaf and soil analysis were conducted at harvest in some treatments to determine their effect on plant nutrient status.

Metham sodium (500 L/ha) was applied from a low pressure boom mounted in front of the blade of a rotary hoe operating to a depth of 20 cm two weeks before sowing. Ridomil 50 G® at 30 kg/ha (equivalent to 1.5 kg metalaxyl/ha) was broadcast across plots at 49 and 104 DAS. Terrazole® (350 g/kg etridiazole) was also broadcast across plots at 104 DAS. Previcur® (600 g/L propamocarb) and Fos-ject® (200 g/L phosphonic acid) were applied as sprays at 104 DAS using a Hardi® back pack and mini boom. Lime sand, gypsum and sulphur were broadcast and rotary hoed in prior to sowing. Seeds were treated with fungicides prior to sowing. All seed fungicide treatments were applied as dusts. The Top Pak and Hipak seed were treated with thiram by the seed company and were not available in untreated form.

Results were analysed by analysis of variance with mean separation by protected l.s.d.

Table 1. List of treatments and rates in the experiment[A]

Treatment code	Variety	Seed treatment®	Other Treatments®
MR	Majestic Red	Untreated	-
MR + T	Majestic Red	Thiram (5 g/kg)	-
MR + B	Majestic Red	Benlate (2 g/kg)	-
TP + T	Top Pak	Thiram (5 g/kg)	-
TP + T	Top Pak	Thiram (5 g/kg)	-
TP + T + A	Top Pak	Thiram (5 g/kg) and Apron (4 g/kg)	-
TP + T + MS	Top Pak	Thiram (5 g/kg)	Metham sodium (500 L/ha)
TP + T + MS + Rid	Top Pak	Thiram (5 g/kg)	Metham sodium (500 L/ha) + Ridomil 50 G (30 kg/ha) at 49 DAS
TP + T + Lime	Top Pak	Thiram (5 g/kg)	Lime sand (5 t/ha) (Preplant incorporated)
TP + T + Sulphur	Top Pak	Thiram (5 g/kg)	Sulphur (2 t/ha) (Preplant incorporated)
TP + T + Gypsum	Top Pak	Thiram (5 g/kg)	Gypsum (8 t/ha) (Preplant incorporated)
TP + T + early Rid	Top Pak	Thiram (5 g/kg)	Ridomil 50G (30 kg/ha) at 49 DAS
TP + T + late Rid	Top Pak	Thiram (5 g/kg)	Ridomil 50G (30 kg/ha) at 104 DAS)
TP + T + Previcur	Top Pak	Thiram (5 g/kg)	Previcur (250 ml/ha) at 104 DAS
TP + T + Terrazole	Top Pak	Thiram (5 g/kg)	Terrazole (80 kg /ha) at 104 DAS
TP + T + Fos-ject	Top Pak	Thiram (5 g/kg)	Fos-ject (9 L/ha) at 104 DAS
HP + T	Hipak	Thiram (5 g/kg)	-
HP + T + MS	Hipak	Thiram (5 g/kg)	Metham sodium (500 L/ha)

[A]MR = Majestic Red (Yates Seed Company), TP = Top Pak and HP = Hipak (South Pacific Seeds). DAS = days after sowing. Rid = Ridomil 50 G at 30 kg/ha product.

Results and Discussion

Treatments that included the variety Hipak had the highest incidence of cavity spot (Table 2). The percentage of cavity spot was less than 10 % of the total yield in most other treatments and no treatment appeared to suppress the disease (Table 2). Although the site had a previous carrot cropping history, the incidence of cavity spot was low perhaps because conditions leading up to harvest were not conducive to severe cavity spot development.

The MR treatment had the lowest level of scab in this experiment (Table 2). The TP + T + A treatment had the highest % of scab disease although the level of scab infection, like cavity spot, was too low for results to be interpreted meaningfully.

Table 2. The effect of treatment combinations on total and marketable yield, and the incidence of cavity spot and scab disease at harvest maturity

Treatment code	Total yield (t/ha)	Marketable yield (t/ha)	Cavity spot (% of total yield)	Scab (% of total yield)
MR	121.9	71.5	8.9	0.5
MR + T	117.7	69.1	8.9	10.1
MR + B	117.5	73.9	8.7	2.3
TP + T	112.6	49.6	8.2	12.2
TP + T + A	111.9	32.9	12.8	22.4
TP + T + MS	115.2	61.9	7.4	12.1
TP + T + MS + Rid	116.1	59.5	6.1	13.1
TP + T + Lime	107.9	48.6	6.1	12.1
TP + T + Sulphur	90.7	13.4	4.2	14.2
TP + T + Gypsum	113.3	50.1	9.4	12.8
TP + T + early Rid	115.8	54.1	10.0	10.1
TP + T + late Rid	115.6	53.1	5.4	8.4
TP + T + Previcur	113.1	57.1	8.7	10.1
TP + T + Terrazole	118.4	58.1	6.7	11.2
TP + T + Fos-ject	107.8	51.7	7.4	12.3
HP + T	113.8	63.0	18.8	1.8
HP + T + MS	117.7	67.7	15.8	4.9
Significance	*	***	***	*
l.s.d (P=0.05)	13.6	12.1	5.7	10.1

Sulphur at 2 t/ha reduced the total and marketable yield of carrots at harvest maturity (Table 2). The soil pH (1:5 water) was 4.7 in sulphur amended plots at harvest (Table 3A) and carrots in this treatment were stunted in appearance. All other treatments produced similar total yields.
The addition of soil amendments and fumigant produced significant differences in the soil and nutrient status in this experiment (Tables 3 and 4). For instance, the addition of sulphur reduced soil pH, bicarbonate extractable phosphorus and increased the concentrations of manganese and zinc in the youngest mature leaves. Addition of lime had a small but significant effect on the soil pH at harvest (Table 3).

In conclusion the incidence of disease was too low in this experiment to determine whether the treatments were effective against cavity spot or scab.

Table 3. The effect of soil amendments on soil test (0-15 cm) results at harvest

Treatment	Extractable P (mg/kg)	Extractable K (mg/kg)	NO_3 (mg/kg)	NH_4 (mg/kg)	Organic carbon (%)	Reactive iron (mg/kg)	Conductivity (dS/m)	pH (1:5 water)
TP +T + Gypsum	22.5	19.0	9.5	2.50	0.54	73.5	0.22	7.1
TP + T + Lime	23.5	23.0	8.3	1.75	0.63	84.5	0.10	7.3
TP + T + Sulphur	14.3	14.7	2.5	4.25	0.61	88.7	0.13	4.7
TP + T	17.8	24.8	7.3	2.25	0.58	84.2	0.30	7.1
TP + T + MS	23.5	28.8	9.3	1.25	0.59	77.5	0.10	7.0
Significance	*	ns	**	**	ns	ns	ns	***
l.s.d (P=0.05)	6.3	-	2.8	1.34	-	-	-	0.17

Table 4. Effect of soil amendments and fumigant on nutrient concentrations in youngest mature leaves at harvest

Treat.	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Na (%)	Cl (%)	Cu (mg/kg)	Zn (mg/kg)	Mn (mg/kg)	Fe (mg/kg)	B (mg/kg)
TP +T + Gypsum	2.94	0.23	1.16	1.69	0.38	6.0	2.7	7.0	49.0	51.9	150.5	44.4
TP + T + Lime	2.86	0.22	1.25	1.59	0.40	4.6	2.6	7.8	45.0	33.1	108.1	40.9
TP + T + Sulphur	3.16	0.29	1.71	1.47	0.40	4.4	3.2	9.3	239.0	215.0	141.4	39.3
TP + T	3.11	0.25	1.28	1.41	0.44	4.5	2.8	8.4	67.0	65.2	160.2	42.1
TP + T + MS	2.81	0.24	1.26	1.63	0.43	5.3	2.8	7.8	74.0	59.2	129.9	44.5
Signific.	*	***	**	*	ns	ns	*	**	***	***	ns	ns
l.s.d (P=0.05)	0.24	0.02	0.23	0.18	-	-	0.3	1.14	69.8	62.0	-	-

2. Experiment 91M074 - Control of cavity spot of carrots with fungicides

The aim of this experiment was to test the efficacy of a range of fungicides for controlling cavity spot of carrots under field conditions.

Materials and Methods

The site was maintained as part of the surrounding commercial carrot crop. The soil was a yellow Karrakatta sand with bicarbonate extractable phosphorus of 60 mg/kg, bicarbonate extractable potassium of 30 mg/kg, 0.55 % organic carbon content and pH(1:5 water) of 6.1. The site was chosen because previous carrot crops were affected by cavity spot.

Pelleted seed of the variety Top Pak (South Pacific Seeds) was sown on 10 May 1991 with an Agricola Italia® air seeder with 6 double rows per 1.92 m bed and a intrarow spacing of 6.2 cm between plants.

Fos-ject ®, Previcur®, Ridomil® and Terrazole® were applied to the 10 m long plots either early (6 August 1991, 10 weeks after sowing) or late (17 September 1991, 16 weeks after sowing) (Table 5). Untreated plots that received no fungicide were included. Each treatment was replicated 4 times in a randomised block design.

Table 5. Registered name, active ingredient, rate and application method of each fungicide

Registered name ®	Active ingredient	Rate per hectare	Application method
Fos-ject	200 g/L phosphonic acid	12 L/ha	spray
Previcur	600 g/L propamocarb	3 L/ha	spray
Ridomil 50G	5 g/kg metalaxyl	30 kg/ha	broadcast
Terrazole WP	240 g/kg etridiazole	15 kg/ha	spray

All sprays were applied with a Hardi® backpack with mini boom. The output at 1 bar was equivalent to 306 L/ha. No wetting agent was added. Ridomil was applied in the granular form.

Carrots were hand harvested from each plot (1.5 m x 3 middle rows) at harvest maturity on 23 October 1991, washed, weighed and examined for cavity spot and other disorders. Carrots were graded according to disease incidence: slight (1 cavity spot lesion per root), moderate (2 to 3 cavity spot lesions per root) and severe (more than 4 cavity spot lesions per root).

Isolations for Pythium fungi were carried out from a sub-sample of cavity spot affected carrots on 3P agar.

Results

Previcur and Ridomil reduced the total percentage of carrots with cavity spot symptoms (Table 6). Ridomil reduced the percentage of carrots with cavity spot by half (Table 6). Fos-ject and Terrazole were not significantly different to control plots (P>0.05). No carrots had more than 4 cavity spot lesions per root.

Statistical analysis showed there was no differences in total yield or rejects between early or late timing of fungicides. There is some evidence to suggest that the timing of the spray is important and can reduce the incidence of cavity spot even further. For instance, only 10 % of the total yield was affected by cavity spot when Ridomil was applied late. In contrast, 18 % of the total yield was affected by cavity spot when Ridomil was applied early (Table 7).

Table 6. The effect of fungicides on the incidence of cavity spot (% of total yield). (Data are means of two spraying times)

Treatment ®	% of total yield Slight	Moderate	Total cavity spot
Untreated	20.3	4.8	25.0
Fos-ject	17.9	2.4	20.3
Previcur	14.0	2.2	16.2
Ridomil	12.3	1.6	13.9
Terrazole	15.8	3.7	19.5
Significance	ns	*	*
l.s.d (P=0.05)	-	1.8	7.1

Fungicide treatments had no effect on crop density or total yields (P>0.05). Average crop density for the site was 78 plants/m^2. The average total yield was 88.4 t/ha and the average marketable yield (export plus marketable shorts) was 44.8 t/ha (Table 8). Fungicide sprays had no effect on percentage of total rejects, undersized, forked, misshapen, rotting or scab compared to untreated plots (Table 9).

Table 7. The effect of early (10 weeks after sowing) and late (16 weeks after sowing) applications of fungicides on the incidence of cavity spot

Treatment ®	Time of fungicide application	Cavity spot Slight	Moderate	Total cavity spot
			(% of total yield)	
Untreated	early	21.4	5.0	26.3
	late	19.2	4.5	23.7
Fos-ject	early	20.4	2.3	22.7
	late	15.5	2.4	17.9
Previcur	early	13.5	3.1	16.6
	late	14.4	1.3	15.8
Ridomil	early	15.5	2.3	17.8
	late	9.1	0.9	10.0
Terrazole	early	13.5	3.1	16.5
	late	18.0	4.3	22.4
Significance (treatment)		ns	*	*
l.s.d (*P*=0.05)		-	1.8	6.9
Significance (time of application)		ns	ns	ns
l.s.d (*P*=0.05)		-	-	-
Significance (treat*time)		ns	ns	ns
l.s.d (*P*=0.05)		-	-	-

Table 8. The effect of fungicides on total yield, density, export and short marketable yield and total rejects of the carrot variety Top Pak harvested on 23 October 1991. Data are means across two application times

Treatment ®	Total yield (t/ha)	Density (plants/m^2)	Export yield (t/ha)	Marketable short yield (t/ha)	Total rejects (t/ha)
Untreated	90.4	79	31.1	10.8	48.5
Fos-ject	90.1	80	39.1	11.0	40.0
Previcur	87.8	78	33.3	11.2	43.3
Ridomil	87.1	77	35.0	11.1	41.0
Terrazole	88.8	78	33.2	8.5	47.1
Significance	ns	ns	ns	ns	ns
l.s.d (*P*=0.05)	-	-	-	-	-

Table 9. The effect of fungicides on the percentage of total rejects, cavity spot, undersize, forked, misshapen, rot and scab for the variety Top Pak harvested on 23 October 1991. Data are means across two application times

Treatment ®	Total rejects	Cavity spot	% of total yield Undersize	Forked	Misshapen	Rot	Scab
Untreated	52.1	25.0	2.1	22.0	1.5	0.6	0.9
Fos-ject	45.1	20.3	1.7	19.4	2.8	0.4	0.5
Previcur	48.3	16.2	1.6	27.8	2.3	0.4	0.0
Ridomil	45.8	13.9	3.7	25.0	2.7	0.0	0.5
Terrazole	51.6	19.5	1.3	27.8	1.6	1.4	0.0
Significance	ns	*	ns	ns	ns	ns	ns
l.s.d. (P=0.05)	-	7.09	-	-	-	-	-

Discussion

Ridomil (metalaxyl) and Previcur (propamocarb) reduced the incidence of cavity spot while Fos-ject (phosphonic acid) and Terrazole (etridiazole) did not significantly reduce the disease.

This agrees with the results of other workers who found that cavity spot was reduced with applications of metalaxyl (Walker 1991; Davis *et al.* 1991). Lyshol *et al.* (1984) found cavity spot was reduced by metalaxyl as well as propamocarb. Walker (1988) found the effect of phosphonic acid (phosphonate) on cavity spot to be inconsistent. Such variability in phosphonate efficacy might have been due to differences in Pythium fungal populations in soils at different sites.

Metalaxyl is used in several countries for controlling cavity spot. Resistance or biodegradation problems which can develop from repeated fungicide application should be Propamocarb is not registered for use on carrots or other vegetable crops.

In further experiments, the effect of rate and time of application of metalaxyl and propamocarb for control of cavity spot will be examined.

3. Experiment 91PE62 - The effect of rate of metalaxyl and propamocarb for controlling cavity spot of carrots

Aim

In a previous experiment (91MO74) propamocarb and metalaxyl were the most effective fungicides for controlling cavity spot, caused by *Pythium* spp. The aim of this experiment was to determine the rate response of metalaxyl and propamocarb for controlling cavity spot disease of carrots.

Materials and Methods

The site was prepared and maintained as part of a commercial carrot crop on a property 100 km, north of Perth. The site had a history of carrot crops affected by cavity spot. The soil type was a yellow Karrakatta sand. The variety Top Pak was sown on 18 December 1991 (5 double rows per 1.92 m bed). Plots were 8 m long. There were 10 treatments and 6 replicates arranged in a randomised block design. Fungicides were applied 6 weeks after sowing using a Hardi® back pack and mini boom. Plots were covered twice to ensure an even wetting pattern, with a final water volume equivalent to 710 L/ha. Metalaxyl was applied in the form of Apron® seed dressing (350 g/kg metalaxyl). Propamocarb was applied in the form of Previcur® (600 g/L propamocarb). The crop was irrigated by overhead sprinklers on a centre pivot irrigator.

Table 10. Rate of active ingredient and rate of product for each fungicide treatment

Rate per ha of active ingredient	Rate per ha of product ®
0.6 kg propamocarb	1 L Previcur
1.2 kg propamocarb	2 L Previcur
1.8 kg propamocarb	3 L Previcur
3.6 kg propamocarb	6 L Previcur
0.5 kg metalaxyl	1.43 kg Apron
1.0 kg metalaxyl	2.86 kg Apron
2.0 kg metalaxyl	5.71 kg Apron
4.0 kg metalaxyl	11.43 kg Apron

At harvest maturity (9 April 1992), 1.5 m from the 3 middle rows from each plot was hand harvested and roots were weighed and graded for disease. The results were analysed by analysis of variance using GENSTAT software. Data are expressed as the percentage of total yield affected by cavity spot and total and export yields are expressed in tonnes per hectare.

Results and Discussion

Fungicides failed to control cavity spot in this experiment (Table 11). There was also no effect of fungicides on the severity of the cavity spot (data not presented). The failure of metalaxyl and propamocarb to control cavity spot contrasts with results from a previous experiment (91MO74). The failure of these fungicides may be caused by the development of resistance to the fungicides by the Pythium fungi (or biodegradation) responsible for cavity spot. This appears unlikely to account for the failure of both fungicides because of differing modes of action (Cohen and Coffey 1986).

The biochemical mode of action of propamocarb in Pythium involves inducing cell leakage, whereas metalaxyl inhibits RNA synthesis (Cohen and Coffey 1986). Propamocarb is reported to strongly bind to organic matter and is relatively immobile in the soil. Metalaxyl, in contrast, is highly mobile compared to many other soil fungicides, especially in sandy soils with low organic matter. However it is susceptible to enhanced biodegradation by soil fungi and bacteria, especially in areas where the metalaxyl has been used repeatedly (Cohen and Coffey 1986).

Table 11. The effect of propamocarb and metalaxyl on the plant density, total yield, export yield and incidence of cavity spot (percentage of total yield) of Top Pak carrots

Rate per ha of active ingredient	Density (plants/m^2)	Total yield (t/ha)	Export yield (t/ha)	Cavity spot (% of total yield)
0.6 kg propamocarb	71	83.3	7.4	71.4
1.2 kg propamocarb	69	80.3	2.8	78.0
1.8 kg propamocarb	66	78.4	4.6	78.9
3.6 kg propamocarb	64	72.7	1.7	69.1
0.5 kg metalaxyl	71	87.3	7.9	63.4
1.0 kg metalaxyl	63	77.8	1.4	77.5
2.0 kg metalaxyl	69	85.1	8.7	66.5
4.0 kg metalaxyl	61	75.2	3.5	71.0
Untreated	68	78.4	2.1	73.8
Significance	*	*	*	ns
l.s.d (P=0.05)	7.0	9.1	5.5	-

The fungicides affected the growth of carrots at high concentrations. High rates of propamocarb reduced plant density, total yield and export yield in this experiment. This effect was not as obvious for metalaxyl treatments (Table 11).

In conclusion, metalaxyl and propamocarb failed to control cavity spot disease in this experiment. The susceptibility of Pythium isolates from cavity spot to metalaxyl and propamocarb needs testing in the laboratory.

4. Experiment 91PE63 and 92PE12 - The effect of time of application of metalaxyl, propamocarb and phosphonic acid for control of carrot cavity spot

Aim

Phycomycete active chemicals have been used to control cavity spot (Lyshol *et al.* 1984, Walker 1988; 1991). Field work in California has shown that repeated small doses of metalaxyl were more effective than a single dose in controlling cavity spot (Davis *et al.* 1991).

The aim of these two experiments were to compare the effect of early, late and split applications of the phycomycete active fungicides metalaxyl, propamocarb and phosphonic acid against cavity spot on two sites.

Materials and Methods

The experiment was conducted on a commercial growers properties, 100 km north of Perth (site 1) and 40 km south of Perth (site 2). The Nantes carrot variety, Top Pak was sown on 18 November 1992 (site 1) and 14 February 1992 (site 2) using an Agricola Italia® air seeder (5 double rows per 1.92 m bed). Twelve treatments (Table 12) replicated 6 times were arranged in a randomised block design. Plots were 8 m long.

There were three unsprayed control plots per replicate. Metalaxyl, propamocarb and phosphonic acid were applied as 'early', 'late' and 'split' as sprays to the crop (Table 12). All sprays were applied with a Hardi® backpack and mini boom. The output of water was equivalent to 305 L/ha at 1 bar. At harvest maturity (7 April 1992- site 1, and 26 May 1992- site 2), 6 m from the three middle rows from each plot were harvested, washed, and weighed and examined for cavity spot lesions. Sections from cavity spot lesions were placed onto selective agar (3P and WA) and incubated at 18° C. Data were analysed by analysis of variance using GENSTAT software.

Table 12. Formulation and rate for each treatment

Treatment®[A]	Formulation	Rate per application (kg a.i/ha)	Total application rate (kg a.i./ha)
Early Fos-ject	200 g/L phosphonic acid	14.0	14.0
Late Fos-ject	200 g/L phosphonic acid	14.0	14.0
Split Fos-ject	200 g/L phosphonic acid	2.33	14.0
Early Apron	350 g/kg metalaxyl	1.0	1.0
Late Apron	350 g/kg metalaxyl	1.0	1.0
Split Apron	350 g/kg metalaxyl	0.17	1.0
Early Previcur	600 g/L propamocarb	1.8	1.8
Late Previcur	600 g/L propamocarb	1.8	1.8
Split Previcur	600 g/L propamocarb	0.3	1.8

[A]Early = application at 6 weeks after sowing, Late = application at 12 weeks after sowing, Split = application at 0, 3, 6, 8, 10 and 12 weeks after sowing.

Results and Discussion

Early, late and split fungicide applications of phosphonic acid, metalaxyl and propamocarb had no effect on the incidence or severity (results not shown) of cavity spot (Tables 13 and 14). On average, 85 % of the total yield was affected by cavity spot at site 1 and 15 % at site 2 (Tables 13 and 14). Carrot yield was not affected by the time of fungicide application or the type of fungicide sprays used.

Pythium spp. were isolated from typical brown sunken lesions using selective media. Metalaxyl (Davis *et al.* 1991; Walker 1988, 1991) and propamocarb (Lyshol *et al.* 1984) have been reported to be effective against cavity spot. A previous experiment (91MO74), showed metalaxyl and propamocarb reduced the incidence of cavity spot. Walker (1988) found the effect of phosphonic acid on cavity spot to be inconsistent, reducing cavity spot at only 1 site out of 4.

The failure of metalaxyl against Pythium has been documented in North America since 1983 in turf (Morton and Urech 1988). It is conceivable that resistance has developed on this site from previous use of metalaxyl for downy mildew control in onions. However, the failure of propamocarb that has a different mode of action to metalaxyl and which is reported to be effective against cavity spot is difficult to explain.

Table 13. Effect of early, late and split applications of fungicides on the total yield, export yield and incidence of cavity spot (% of the total yield) of Top Pak carrots at site 1

Treatment ®	Total yield (t/ha)	Export yield (t/ha)	Cavity spot (% of total yield)
Early Fos-ject	79.0	7.3	88.6
Late Fos-ject	82.5	12.3	80.5
Split Fos-ject	82.2	14.6	74.0
Early Apron	81.3	6.4	88.3
Late Apron	83.3	8.0	85.5
Split Apron	73.8	7.0	89.7
Early Previcur	85.8	4.9	93.9
Late Previcur	85.1	12.4	80.8
Split Previcur	81.5	8.8	85.6
Untreated	83.1	93.1	83.4
Significance	ns	ns	ns
l.s.d (P=0.05)	-	-	-

Table 14. Effect of early, late and split applications of fungicides on the total yield, export yield and incidence of cavity spot (% of the total yield) of Top Pak carrots at site 2

Treatment ®	Total yield (t/ha)	Export yield (t/ha)	Cavity spot (% of total yield)
Early Fos-ject	72.1	53.3	9.6
Late Fos-ject	61.8	52.6	11.2
Split Fos-ject	71.1	47.1	13.6
Early Apron	65.8	52.5	20.2
Late Apron	64.8	53.4	18.4
Split Apron	65.0	56.5	12.9
Early Previcur	70.0	60.1	13.6
Late Previcur	61.2	54.7	10.5
Split Previcur	65.6	51.6	21.4
Untreated	65.7	45.6	14.4
Significance	ns	ns	ns
l.s.d (P=0.05)	-	-	-

5. Experiment 91PE64 - The effect of soil amendments and metalaxyl on cavity spot disease of carrots

Aim

Integrated management of disease using soil amendments together with strategic use of fungicides may offer better long term prospects for cavity spot management.

Scaife *et al.* (1983) and White (1988) have reported cavity spot incidence was lower in high pH soils (greater than 8). Most of the carrots produced in Western Australian are grown on sandy soils of pH (1:5 water) ranging from 5 to 8. A survey of over 200 commercial carrot crops in 1990-91 showed the incidence of cavity spot was lower in soils with pH greater than 7 (McKay and Galati 1992).

We hypothesised that increasing soil pH in conjunction with fungicide treatments of metalaxyl would effectively reduce the incidence of cavity spot disease of carrots.

Materials and Methods

Pelleted seed of the variety Top Pak (South Pacific Seeds) were sown on 18 December 1992, using an Agricola Italia® air seeder with 5 double rows per 1.92 cm bed and an intrarow spacing of 7 cm between plants (72 plants/m^2). The site [yellow phase Karrakatta sand, soil pH (1:5 water) 6.2 and soil bicarbonate extractable phosphorus 44 mg/kg] was maintained as per the surrounding commercial carrot crop.

A commercial application of metham sodium had been made to the site at a rate of 500 L/ha prior to sowing the experiment.

Treatments were arranged in a randomised split-plot design with 6 replicates. The main treatments included 2 untreated controls, lime at 5 t/ha, gypsum at 8 t/ha and sulphur at 0.5 t/ha. The 2 subtreatments were metalaxyl treated and untreated. Amendments were applied to plots and were incorporated to a depth of 20 cm by rotary hoeing before sowing. Metalaxyl was applied to half of the 8 m plots six weeks after sowing. The metalaxyl (Apron® at 1 kg/ha a.i.) was applied with a Hardi® back pack and mini boom. The output was 306 L/ha at 1 bar.

At harvest, twenty youngest mature leaves (YML) were sampled from each plot for nutrient analysis. Soil samples (0 to 15 cm) were also taken from each plot to determine soil pH (1:5 water).

Carrots were harvested on 9 April 1992. Six 0.5 m samples were taken from the middle rows of each plot. Each sample was washed, weighed, sorted and graded according to disease incidence (nil, moderate: 1 to 2 small spots per carrot, and severe: more than 3 spots per carrot). Data were analysed by analysis of variance using GENSTAT software. The 'nil' grade was analysed by arcsin transformation because of the high incidence of zeros data points, but no significant differences were recorded and therefore the untransformed data are presented.

Results and Discussion

Analysis of the data showed 1 kg/ha a.i. metalaxyl at 6 weeks after sowing failed to reduce the incidence or severity of cavity spot. (Average with metalaxyl = 96.4 % of total yield with cavity spot, average without metalaxyl = 97.8 % of total yield with cavity spot, P=0.141). The results presented are averages across metalaxyl subtreatments.

There were significant differences (P<0.05) in the total yield across treatments (Table 15). Lime amended plots produced a total yield of 84.6 t/ha compared to the control plots at 76.5 t/ha. The addition of sulphur reduced germination and final yield. Sulphur significantly reduced plant density and total yield possibly as a result of manganese toxicity (Table 16).

There were no differences between treatments in the percentage of the total yield affected by cavity spot (Table 15). However there were significant differences between treatments in the severity of the disease. Carrots grown on lime amended soil had a significantly lower percentage of the total yield severely affected by cavity spot (Table 15). About 50 % of the total yield in the limed amended plots showed moderate cavity spot symptoms. Many of the carrots in this category had only minor symptoms on the roots and could be sold on the local market. Liming soil reduced the severity of cavity spot in this experiment.

Table 15. The effect of soil amendments on the total yield, density and % of total yield affected by cavity spot of the variety Top Pak sown on 18 December 1991

Treatment	Total yield (t/ha)	Density (plants/m^2)	% cavity spot of total yield Nil	Moderate	Severe	Total cavity spot[A]
Untreated	76.5	63	2.0	37.7	60.3	98.0
Gypsum	70.5	56	1.9	41.8	56.3	98.1
Lime	84.6	65	5.0	51.1	43.9	95.0
Sulphur	56.6	52	3.8	36.0	60.2	96.2
Significance	*	***	ns	*	*	ns
l.s.d (P=0.05)	8.0	6.0	-	9.3	10.7	-

[A]moderate + severe

Cavity spot was reported to be induced by calcium deficiency by Maynard *et. al.* (1961). This was later discounted as the primary cause by subsequent work that showed *Pythium* spp. as the causal agent. Calcium, however, may still affect disease severity. Leaf analysis at harvest maturity showed high concentrations of calcium in the YML did not correlate with cavity spot incidence (R^2=0.1). The suggested critical concentration of calcium in the YML is 1.5 % for carrots at harvest maturity (Piggott 1986). Calcium concentrations in the YML from gypsum amended plots were significantly higher than in control plots (Table 2). However, the cavity spot incidence was not significantly different (P>0.05). The reduction in cavity spot was apparently due to increases in soil pH rather than differences in calcium concentrations in the plant. Application of lime in this experiment increased soil pH from 6.4 to 7.3.

Liming also has the additional benefit of reducing the high concentrations Mn and Zn in plants at this site. Manganese is toxic to carrots at concentrations greater than 300 mg/kg (Piggott 1986). Lime reduced the concentration of manganese in the YML by 100 mg/kg compared to control plots. The application of sulphur reduced soil pH and increased leaf manganese and zinc concentrations at harvest maturity (Table 16). Sulphur increased leaf manganese to toxic concentrations in the plant.

Table 16. The effect of soil amendments on soil pH (1:5 water) and K, Ca, Cu, Zn and Mn in YML of carrots at harvest

Treatment	Soil pH (1:5 water)	K (%)	Ca (%)	Cu (mg/kg)	Zn (mg/kg)	Mn (mg/kg)
Untreated	6.38	3.12	1.15	14.96	149.5	399
Gypsum	5.88	3.17	1.58	15.91	188.6	502
Lime	7.28	2.83	1.41	13.18	114.3	300
Sulphur	5.19	3.15	1.07	16.15	221.8	1000
Significance	***	*	***	*	***	***
l.s.d (P=0.05)	0.302	0.24	0.128	2.21	21.1	88.6

This experiment showed that metalaxyl failed to control cavity spot when applied at six weeks after sowing. The application of lime reduced the severity of cavity spot. Future work will test the hypothesis that increasing the rate of lime will further reduce cavity spot.

In conclusion, this experiment showed that lime has the potential to reduce cavity spot in carrots growing in sandy soils.

---

6. *Experiment 92PE72 - The effect of metham sodium, soil solarisation and soil amendments on the incidence carrot cavity spot disease*

Aim

Field experiments (91PE62-64) with the fungicides metalaxyl, phosphonic acid and propamocarb failed to reduce the incidence of the disease.

Soil solarisation involves heating soil for 4-6 weeks by covering areas with transparent plastic. Soil solarisation has been shown to control soilborne diseases including fungi (*Pythium, Rhizoctonia* and *Verticillium*) and root knot nematode (Katan 1981). Solarisation has other benefits, such as the control of weeds and the release of nutrients (Katan 1981; Stapleton *et al.* 1985).

Metham sodium is a general purpose soil fumigant widely used by the local carrot industry. Field observations suggest metham sodium may not be effective in controlling cavity spot of carrots, however no direct evidence is available.

The aim of this experiment was to compare the efficacy of metham sodium, solarisation, lime and copper sulphate on the incidence and severity of cavity spot disease of carrots.

Materials and Methods

The experiment was conducted on a commercial property, 100 km north of Perth, in an area that had a recent history of carrots severely affected by cavity spot.

There were 7 treatments, including two untreated controls (Table 17), arranged in a randomised block design with 4 replicates. The soil was irrigated to field capacity before the plastic being layed in the solarisation treatment. Transparent polyethylene plastic sheets (2 m wide, 25.4 μm thick) were placed on plots with a plastic laying device with the edges sealed by burying the plastic. The plastic remained on plots for 6 weeks. Two weeks before planting, metham sodium was applied to plots at two rates (500 and 1000 L/ha) from low pressure nozzles just in front of the blades a rotary hoe. Lime sand (8t/ha) and copper sulphate (40 kg/ha) were applied to the appropriate plots before sowing and incorporated by rotary hoeing to 20 cm. Each plot was 1.92 m wide by 15 m long. Soil temperature in solarised and bare soil was measured at a depth of 10, 20 and 30 cm with Wesdata® loggers, as was the air temperature above the soil. Temperatures were recorded from 27 January to 19

February 1993. The trial area was sown to the variety Top Pak on 18 February 1993 with a precision air seeder. The crop was fertilised and managed according to commercial practice.

At harvest maturity (22 June 1993), six by 0.5 m lengths of row was sampled and the carrots were washed, weighed and graded according to size. The samples were then regraded for cavity spot incidence and severity (slight, moderate and severe). An analysis of variance was performed on the data using GENSTAT software.

Results and Discussion

No treatment effectively reduced the incidence or severity of cavity spot (Table 17). The solarisation treatment halved the number of carrots with cavity spot with 'mild' symptoms compared to the control. However, there were twice the number of carrots with 'severe' cavity spot symptoms compared to the control. Overall, solarisation had no effect on total percentage of carrots affected by cavity spot (Table 17).

Table 17. The effect of soil treatments on the percentage of carrots affected by cavity spot

	Number of carrots with cavity spot (% of total number of carrots)			
Treatment	Slight	Moderate	Severe	Total
Untreated	30.6	16.4	9.9	56.8
Copper	26.9	19.8	12.2	59.0
Lime	32.0	14.0	5.0	51.0
Metham sodium (500 L/ha)	35.0	22.5	8.0	65.6
Metham sodium (1000 L/ha)	26.7	18.0	15.9	60.6
Solarisation	15.2	21.7	19.8	56.7
Significance	*	ns	**	*
l.s.d (P=0.05)	8.0	-	6.8	7.6

Metham sodium was also ineffective against cavity spot. Davis (1991), working in California, was unable to achieve consistent control of cavity spot of carrot with metham sodium. In fact a higher percentage of carrots was affected by cavity spot in the metham sodium treatment (Table 17). Metham sodium may have exacerbated the disease. This effect has been observed with fumigation with methyl bromide in tomatoes. A 'biological vacuum' that follows fumigation facilitates rapid colonisation of treated soils, by fungi such as *Pythium* spp. Ploetz and Stempel (1989) recovered *Pythium ultimum* and *P. aphanidermatum* 80 days after fumigation in tomato beds. Sumner and Phatak (1988) found populations of *Pythium* spp. were reduced but not eliminated with metham sodium between 200 and 1800 L/ha. The efficacy of metham sodium was highly dependent on mode of application (drip vs. overhead irrigation) and environmental conditions (Sumner and Phatak 1988).

Treatments such as metham sodium and solarisation are possibly not effective against cavity spot because the disease is usually detected when carrots are near harvest maturity. Metham sodium and solarisation are effective in controlling diseases responsible for plant damage early in the crop cycle (eg nematodes (*Meloidogyne* spp), damping off (*Pythium* spp.) and club root (*Plasmodiophora brassicae*) (Porter and Merriman 1985).

Copper sulphate did not control cavity spot (Table 17). Lime was not as effective as expected although it produced the lowest percentage of the total number of carrots affected by cavity spot (Table 17). The addition of 8 t/ha of lime significantly increased soil pH (1:5 water) from 7.0 to 7.7. Other experiments have shown that a pH greater than 7.5 is needed to reduce the severity of cavity spot (92PE68).

Table 18. The effect of soil treatments on yield and density of carrots at harvest maturity

Treatment	Density (plants/m^2)	Total yield (t/ha)	Export yield (t/ha)	Marketable short yield (t/ha)
Untreated	60.7	65.7	34.8	19.7
Copper	62.5	62.3	28.2	23.2
Lime	68.4	66.1	26.3	27.4
Metham sodium (500 L/ha)	68.0	65.3	29.1	28.5
Metham sodium (1000 L/ha)	66.0	66.1	25.8	30.0
Solarisation	54.1	76.6	50.0	15.0
Significance	ns	*	**	**
l.s.d (P=0.05)	-	7.3	11.3	7.2

Carrot seedling emergence in the solarised treatment was not uniform compared to the control plots at germination. Solarisation of soil produced higher total and marketable yields in this experiment (Table 18). Solarised soils often contain higher levels of soluble mineral nutrients such as nitrogen (Stapleton and DeVay 1986). The significantly higher yields might be attributed to the release of nutrients during solarisation. Also, plant densities tended to be lower in the solarisation treatment, although this result was not significant (Table 18).

Temperatures under plastic were always higher than in bare soil (Fig.1). Temperatures under plastic were 35-40°C during the day at 10 cm soil depth, 30-35°C at 20 cm and 25-30°C at 30 cm (Fig. 1). The temperatures found by other workers ranged from 45-50°C at 10 cm and 38-45°C at 20 cm (Katan 1981). Chauhan *et al.* (1988) working in India, reported temperatures exceeding 60°C at 5 cm and 42°C at 20 cm soil depth under plastic.

Metham sodium at 500 and 1000 L/ha had no effect on density or yield (Table 18). Copper and lime treatments produced total and marketable yields the same as the controls (Table 18). The incidence of forking was reduced by metham sodium treatment but only at the highest rate (1000 L/ha) and by the solarisation treatment (Table 19). The incidence of forking was not significantly different in the control, lime and copper treatments.

In conclusion, treatments such as metham sodium and solarisation were not effective against cavity spot disease at this site.

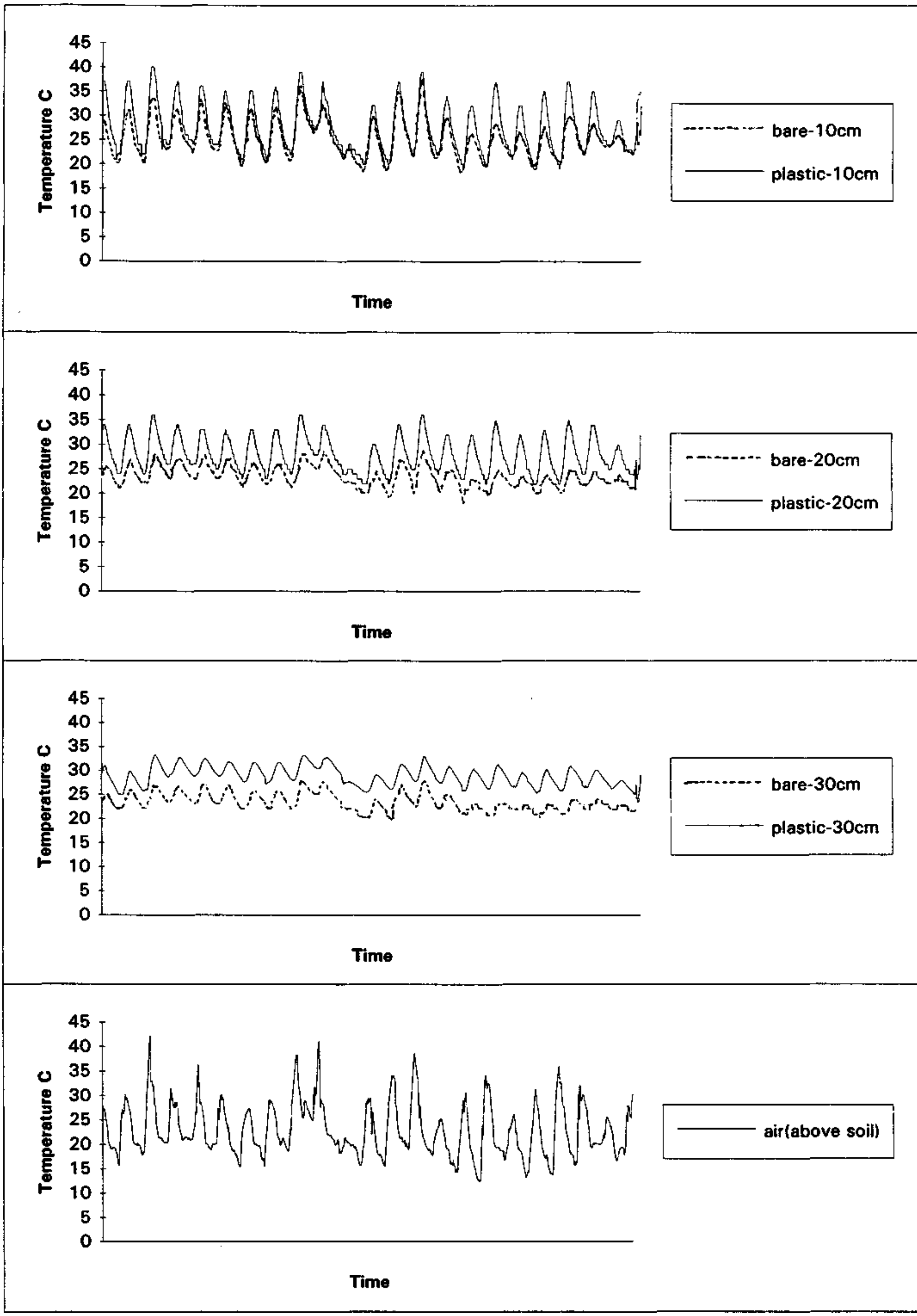


Fig. 1. Soil temperature at 10, 20 and 30 cm under bare soil and plastic over time. Measurements from 27/1/93 to 19/2/93. Air temperature 20 cm above soil surface.

Table 19. The effect of soil treatments on reject incidence (% of the total yield) of carrots at harvest maturity

Treatment	% of total yield Undersize	Forked	Oversize
Untreated	5.0	11.4	0.6
Copper	7.0	10.0	0.5
Lime	8.1	10.7	0.0
Metham sodium (500 L/ha)	7.7	6.6	0.7
Metham sodium (1000 L/ha)	9.0	3.4	0.1
Solarisation	3.8	2.7	8.5
Significance	ns	*	***
l.s.d (P=0.05)	-	5.7	2.7

7. Experiment 92PE57 -Metalaxyl sensitivity of Pythium *spp. isolated from carrot cavity spot lesions*

Aim

Phenylamide fungicides, including metalaxyl, are selectively active against soilborne Oomycetes, such as *Pythium* spp. (Cohen and Coffey 1986).

The use of these fungicides to control soil borne diseases can become a problem because frequent applications may allow resistance to develop (Cohen and Coffey 1986; Morton and Urech 1988).

In Western Australian field experiments, metalaxyl failed to provide control of cavity spot disease of carrots (91PE62, 91PE63, 92PE12). Cavity spot is caused by *Pythium* spp. in many countries (White 1986; Montfort and Rouxel 1988; Vivoda *et al.* 1991) and *Pythium* spp. have been shown to be the causal organism in Western Australia (93PE79).

We hypothesise that failure of metalaxyl to control cavity spot in the field is due to metalaxyl resistance of cavity spot causing Pythium fungi. The objective of this experiment was to compare the responses of *Pythium* isolates from cavity spot to metalaxyl *in vitro.*

Materials and Methods

Ten Pythium isolates from cavity spot lesions from commercial properties in Western Australia were checked for sensitivity to metalaxyl at concentrations of 0, 5, 50 and 100 µg/ml in the media. In a second experiment, isolates from Western Australia were compared to those from UK and the USA for sensitivity to metalaxyl. Rates ranged from 0.125, 0.25, 0.5, 1.0 and 2.0 µg metalaxyl/ml in the agar.

Metalaxyl was incorporated into corn meal agar and poured into petri dishes as described by White *et al.* (1988). Metalaxyl was in the form of Apron® seed dressing (350 g/kg metalaxyl).

The isolates were grown 20°C for 4 days on corn meal agar free of metalaxyl. An agar plug (5 mm diameter) of the isolates was then placed onto the centre of metalaxyl amended plates. There were 3 replicates per treatment and plates were incubated at 15 °C. Colony diameter was measured daily and percent inhibition relative to the control was calculated for each concentration. In the second experiment, data were used to calculate the ED_{50} values obtained when the growth of unamended media had covered approximately two-thirds of the plate (≈ 6 cm). The ED_{50} value is the estimated dose that reduced radial growth by 50 %. Data was analysed by GENSTAT software.

Results

The first experiment with 10 Pythium isolates from carrot cavity spot lesions showed the isolates varied in their ability to maintain growth at high rates of metalaxyl (Table 20). Isolate 364 was the most tolerant of metalaxyl continuing to grow at over 50 % of the control rate on agar with 100 µg metalaxyl/ml.

Table 20. Percentage growth (relative to control) for 10 *Pythium* isolates on agar with three rates of metalaxyl

	Metalaxyl concentration (µg/ml)		
Isolate code	5	50	100
		% growth relative to control	
47.1	37	7	6
b564	41	9	7
a546	36	10	7
159.2	41	9	7
30.1	40	9	9
130	46	15	11
208g5	26	26	21
677	30	25	23
vi	45	31	24
364	88	73	54

The second experiment examined the effect of metalaxyl on isolates from the USA, UK and Australia. Data are expressed as percentage growth relative to the control. ED_{50} values are also presented (Table 21).

Table 21. The growth of *Pythium* isolates on agar containing varying rates of metalaxyl (as a % of growth on untreated media) and ED_{50} values

Isolate code	Source	Species	0.125 µg/ml	0.25 µg/ml	0.5 µg/ml	1.0 µg/ml	2 µg/ml	5 µg/ml	ED_{50} µg/ml
					% growth relative to control				
819	UK	*P. sulcatum*	100	94	44	35	29	22	0.45
822	CBS[A]	*P. sulcatum*	70	56	11	11	11	8	0.20
821	USA	*P. violae*	26	9	9	8	8	8	0.05
820	UK	*P. violae*	26	9	8	7	7	7	0.05
817	WA	*Pythium spp.*	75	63	36	34	31	29	0.19
823	WA	*Pythium spp.*	96	88	38	34	29	27	0.38

[A]Centraal Bureau voor Schimnelcultures, Netherlands

P. violae had the lowest ED_{50} in this experiment and *P. sulcatum* (UK) had the highest ED_{50} value (Table 21). The WA isolates, 817 and 823, were moderately susceptible with the ED_{50} for isolate 823 approaching that of the *P. sulcatum* from the United Kingdom (isolate 819).

Discussion

The WA isolates were found to be more tolerant to metalaxyl than *P. violae* from the UK and the USA. *P. violae* is considered the major cause of cavity spot in the UK and USA and metalaxyl usually offers at least partial control of cavity spot. ED_{50} values of Western Australian isolates were similar to those of *P. sulcatum* in this experiment. Preliminary identification of WA isolates show that they are taxonomically similar to, though possibly not identical to, *P. sulcatum* (93PE79).

Metalaxyl greatly reduced the incidence of cavity spot in field and pot experiments (Lyshol *et al.* 1984; White 1986). However, there is concern over the efficacy of metalaxyl as a treatment because of the development of resistance in the pathogens (Cohen and Coffey 1986). *Pythium* spp. may therefore develop resistance to metalaxyl if the fungicide was used in preceding crops (eg. downy mildew control in onions or lettuce).

White *et al.* (1988) reported metalaxyl failure from one field where *P. sulcatum* was identified as the primary pathogen involved in cavity spot development. However, in fields where *P. violae* was identified as the causal pathogen, cavity spot was adequately controlled with metalaxyl.

Further assessment should be made of the Oomycete fungicide sensitivity of Pythium isolates from carrot cavity spot in Western Australia to clarify where such fungicides may be of value in controlling cavity spot.

8. Experiment 93PE31 - Preliminary screening of efficacy of products against cavity spot disease of carrots

Aim

Control of Pythium fungi has proven difficult because of the development of resistance to fungicides such as metalaxyl (Morton and Urech 1988). Other control methods need to be investigated.

One novel control method involves lysing Pythium zoospores with Agral® a non-ionic surfactant *in vitro* (Stanghellini and Tomlinson 1987). Silicate amendments added to hydroponic solutions reduced the incidence of Pythium dieback (Cherif and Belanger 1992). Cavity spot was reported as a physiological disorder induced by calcium deficiency by Maynard *et al.* (1961) but was later shown to be caused by *Pythium* spp. (Lyshol *et al.* 1984). It is still possible that high calcium has a modifying effect on Pythium caused cavity spot.

The aim of this experiment was to test the efficacy of a range of materials with potential to control Pythium species.

Materials and Methods

There were 10 treatments (including two untreated controls) replicated 4 times in a randomised block design (Table 22). The variety Top Pak was sown on 1 January 1993 with a precision air seeder on a site with a previous carrot cropping history. Each plot was 2 m long and 1.92 m wide. Table 2 lists the rate and application method for each treatment.

Table 22. Rate and application method for each treatment

Treatment	Rate	Application method
Untreated	-	-
Sodium silicate	90 L/ha	Spray
Sodium silicate	180 L/ha	Soil drench
Agral®	15 6 L/ha	Soil drench
Calcium nitrate	333 kg/ha	Broadcast
Calcium chloride	185 kg/ha	Soil drench
Ammonium nitrate	147 kg/ha	Broadcast
Metalaxyl	1.0 kg/ha	Spray
Propamocarb	0.9 kg/ha	Spray

Each treatment was applied to plots on 24 March 1993 (83 days after sowing, DAS) and 29 April 1993 (119 DAS). Metalaxyl was applied as a 350 g/kg formulation (Apron®) and propamocarb was applied as a 600 g/L formulation (Previcur®). Sprays were applied with a Hardi® back pack and mini boom with the equivalent water output 711 L/ha. Soil drenches were applied in 4L water and applied to plots with watering cans.

At harvest maturity, 173 DAS (22 June 1993), four 0.5 m lengths of row from the middle rows from each plot were harvested, washed and weighed. Each plot was then regraded for cavity spot and each carrot was graded according to disease severity: slight (1 lesion per root), moderate (2 to 3 lesions per root), and severe (more than 3 lesions per root).

Results and Discussion

Preliminary screening of materials reported in the literature as active against Pythium fungi showed they were not effective against cavity spot disease in the field at the rates applied in this experiment (Table 23). Calcium fertilisers failed to reduce cavity spot in this experiment and metalaxyl and propamocarb had no effect on the percentage of carrots affected by cavity spot. The treatments had no effect on plant density, yield or marketability of carrots (Table 24).

Table 23. Preliminary screening of products for activity against cavity spot

	% of carrots			
Treatment	Slight	Moderate	Severe	Total cavity spot
Untreated	32.8	21.1	11.7	65.6
Sodium silicate (spray)	29.9	16.8	18.9	65.6
Sodium silicate (drench)	31.6	18.1	12.5	62.2
Agral®	32.8	13.9	10.0	56.8
Calcium nitrate	28.3	16.8	10.5	55.6
Calcium chloride	33.1	15.9	10.1	59.2
Ammonium nitrate	31.7	20.9	11.2	63.9
Metalaxyl	31.1	16.9	12.5	60.5
Propamocarb	31.3	9.9	14.7	55.9
Significance	ns	ns	ns	ns
l.s.d (P=0.05)	-	-	-	-

In conclusion, at this site, where cavity spot has been severe and where metalaxyl failure has been previously observed, none of the treatments tested showed any promise for the control of cavity spot.

Table 24. The effect of treatments on density, yield and rejects of carrots[A]

Treatment	Density (plants/m^2)	Total yield (t/ha)	Export yield (t/ha)	Marketable short yield (t/ha)	Under-size (t/ha)	Forked (t/ha)	Other (t/ha)
Untreated	59	76.5	30.6	31.3	9.8	2.4	2.4
Sodium silicate (spray)	63	69.9	31.6	26.3	9.5	1.0	1.5
Sodium silicate (drench)	65	71.7	25.4	32.1	9.9	2.8	1.5
Agral®	64	74.0	29.0	35.5	6.9	1.0	1.6
Calcium nitrate	64	87.6	40.8	37.0	6.1	0.8	2.9
Calcium chloride	69	67.5	22.9	30.6	12.0	2.0	0.0
Ammonium nitrate	62	87.8	33.2	30.2	10.3	4.6	9.5
Metalaxyl	58	68.0	20.4	29.8	9.1	1.6	7.1
Propamocarb	63	70.1	26.5	27.9	9.5	1.6	4.6
Significance	ns	ns	ns	ns	ns	ns	ns
l.s.d (0=0.05)	-	-	-	-	-	-	-

[A]graded without considering cavity spot.

9. Experiment 93PE57 - Laboratory test predicts field tolerance of carrot varieties to cavity spot disease

Aim

Nantes carrot varieties have previously been screened for field tolerance to cavity spot (92PE72, 93PE9). Use of tolerant varieties would allow growers to become less dependent on unreliable chemical methods for cavity spot control.

The aim of this experiment was to determine the cavity spot tolerance of some carrot varieties using a laboratory screening method, and to compare the laboratory results with those from field screenings.

Materials and Methods

Twelve carrot varieties (Table 25) were sown on a site with no previous carrot cropping history, and were maintained as per commercial practice. Ten mature carrots of each variety were harvested and washed free from soil. Carrots were then rinsed in sterile distilled water and inoculated with 4 agar plugs (5 mm diameter) from 5 day old cultures of Pythium isolate 817. The isolate was typical of isolates obtained from cavity spot lesions on field grown carrots on a property north of Perth. In addition, each inoculated carrot was also inoculated with a sterile agar plug that acted as a control.

The inoculated carrots were placed in moist trays (paper towels wet with sterile distilled water) and enclosed in a plastic bag. Each tray contained one carrot of each variety and represented one replicate. There were 10 replications. Trays were maintained at 18°C. After 4 days, the lesion diameter was measured (length by width) for each inoculation point with electronic calipers. An average lesion diameter per root was determined from the 4 inoculation points on each carrot. Fungi were reisolated from lesions to satisfy Koch's postulates.

An analysis of variance was performed on the data using GENSTAT 5 software.

Average lesion diameter was correlated against the cavity spot index [Cavity spot index = {(slight x 1) + (moderate x 2) + (severe x 3)}/3] of carrots from 3 independent field experiments conducted during 1992-93. Relative cavity spot index was calculated by expressing the cavity spot index of a variety as a proportion of the site mean cavity spot index. This was done to give each of the sites equal weighting in the averages calculated across the site.

Results

Lesions were produced in over 95 % of the Pythium agar plug inoculations. Lesions were brown, slightly sunken and round to elliptical in shape. Sterile agar plugs did not produce symptoms.

Table 25. Average lesion diameter on carrots following laboratory inoculation with Pythium isolate 817 and average relative cavity spot index from field experiments

Variety	Average lesion diameter (mm)		Average relative cavity spot index[A]
Primo	10.16	a	3.02
SPS 543 (Crusader)	9.95	a	1.64
RS 87 2365 (Espredo)	9.12	ab	1.83
Nandor	8.54	abc	0.94
Hinan	7.68	bcd	1.10
Navarre	7.05	cde	0.40
Y 61	6.64	de	0.63
Narbonne	6.53	de	0.36
Balin	6.15	def	0.48
Top Pak	5.94	ef	1.42
SPS 567	5.47	ef	0.27
Bolero	4.59	f	0.51
Significance	***		
l.s.d (P=0.05)	1.69		

[A]Average relative cavity spot index from 3 field sites, except for the varieties Primo and Balin (from one site only.

There were highly significant (P<0.001) differences in average lesion diameter for the 12 varieties (Table 25). SPS 543, RS 87 2365 and Primo had the largest lesion diameters while Bolero and SPS 567 developed the smallest lesions.

Correlation of the average relative cavity spot index from 3 independent field experiments and average lesion diameter from laboratory inoculation gave a correlation coefficient of $r = 0.78$.

Discussion

In vitro testing showed significant differences among varieties for the size of cavity spot lesions. Bolero and SPS 567 were found to be tolerant to cavity spot whereas varieties such as SPS 543 and RS 87 2365 were susceptible. Bolero and Narbonne have shown field tolerance in UK experiments (Anon 1993). Anon (1992) reported Balin having good tolerance to cavity spot and *in vitro* tests also show this to be so. Commercial field observations of Primo in WA have shown it to be highly susceptible to cavity spot when compared to other varieties. *In vitro* tests also found that Primo produced the largest lesion diameter indicating high cavity spot susceptibility.

Vivoda *et al.* (1991) inoculated whole carrots with *P. violae* and *P. ultimum.* They found that artificially inoculated lesions were superficial, discoloured areas and were indistinct in shape. They suggested that harvested carrots were unable to respond to fungal attack to produce characteristic elliptical sharp-edged lesions. They then concluded that screening for resistance by placing inoculated agar plugs on harvested, surface sterilised carrots may not be an accurate technique. In contrast, results of Punja and Benard (1992) showed that *in vitro* screening would be useful to predict field results. Inoculation of carrots in our experiment did produce brown depressed lesions with clearly defined edges.

Sweet *et al.* (1986) using a similar inoculation method with *P. violae*, found no differences in susceptibility between the carrot variety groups, Nantes, Autumn King and Chantenay. However, there were considerable differences between varieties within any single group and their work showed a reasonable correlation between disease levels found in the field and levels induced by inoculation in the laboratory.

In our work, laboratory tolerance to cavity spot was well correlated to field experiments ($r = 0.78$). Punja and Bernard (1992) using a similar *in vitro* method found that most varieties were fairly consistent regarding susceptibility to cavity spot.

The mechanisms of Pythium infection of carrot roots and the factors affecting subsequent lesion development are not understood. In the field in Western Australia, cavity spot lesions are usually observed within a month of normal commercial harvest. Disease symptoms usually develop rapidly in the 10-14 days preceding harvest maturity.

Vivoda *et al.* (1991) found that 5 month old carrots developed nearly twice as many lesions as 3 or 4 month old carrots following transplanting into soil inoculated with *P. violae* and *P. ultimum*. The severity of lesions was not reported.

Apart from the obvious consideration of soil surface area contacted by the larger, older carrots a possibility is that carrots become more susceptible to infection as physiological age increases. The frequency of infection may thus increase with physiological age while the severity of lesion developing from individual infection sites may be a function of host genetic susceptibility.

Top Pak may have scored a high disease index in the field partly because it is early maturing relative to the other varieties tested and developed a high number of small lesions. In the laboratory test, only one lesion arose from an infection site and the severity of this may reflect more closely the genetic susceptibility of the variety.

In vitro testing of carrot varieties has the potential to be a useful tool for preliminary screening for cavity spot tolerance.

---

10. Experiment 93PE65 - Growth responses of Pythium isolates to changes in pH

Aim

The application of lime to sandy soils reduced the incidence and severity of cavity spot in recent field experiments (92PE68). However the mode of action of the lime is unclear. The objective of this experiment was to examine the effect of pH on the growth of several Pythium isolate associated with cavity spot of carrots..

Materials and Methods

To determine the effect of pH on the mycelical growth of *Pythium* species associated with cavity spot, agar was made by the addition of 0.01 M biological buffers (Good 1966) with a pKa in the desired pH range. Biological buffers were included in the agar because they do not complex with cations or participate in or stimulate chemical reactions and are not toxic to pathogens, hosts or plants (Good 1966). Other buffers (e.g. citrate phosphate buffers) have undesirable reactivity (e.g. precipitation with cations) and toxicity effects when in solutions (Good 1966).

Stock solutions (0.01 M) of each buffer were made up in distilled water and the pH measured. The pH of each stock solution was adjusted to the pKa value with either 0.1 M KOH or 0.1 M HCl. Corn meal agar was made up with each of the stock buffer solutions and autoclaved. Agar was cooled and the pH was measured prior to pouring into 9 cm diameter petri dishes. The buffers, pKa and final pH are shown in Table 26.

Table 26. Buffers, pKa, pH range of buffers and final pH of agar after autoclaving

Buffer	pKa	pH range of buffer	Final pH after autoclaving
MES *2-[N-Morpholino]ethanesulfonic acid*	6.1	5.5-6.7	5.84
MES *2-[N-Morpholino]ethanesulfonic acid*	6.1	5.5-6.7	6.10
PIPES *Piperazine-N, N`-bis[2-ethanesulfonic acid]*	6.8	6.1-7.5	6.68
BES *N, N-bis[2-Hydroxyethyl]-2- aminoethanesulfonic acid*	7.1	6.4-7.8	6.81
HEPES *N-[2-Hydroxyethyl] piperazine-N`-[2 ethanesulfonic acid]*	7.5	6.8-8.2	7.39
EPPS *N-[2-Hydroxyethyl] piperazine-N`-[3- propanesulfonic acid]*	8.0	7.3-8.7	7.79
TAPS *N-tris[Hydroxymethyl] methyl-3-aminopropanesulfonic acid*	8.5	7.7-9.1	8.41

Six Pythium isolates were subcultured and grown on agar for 4 days at 20°C. Isolates 817 and 823 were isolated from cavity spot lesions of carrots grown in Western Australia. Isolates 820 and 821 were *Pythium violae* originating from J. White (UK) and R. Davis (USA), respectively. Isolates of *P. sulcatum* (819 and 822) originated from J. White (UK) and Centraal Bureau voor Schimmelcultures, (Netherlands), respectively. Agar plugs (5 mm diameter) were transferred from source isolates to the centre of pH amended agar plates. Plates were incubated at 20°C. Colony diameter was measured and recorded daily. Each isolate was subcultured twice onto agar plates of each pH treatment.

An analysis of variance was undertaken on the data to determine differences between pH, isolates and their interactions for each isolate. Quadratic curves were fitted for growth 4 days after inoculation against pH.

Results and Discussion

All isolates grew on pH amended agar ranging from 5.8 to 8.4 (Fig. 2). Analysis of variance showed significant differences ($P<0.001$) among isolates and their interactions with pH (Table 27). The effect of pH was also significant ($P<0.001$) (Table 27).

Table 27. The effect of pH on growth of Pythium isolates after 4 days at 20°C

pH	Growth of isolates (mm)					
	817 *Pythium* spp.	819 *P. sulcatum*	820 *P. violae*	821 *P. violae*	822 *P. sulcatum*	823 *Pythium* spp.
5.84	23.5	27.0	78.0	76.0	20.0	26.0
6.10	40.0	41.5	80.0	82.5	33.0	44.0
6.68	43.5	45.0	74.5	65.0	34.5	47.5
6.81	55.5	44.0	72.5	64.0	33.5	53.0
7.39	54.5	48.5	71.0	56.0	35.0	57.0
7.79	48.5	43.5	70.5	48.5	31.0	53.0
8.41	21.0	28.5	27.0	22.0	23.5	13.5
Significance (isolate)			***			
l.s.d (P=0.05)			1.5			
Significance (pH)			***			
l.s.d (P=0.05)			1.7			
Significance (isolate*pH)			***			
l.s.d (P=0.05)			4.25			

The *P. violae* isolate (821), grew optimally when the pH ranged from 5.8 to 6.8. While the isolate 820 achieved more growth at the pH range from 5.8 to 7.8 However, the *P. sulcatum* (819, 822) and the *Pythium* spp. isolates from WA (817, 823) grew optimally between pH 6.8 to 7.4. Growth of these isolates were retarded above pH 7.8.

Schrandt *et al.* (1994) found that *P. violae* grew at a optimum pH range of 5.5 to 8.0. This is in contrast with our results. These workers adjusted the pH of media by the addition of either 0.1 N NaOH or 1 N HCl, and failed to include buffers in their media. Biological buffers, such as those used in our experiment were developed mainly because they overcame the effects of pH instability in solutions. It is possible that the pH in unbuffered agar may be more easily modified by the fungus as it grows.

Schrandt *et al.* (1994) also found that growth of *P. violae* was suppressed at pH 5.5 but it grew well under highly alkaline conditions. A survey in California by Vivoda *et al.* (1991) showed no relationship between pH (5.5-7.7) and cavity spot incidence. In contrast, work conducted in the UK by White (1988) and Scaife (1983) showed the incidence of cavity spot negatively correlated with increasing pH. Experimental and survey work conducted in Western Australia also showed that cavity spot incidence was reduced with pH above 7 (McKay and Galati 1992).

Lime reduced the incidence of cavity spot when pH was raised above 7.5 in our experimental work. Other diseases, such as clubroot, have been reported to be controlled by liming of soil (Karling 1968). However, it is not known if the effect of lime on cavity spot is due to a host or pathogen response. This work shows that pythia mycelial growth was reduced by high pH. Future work is required to determine if there is a host (i.e. carrot) response to pH and lime.

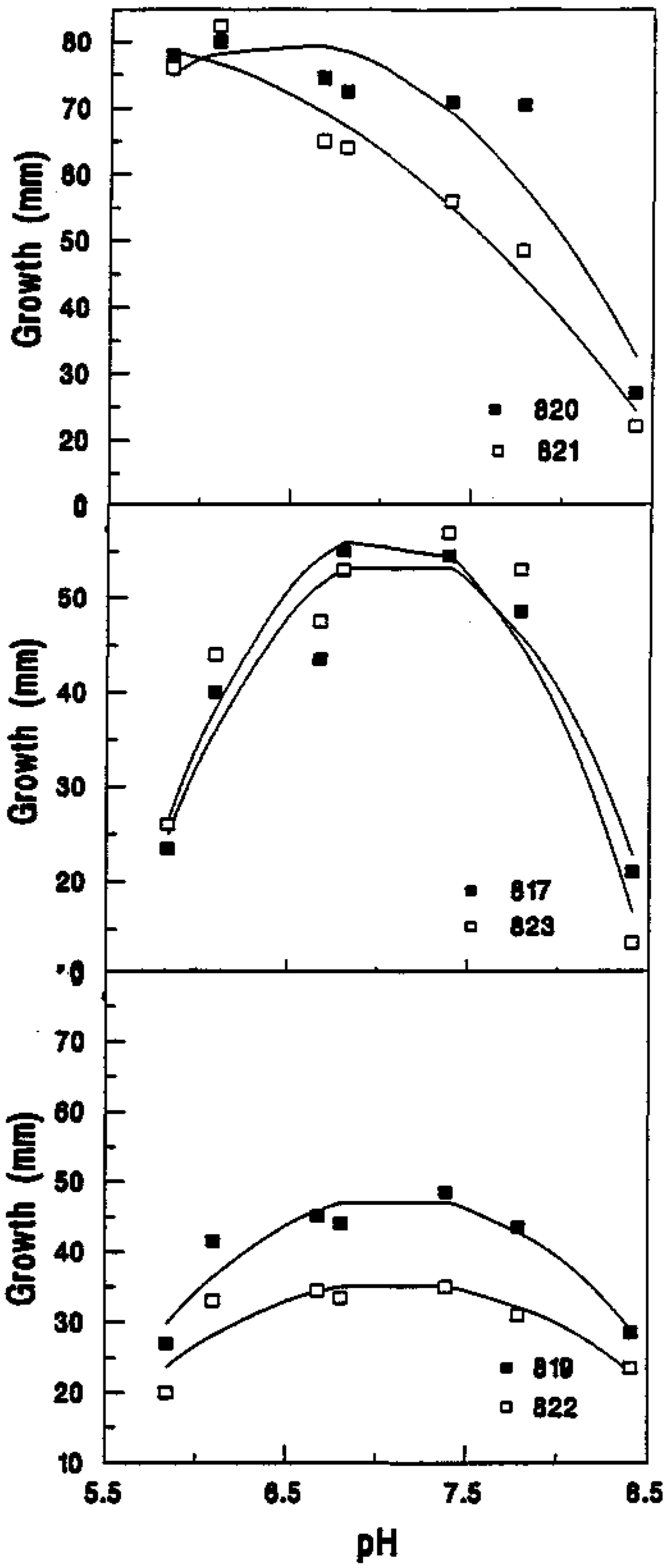


Fig. 2. The effect of pH on growth of Pythium isolates.

820 : $Y = -449 + 163.4\ pH - 12.62\ pH^2$, 821 : $Y = -86 + 62.4\ pH - 5.86\ pH^2$
817 : $Y = -892.6 + 266.7\ pH - 18.77\ pH^2$, 823 : $Y = -1003.7 + 301.4\ pH - 21.41\ pH^2$
819 : $Y = -524.5 + 161\ pH - 11.32\ pH^2$, 822 : $Y = -343.3 + 106.7\ pH - 7.51\ pH^2$

10. Experiment 93PE79 - Preliminary identification of **Pythium** *species associated with cavity spot of carrots in Western Australia*

Aim

Pythium fungi are the causal organism of carrot cavity spot disease (Lyshol *et al.* 1984). Several species are associated with the disease. These include *P. violae* (Groom and Perry 1985; White 1986; Montfort and Rouxel 1988; Vivoda *et al.* 1991), *P. sulcatum* (White 1986; Watanabe *et al.* 1986), *P. intermedium, P. sylvaticum, P. dissotocum,* (White 1986), *P. irregulare* (Shlevin *et al.* 1987) and *P. ultimum* (White 1986; Vivoda *et al.* 1991).

In 1990 to 1993, over 80 Pythium isolates were collected from cavity spot lesions on field grown carrots in Western Australia. The aim of this work was to identify some of the isolates to species level.

Materials and Methods

Thirty isolates were selected from the original collection. In order to identify pythia to species level, both the asexual and sexual cycles need to be present. The life cycle of Pythium fungi includes an :

Asexual cycle; sporangia and zoospore production, and a,
Sexual cycle; oogonia (female), antheridia (male) and oospores (sexual structure produced after union between male and female structures.

To induce the production of sporangia, the isolates were grown on V8 agar, and small sections of agar were placed in soil water extract at room temperature, 20°C and 25°C. Cultures were checked twice daily for sporangia and zoospore production. Where this method failed to induce sporangia formation, other methods including the introduction of grass blades, repeated water washes, pond water and cold shocks (Waterhouse 1967) were undertaken.

Corn meal and V8 agars were used to encourage the production of sexual structures. Plates were incubated at 20°C and examined after 3 to 7 days. Sections were cut from the edges of agar, mounted onto slides and examined under a microscope. Characteristics of the fungi were used to key out species according to the keys of van der Plaats-Niterink (1981) and Dick (1990).

Results and Discussion

Of the 30 isolates examined, only 5 produced zoospores. Of these, 2 isolates did not produce sexual structures. The 3 remaining isolates were similar in many respects to *P. sulcatum* however there were some morphological differences notably, the absence of complicated furrowed antheridia (Pratt and Mitchell 1973).

Zoospore production could not be induced for 25 of the 30 isolates (Table 29). Taxonomic keys often rely on such characteristics for identification. However, zoospore production is often not observed with Pythium isolates. Over 180 species of Pythium have been described world-wide but the taxonomic keys have only been developed for about 85 species (Dick 1990).

P. violae and *P. sulcatum* are considered to be the most closely involved with cavity spot development in carrots (White 1988; Vivoda *et al.* 1991). There are several characteristics to distinguish between *Pythium violae* and *Pythium sulcatum* according to the Pythium key of van de Plaats-Niterink (1981) (Table 28).

Table 28. Characteristics of *Pythium violae*, *Pythium sulcatum* and WA isolates

Characteristics	*P. violae*	*P. sulcatum*	*WA isolates*
Produces sporangia	No	Yes	5/30 only
Oospore size	27 *μm*	14 *μm*	14-22 *μm*
Oospore type	aplerotic	aplerotic	mostly aplerotic
Antheridia number	1-8	1-3	1-5

Many of the isolates failed to produced sporangia or produced 'sporangial type structures' (Fig. 3) without zoospore dispersal. Sporangia were either filamentous or lobate in shape (Table 29, Fig. 3). Hyphal swellings were present in most isolates.

Oogonia were smooth and mostly intercalary or terminal (Table 29). The oospore size of these isolates were between 14-20μm and were considered too small to be *P. violae*. Our isolates did not resemble *P. violae* which is characterised by numerous antheridia that originate at a short distance from the oogonium (van de Plaats-Niterink 1981). Antheridia of our isolates were diclinous or monoclinous, with usually 1 to 2, but sometimes 2 to 5 per oogonia (Fig. 4). Oospores were mostly aplerotic (Table 28). Although many of these isolates resemble *P. sulcatum*, even with the lack of zoospore production, other structures (eg. antheridia) were not always typical of *P. sulcatum*, (as described by Pratt and Mitchell 1973). This suggests that while many of the isolates were very similar to *P. sulcatum* they could not be confirmed as such.

Isolates of fungi from cavity spot lesions in Western Australia were often morphologically similar to *P. sulcatum*, but displayed some differences. None of the isolates examined resembled *P. violae*. It is possible the isolates which did produce sexual and asexual structures belong to another species that is not described in the taxonomic keys. Inoculation of these isolates onto whole carrots produced brown sunken lesions (93PE57), indicating that the isolates are pathogenic to carrots.

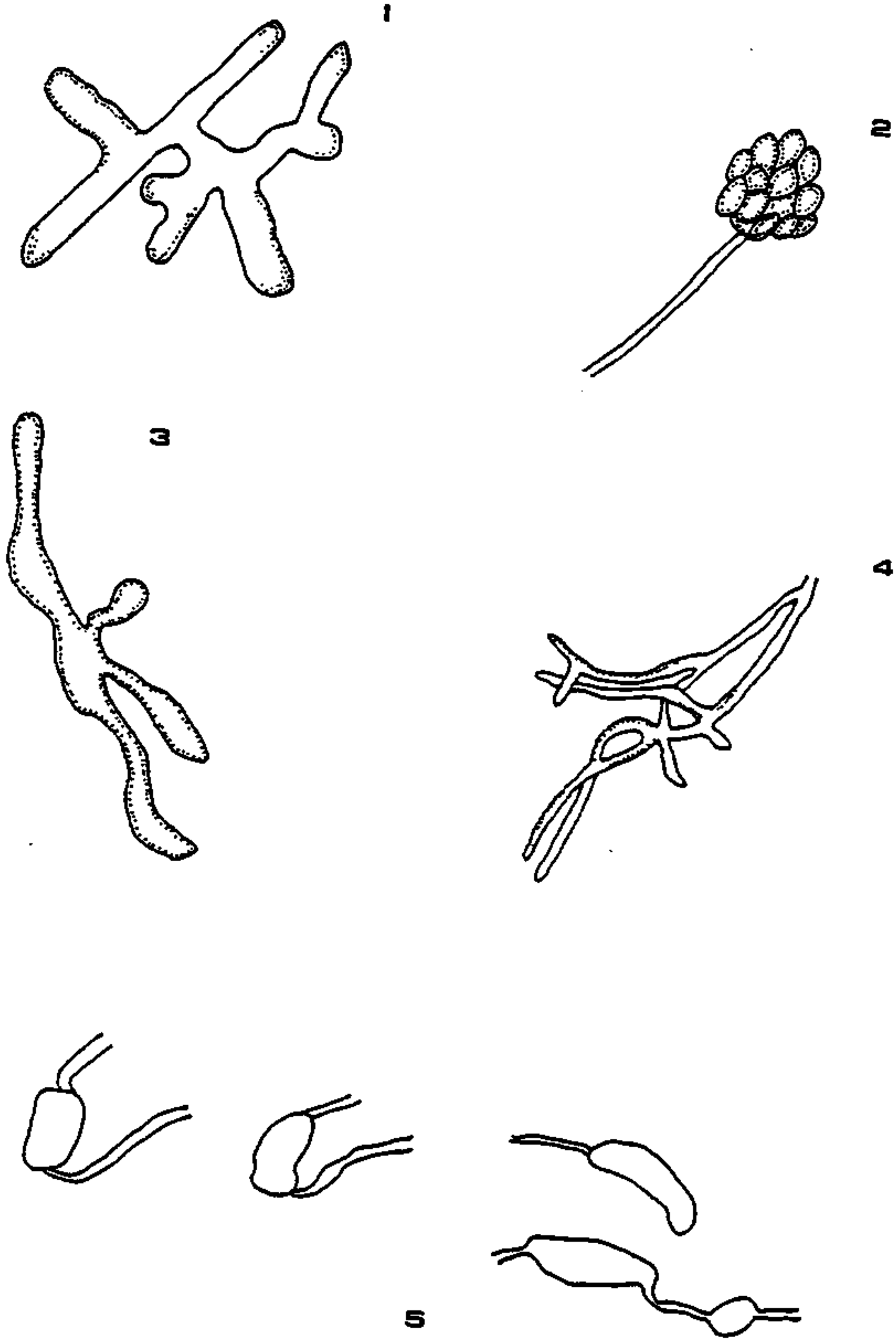


Fig. 3. Asexual structure of Pythium isolates from soil water extract and V8 agar.
1, 3 Lobate sporangia
4 Filamentous sporangia
2 Vesicle with zoospores
5 Appressoria

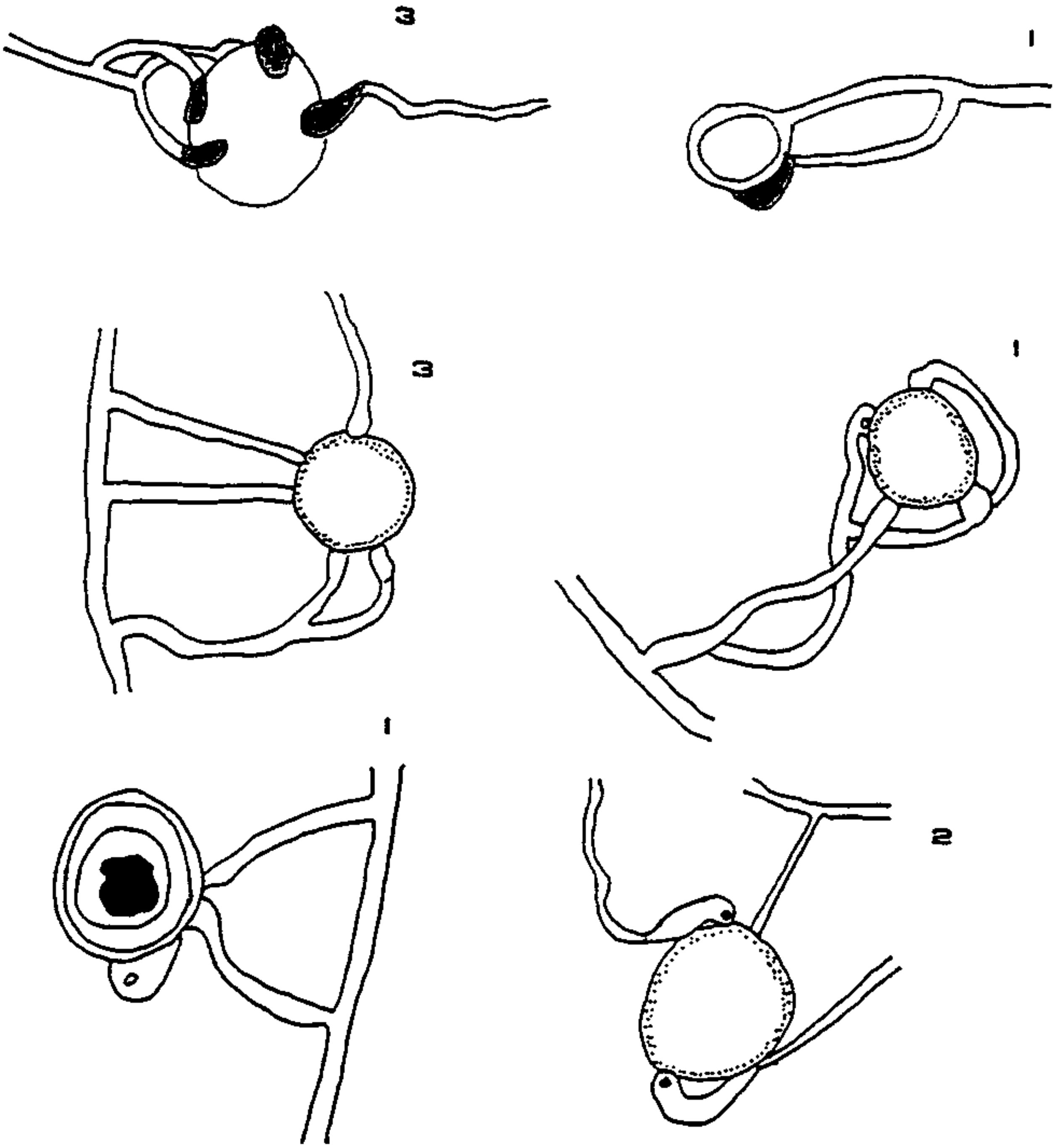


Fig.4. Sexual structure of Pythium isolates from V8 agar.

[1] Monoclinous antheridia with terminal oogonia

[2] Diclinous antheridia with terminal oogonia

[3] Monoclinous and diclinous antheridia with terminal oogonia

Table 29. Taxonomic characteristics of 30 Pythium isolates from carrots in Western Australia

SPORANGIA				OOGONIA				OOSPORES		ANTHERIDIA				
Isolate No	Filament-ous	Lobate	None or hyphal swellings	Terminal	Inter-catary	Rough	Smooth	Plerotic	Aplerotic	1-2	1-5 usually 2-4	<6	mono-clinous	diclinous
15.1			+	$+^{M}$	+		+		+		+			+
30.1			+	$+^{M}$	+		+			+			+	$+^{M}$
47.1			+	$+^{M}$	+		+		+	+			+	$+^{M}$
58			+	+			+				+		+	$+^{M}$
84			+	$+^{M}$	+		+			+			+	$+^{M}$
89.2			+	$+^{M}$	+		+	+		+			+	$+^{M}$
96			+	$+^{M}$	+		+			+			+	$+^{M}$
102	+													
109			+											
130			+	+	+		+		+	+			+	$+^{M}$
159.2			+	+			+				+		+	$+^{M}$
174.1			+	+	+		+			+				+
201.1			+											
201.2			+	$+^{M}$	+		+		+		+		+	$+^{M}$
208		+												
230			+	+			+				+		+	$+^{M}$
239B			+	+			+		+	+			+	$+^{M}$
364	+			+			+		+		+			+
365			+	$+^{M}$	+		+			+			+	$+^{M}$
368	+			+	+		+	+		+				+
542B			+	$+^{M}$	+		+		+	+			+	$+^{M}$
551			+	+			+		+				+	$+^{M}$
564B			+	+			+			+			+	$+^{M}$
602C			+	$+^{M}$	+		+				+			+
603A														
677			+	$+^{M}$	+		+		+	+				$+^{M}$
752														
E1A			+	+			+			+			$+^{M}$	+
V1	+			$+^{M}$	+		+	+			+		+	$+^{M}$

$+^{M}$ = most prominent structure type

Glossary of terms in Tables 28 and 29.
Antheridium: male gametangium
Oogonium: female gametangium
Oospore: produce of union between antheridium and oogonium
Monoclinous: antheridium arises as a branch of oogonial hypha.
Diclinous: antheridium arises from any hypha other than oogonial branch.
Plerotic oospore: oospore fills oogonium
Aplerotic oospore: clear space between oospore and oogonial wall.
Terminal oogonium: arises at the end of hyphal branch
Intercalary oogonium: arises between hyphal branch.
Sporangium: asexual structure that encases spores, can be filamentous or lobate in shape.
Zoospores (or sporangiospores): motile asexual structures

---

12. Experiment 92PE68-Lime reduces cavity spot disease of carrots in sandy soils

Introduction

Cavity spot, caused by Pythium fungi, appears as brown sunken spots on carrots and is a major disease in Western Australia. The disease has proven difficult to control, with fungicides such as metalaxyl failing to control the disease in experiments on commercial properties.

Amending soil to change the environment in which the Pythium fungi grow, without any detrimental effect on the plant, is one way of managing the disease. Scaife *et al.* (1983) and White (1988) reported cavity spot incidence was lower in soils with a naturally high soil pH (greater than 8). Soils of the Western Australian Swan coastal plain, where most of the State's carrots are grown range in pH (1:5 water) between 5 and 8. A commercial survey of carrot crops in Western Australia during 1990-91, also showed that the incidence of cavity spot was lower in soils with a pH greater than 7 (McKay and Galati 1992).

One of the objectives of this experiment was to determine the effect of lime on the yield and the incidence of cavity spot in carrots over 3 cropping sequences. The effect of lime on the yield and quality of potato, which forms part of the crop rotation for many growers was also examined. In addition, the effect of lime on the yield and the incidence of cavity spot was determined for the varieties Top Pak and Bolero. Finally, the effect of lime on the yield and incidence of cavity spot for Top Pak grown on areas with a previous cropping history (carrot/potato vs. carrot/carrot rotation) was compared.

Materials and Methods

The experiment was conducted on a Karrakatta sand, 100 km north of Perth. Three successive carrot crops were grown on areas treated with various rates of lime applied before planting the first crop. Lime sand was applied at rates of 4, 8, 16 and 32 t/ha. Hydrated lime (calcium hydroxide) was applied at rates of 3 and 12 t/ha. Treatments including two untreated controls were replicated 4 times and arranged in a randomised block design. Each plot consisted of three 1.92 m wide (5.76 m wide in total) by 10 m in length beds. Carrots in previous commercial crops on this site were affected by cavity spot. Lime was applied only once. It was broadcast by hand to plots and then rotary hoed to a depth of 20 cm two days before sowing the first carrot crop. Double superphosphate (250 kg/ha) and muriate of potash (200 kg/ha) were broadcast across the site before sowing each crop. The crops were maintained according to commercial practice.

Table 30 provides details of sowing and harvest dates and crop duration for each of the 3 crops.

The Nantes variety Top Pak (South Pacific Seeds) was sown with an Agricola Italia® precision air seeder. Four twin rows were sown on each 1.92 m wide bed.

In the second crop cycle, the potato variety Coliban was sown in 1 of the 3 beds per plot with a commercial potato seeder on 10 August 1993 with 2 rows per 1.92 m bed at a 20 cm intrarow spacing.

Table 30. Sowing and harvest date and crop duration for each of the 3 carrot crops

Crop	Sowing date	Harvest date	Crop duration (days)
1	22 December 1992	27 April 1993	126
2[A]	10 August 1993	21 December 1993	126
3	27 January 1994	25 May 1994	118

[A]Potatoes sown 10 August 1993 and harvested 7 December 1993 (112 days)

In the third crop, the varieties Top Pak and Bolero (Vilmorin Seeds) were sown onto areas where the previous crop was potatoes. The effect of cropping history on cavity spot incidence was determined by including a treatment of Top Pak sown on beds where the previous crops were either potato or carrot. Treatments were arranged in split-plot design with lime rate as the main treatments and cropping history as the sub-treatment.

At each carrot harvest, 6 samples of 0.5 m length of row were collected from the middle rows from each plot. The roots were washed, graded according to size and weighed. The carrots were then regraded for cavity spot incidence. Each carrot was graded according to disease severity using the following rating scale: nil, slight (1 lesion per root), moderate (2 lesions per root), and severe (more than 3 lesions per root). In addition, a cavity spot index that weights the incidence of each disease category (% of total yield) according to increasing severity was calculated using the following formula:

$$\text{Cavity spot index} = \frac{(\%\text{ slight} \times 1) + (\%\text{ moderate} \times 2) + (\%\text{ severe} \times 3)}{3}$$

Potatoes planted in the second crop cycle were harvested on 7 December 1993. A twin row digger harvested potatoes from the 1.92 m by 10 m plot. Tubers were graded according to weight and for the incidence of powdery scab and common scab.

Soil samples (0 to 15 cm depth) were taken at various stages of the experiment to determine soil pH (1:5 0.01M $CaCl_2$). The roots and youngest mature leaves of potatoes and carrots were measured at various stages, washed in distilled water, dried and analysed for nutrient content. Data was analysed by analysis of variance using GENSTAT software.

Results

The effect of lime on cavity spot incidence and yield of carrots. Cavity spot affected about 60 to 66% of the total yield of carrots in the control treatments over the 3 crops (Tables31-33). Apart from the lowest rate of lime sand (4 t/ha), all lime treatments significantly (P<0.05) reduced the incidence of cavity spot in the first crop (Table 31).

Table 31. The effect of liming soil on the incidence and severity of cavity spot disease of Top Pak carrots in crop 1

Treatment	Slight	Moderate	Severe	Total cavity spot	Cavity spot index
		% of the total yield			
Untreated	26.6	16.3	23.4	66.3	40.9
Hydrated lime 3 t/ha	22.4	5.9	9.8	38.1	19.1
Hydrated lime 12 t/ha	13.7	11.1	7.7	32.6	19.1
Lime sand 4 t/ha	17.6	7.9	25.9	61.2	36.4
Lime sand 8 t/ha	27.4	7.7	7.1	32.5	17.2
Lime sand 16 t/ha	20.6	13.4	6.8	40.9	21.7
Lime sand 32 t/ha	18.3	9.9	15.8	43.9	25.7
Significance	*	*	ns[A]	*	*
l.s.d (P=0.05)	9.8	9.1	-	24.5	18.3

[A]P <0.1

Lime sand at 8, 16 and 32 t/ha and hydrated lime (12 t/ha) significantly (P<0.001) reduced the incidence of cavity spot in the second crop (Table 32). Hydrated lime at 12 t/ha reduced the incidence of cavity spot from 59.8 % in the untreated crop to 25.1%. Lime sand at 32 t/ha reduced cavity spot incidence to 28.8% (Table 33). Hydrated lime at 3 t/ha nearly halved the cavity spot incidence in the first crop but was ineffective in the second crop.

Table 32. The effect of liming soil on the incidence and severity of cavity spot disease of Top Pak carrots in crop 2

Treatment	Slight	Moderate	Severe	Total cavity spot	Cavity spot index
		% of the total yield			
Untreated	26.1	8.7	25.0	59.8	36.9
Hydrated lime 3 t/ha	21.8	9.8	27.0	58.6	38.0
Hydrated lime 12 t/ha	17.6	3.1	4.4	25.1	11.9
Lime sand 4 t/ha	26.0	9.8	13.6	49.5	27.5
Lime sand 8 t/ha	30.2	8.1	7.5	45.7	21.6
Lime sand 16 t/ha	19.4	5.7	8.4	33.5	17.3
Lime sand 32 t/ha	18.5	5.1	5.3	28.8	13.9
Significance	*	ns	***	***	***
l.s.d (P=0.05)	7.3	-	10.1	13.6	10.3

Lime sand at 8, 16 and 32 t/ha and hydrated lime at 12 t/ha were still effective in reducing cavity spot in the third crop. Lime sand at 4 t/ha was ineffective in the second and third crops (Tables 32 and 33). In the third crop, lime sand at 32 t/ha caused the greatest reduction in the incidence of total and severe cavity spot.

Table 33. The effect of liming soil on the incidence and severity of cavity spot disease of carrots in crop 3. Results shown are main effect of lime on cavity spot

Treatment	Slight	Moderate	Severe	Total cavity spot	Cavity spot index
		% of the total yield			
Untreated	21.9	15.0	28.6	65.4	43.3
Hydrated lime 3 t/ha	22.6	9.4	20.1	53.8	32.9
Hydrated lime 12 t/ha	18.9	10.2	20.8	48.2	30.1
Lime sand 4 t/ha	20.7	12.6	27.5	60.8	40.8
Lime sand 8 t/ha	18.8	10.6	15.2	44.6	26.6
Lime sand 16 t/ha	19.1	10.2	15.0	44.3	26.1
Lime sand 32 t/ha	18.1	7.3	5.6	31.0	15.4
Significance	ns	ns[A]	***	**	***
l.s.d (P=0.05)	-	-	10.3	10.0	9.8

[A] P=0.09

Lime treatments generally improved total and export yields of carrots in each of the 3 cropping sequences (Tables 7A-39A). For instance, in the first crop hydrated lime (12 t/ha) more than doubled the export yield from 19.1 t/ha to 48.6 t/ha (Table 37A).

In addition, all lime treatments reduced the incidence of carrot 'scab' in the second crop, from 8 % in the control to down to between 1.4 and 4 % for the lime treatments (Table 38A). Liming also reduced the incidence of root splitting in the third crop (Table 39A). The level of forking was also reduced in the third crop by liming (Table 39A).

Effect of lime on cavity spot incidence and yield of Top Pak and Bolero. Bolero had a significantly ($P<0.001$) lower percentage by weight of carrots with moderate and severe symptoms as well as total cavity spot incidence compared to Top Pak. There was no lime x variety interaction for cavity spot incidence or severity (Table 34). However, Top Pak produced higher total yields($P<0.01$) than Bolero across all treatments (Table 40A).

Table 34. The effect of liming soil on the incidence and severity of cavity spot disease in Top Pak and Bolero in crop 3

Treatment	*% of the total yield*							
	Slight		Moderate		Severe		Total cavity spot	
	Bolero	*Top Pak*	*Bolero*	*Top Pak*	*Bolero*	*Top Pak*	*Bolero*	*Top Pak*
Untreated	23.5	20.3	14.8	15.0	16.2	41.0	54.4	76.3
Hydrated lime 3 t/ha	25.8	19.4	8.6	10.2	10.6	33.0	45.0	62.6
Hydrated lime 12 t/ha	20.7	17.1	8.5	11.9	3.8	34.5	32.9	63.5
Lime sand 4 t/ha	23.9	17.4	10.2	15.1	8.6	46.5	42.7	79.0
Lime sand 8 t/ha	14.7	22.9	5.1	16.2	2.3	28.1	22.1	67.2
Lime sand 16 t/ha	15.1	23.1	5.7	14.7	4.0	25.9	24.9	63.7
Lime sand 32 t/ha	14.1	22.2	6.3	8.2	2.8	8.2	23.2	38.7
Significance (lime)	ns		ns		**		***	
l.s.d (P=0.05)	-		-		10.3		10.0	
Significance (var)	ns		**		***		***	
l.s.d (P=0.05)	-		3.0		6.7		7.6	
Significance (lime*var)	ns		ns		ns		ns	
l.s.d (P=0.05)	-		-		-		-	

The effect of lime on soil pH and leaf/root nutrient concentrations. Table 6 shows the effect of lime on soil pH over time. After 5 months, the pH of soil in all the lime treated plots had increased (Table 35).

The relationship between soil pH and cavity spot incidence over the 3 carrot crops is shown in Fig. 5. In crops 1 and 2 of the experiment, there was a highly correlated linear relationship between soil pH and cavity spot incidence. However, there was a poor correlation between pH and cavity spot incidence by crop 3 (Fig. 5).

Table 35. Effect of liming on soil pH

Treatment	Months after treatment 5	8	12	15	18
			pH ($CaCl_2$)		
Untreated	5.94	5.35	5.58	6.05	6.06
Hydrated lime 3 t/ha	7.32	6.88	7.00	7.05	7.25
Hydrated lime 12 t/ha	7.90	7.68	7.95	7.58	7.82
Lime sand 4 t/ha	6.85	6.85	6.87	7.00	7.08
Lime sand 8 t/ha	6.90	6.78	7.30	7.08	7.17
Lime sand 16 t/ha	7.12	7.00	7.48	7.20	7.38
Lime sand 32 t/ha	7.28	7.20	7.63	7.20	7.45
Significance	***	***	***	***	***
l.s.d (P=0.05)	0.47	0.32	0.40	0.40	0.39

After 12 months, the soil pH at varying depths was measured in control and lime at 32 t/ha plots. The lime treatment had increased pH to over 7 in the top 30 cm and had increased pH by about 1 unit between 30 and 50cm (Table 41A).

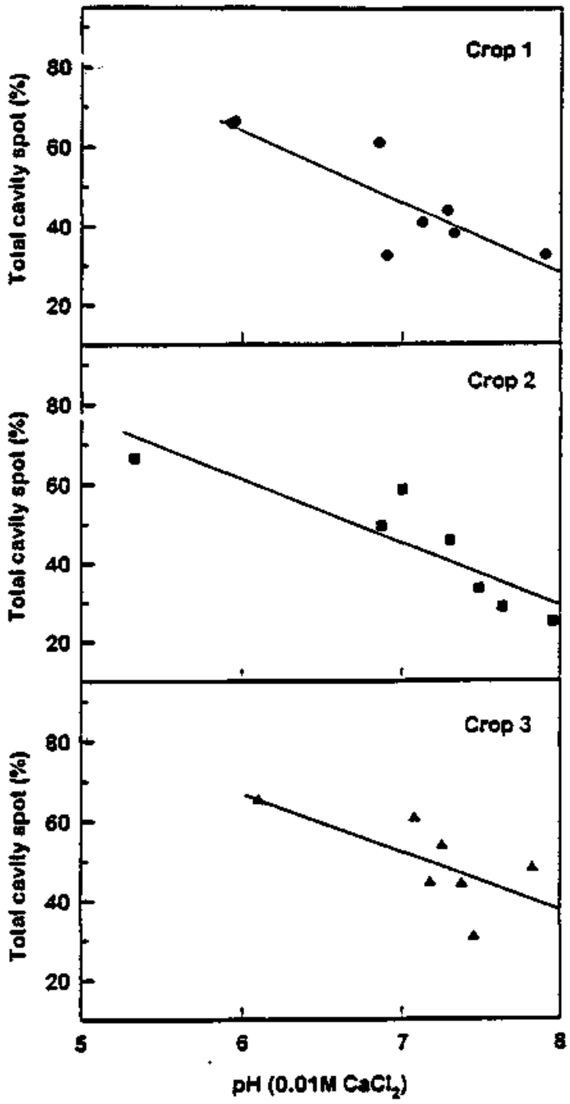


Fig. 5. The relationship between pH and cavity spot.
Crop 1: Y = 172.89 - 18.13 X (R^2 =0.71)
Crop 2: Y = 157.93 - 16.09 X (R^2 = 0.78)
Crop 3: Y = 154.21 - 14.55 X (R^2 = 0.46)

Lime treatments significantly reduced concentrations of Cu, Zn and Mn in the YML's and roots of carrots and potatoes (Tables 42A-46A). Lime had no effect on the concentrations of calcium and magnesium in carrot roots which were measured only in the third crop (Table 42A).

The effect of lime on yield and quality of potato

Lime had no effect on total yield or size grades of potatoes in the second crop cycle. Lime had no effect on the incidence of common scab (P=0.08) or powdery scab (Table 36). The average incidence across treatments of powdery scab was 4.9 % compared to 2.7% for common scab. Test for lime to reduce common scab.

Table 36. The effect of lime on yield and rejects of Coliban potatoes in crop 2

Treatment	Total yield (t/ha)	Tubers 0-80g (t/ha)	Tubers 80-450g (t/ha)	Powdery scab (%)	Common scab (%)	Other rejects (%)[A]
Untreated	17.6	4.6	10.9	6.2	4.0	1.5
Hydrated lime 3 t/ha	18.9	5.3	11.8	3.7	3.2	1.7
Hydrated lime 12 t/ha	16.9	4.1	12.0	1.5	1.6	2.0
Lime sand 4 t/ha	19.0	5.5	11.3	4.9	6.4	0.8
Lime sand 8 t/ha	18.1	4.4	11.9	7.4	1.0	1.8
Lime sand 16 t/ha	18.5	4.9	11.9	5.1	1.8	2.0
Lime sand 32 t/ha	17.6	4.5	12.0	4.5	0.8	0.8
Significance	ns	ns	ns	ns	P=0.08	ns
l.s.d (P=0.05)	-	-	-	-		-

[A]insect damage, rots

The effect of previous crop history on cavity spot

The incidence and severity of cavity spot in Top Pak grown on areas where the preceeding crop (second crop) was carrot or potatoes were measured in the third crop. Previous cropping history had no effect on cavity spot incidence in this experiment. However, the export yield of Top Pak following potatoes was significantly (P<0.05) lower than the export yield of Top Pak following carrots. The difference was about 5%. Cropping history had no effect on total yield or components of rejects (results not shown).

Discussion

Lime applied before cropping reduced the incidence and severity of cavity spot and increased total and export yields of Nantes carrots.

Cavity spot incidence was highly correlated to soil pH measured in the first and second crops, whereas, by the third crop, there was a poor relationship between cavity spot incidence and soil pH. The addition of hydrated lime at 12 t/ha produced a pH of 7.82 after 18 months. However, it was not as effective in reducing the incidence of 'severe' cavity spot symptoms in the third crop. Lime sand at 32 t/ha caused the greatest reduction in the incidence of total and severe cavity spot in the third crop, but produced a slighly lower pH of 7.45. This pH was not significantly different to that of hydrated lime at 12 t/ha.

It is possible that it is not the effect of alkalinity *per se*, but an effect caused by varying concentrations of cations in soil solution associated with lime amendments used in modifying soil pH. However, it is difficult to separate the effect of pH and levels of cations such as calcium under field conditions.

Clubroot is a disease of brassicas where lime and other soil amendments have been used extensively for control, but with inconsistent results (Karling 1968). Myers and Campbell (1985), adjusted pH and calcium concentrations independently by the use of organic buffers in sand culture, for studying the effect of clubroot on broccoli. Calcium affected clubroot development, but the effect was pH dependent. Increasing calcium concentrations decreased the number of infections and the amount of root clubbing. Less calcium was required to prevent clubbing as the pH was increased from 6.2 to 7.2. Campbell *et al.* (1985) concluded that the degree to which clubroot is controlled may depend on the balance between pH and concentrations of the cations calcium and magnesium.

Consequently, the pH is probably the most important factor for clubroot development but high concentrations of the cations calcium and magnesium may give control at pH less than 7.2. Similarly, low concentrations may permit disease development at pH greater than 7.2. Although we did not measure the concentrations of exchangeable cations such as calcium and magnesium in soil, the concentrations of calcium and magnesium were measured in the carrot roots at harvest of the third crop. The results showed that the concentrations of calcium and magnesium in roots were not significantly different across all treatments.

The effect of cations such as calcium were originally thought to be linked to cavity spot (Maynard *et al.* 1961), but was later disproved. Vivoda *et al.* (1991) in a survey of 54 fields in California found cavity spot incidence was not correlated to pH or total or exchangeable calcium. Perry and Harrison (1979) also found there was no relationship between calcium concentrations in soil and cavity spot incidence.

The mechanism for suppression of cavity spot by lime is not understood. This experiment shows the necessity for further work in understanding the mechanism behind the effectiveness of lime as pH alone does not simply explain why high rates of lime reduced cavity spot in sandy soils in the first 2 crops at this site.

Potatoes are often grown in rotation with carrots in Western Australia. However potatoes are usually regarded as having an optimum pH lower than those achieved by liming in our experiment (Lorenz and Maynard 1988). Although total and export yields of potatoes across all treatments were low because of Alternaria blight, lime had no effect on yield. Liming soil had no effect on the incidence of common scab in potatoes in this experiment, although like clubroot, the increase in scab cannot regularly be explained by an effect of soil pH alone (Hooker 1981; Lambert and Manzer 1991). The incidence of common scab was low in this experiment, possibly because wet conditions at tuber initiation were not conducive to common scab development (Hooker 1981).

Crop rotation is one potential strategy for reducing cavity spot. Potatoes grown in rotation did not reduce the incidence of cavity spot in the following carrot crop. However work by Huiskamp (1990) showed that the cavity spot incidence in carrot was significantly lower if the preceding crop was onion, but were similar if the preceding crop was potatoes or Brussel sprouts.

Lime had a positive effect by improving total and export yields in this experiment. Raising the pH reduced the availability of some nutrients, particularly zinc and manganese in this experiment. There will be a need to monitor trace elements by leaf analysis and correct for, if necessary, with foliar trace element sprays if lime is to be used extensively by carrot producers.

The variety Bolero had significantly less cavity spot than Top Pak. However, the yields of Bolero were significantly lower than Top Pak. Tolerant varieties, with comparable yields to Top Pak, could also be used in conjuction with lime on areas with known cavity spot history as part of an integrated management program.

Further work is required to clarify the independent effects of pH and cations such as calcium on the cavity spot incidence in carrots. Further work is also required to determine whether lime reduced the severity of cavity spot by a pH effect on the host (ie the carrot) or a pH effect on Pythium antagonists, rather than a pH effect on the growth of the pathogen.

Appendix

Table 37A. Effect of lime on density, leaf yield, marketable yield and rejects in crop 1

Treatment	Leaf yield (t/ha)	Density (plants/m^2)	Total yield (t/ha)	Export yield (t/ha)^A	Marketable short (t/ha)^B	Undersize (%)^C	Other^D (%)
Untreated	9.5	58	57.6	19.1	21.0	12.0	5.4
Hydrated lime 3 t/ha	9.7	65	63.9	36.9	17.3	8.8	0.8
Hydrated lime 12 t/ha	10.3	65	71.4	48.6	10.5	2.9	9.3
Lime sand 4 t/ha	9.1	61	57.6	18.8	22.5	10.4	3.0
Lime sand 8 t/ha	9.3	65	57.9	23.8	20.8	10.0	3.4
Lime sand 6 t/ha	9.0	62	57.0	22.1	20.4	11.7	2.8
Lime sand 32 t/ha	10.4	66	64.7	29.8	24.2	8.6	2.2
Significance	ns	ns	*	***	**		ns
l.s.d. (P=0.05)	-	-	8.8	11.1	6.4	4.9	-

^{A} 25 to 50 mm diameter, greater than 150 mm length, ^{B} 25 to 50 mm diameter, 100 to 150 mm length
^{C} less than 25 mm diameter, less than 150 mm length, ^{D} Forked, oversize, misshapen, split.

Table 38A. The effect of lime on density, leaf yield and marketable yield of carrots at harvest in crop 2

Treatment	Leaf yield (t/ha)	Density (plants/m²)	Total yield (t/ha)	Export yield (t/ha)	Marketable short yield (t/ha)	Scab (%)	Other[A] (%)
Untreated	4.6	64	53.8	28.6	11.9	8.2	16.5
Hydrated lime 3 t/ha	5.6	63	58.2	34.9	10.1	4.3	18.6
Hydrated lime 12 t/ha	6.0	65	58.0	36.5	9.6	3.8	17.2
Lime sand 4 t/ha	5.3	65	56.3	33.2	9.9	4.0	18.9
Lime sand 8 t/ha	6.7	71	65.3	39.1	13.2	1.4	18.2
Lime sand 16 t/ha	6.4	68	60.8	36.2	15.1	1.8	13.6
Lime sand 32 t/ha	6.5	70	64.5	40.7	14.9	2.6	11.3
Significance	***	ns	**	*	ns	**	ns
l.s.d. (P=0.05)	0.8	-	6.3	7.2	-	3.4	-

[A] Undersize, forked misshapen. % forking not significant across treatments.

Table 39A. Effect of lime on yield for carrots in crop 3. Results presented show main effect across varieties

Treatment	Density (plants/m²)	Total yield (t/ha)	Export yield (t/ha)	Marketable short yield (t/ha)	Under size (%)	Split (%)	Forked (%)	Other[A] (%)
Untreated	58	59.2	22.0	18.7	11.6	5.0	12.5	2.6
Hydrated lime 3 t/ha	65	64.7	35.1	16.2	10.4	0.7	6.5	3.5
Hydrated lime 12 t/ha	62	65.6	36.2	18.1	12.5	0.6	4.2	0
Lime sand 4 t/ha	62	66.3	37.2	16.3	9.2	2.0	5.6	1.9
Lime sand 8 t/ha	66	71.2	43.3	16.9	5.7	2.1	6.1	1.5
Lime sand 16 t/ha	66	73.1	48.0	15.7	5.0	2.5	4.7	0.4
Lime sand 32 t/ha	64	69.3	43.3	18.1	5.4	0.9	4.8	0.3
Significance	ns	*	*	ns	ns	**	*	ns
l.s.d. (P=0.05)	-	9.5	9.0	-	-	2.0	4.0	-

[A] oversize, rots

Table 40A. The effect of liming soil on yield for Top Pak and Bolero in crop 3

Treatment	Density (plants/m^2)		Total yield (t/ha)		Export yield (t/ha)		Marketable short yield (t/ha)	
	Bolero	*Top Pak*	*Bolero*	*Top Pak*	*Bolero*	*Top Pak*	*Bolero*	*Top Pak*
Untreated	58	59	56.0	62.4	23.6	20.4	15.7	21.7
Hydrated lime 3 t/ha	60	59	60.3	69.2	33.1	37.1	13.6	18.7
Hydrated lime 12 t/ha	66	59	57.8	73.4	34.7	37.8	12.6	23.7
Lime sand 4 t/ha	65	66	60.1	72.4	37.8	36.7	13.9	18.9
Lime sand 8 t/ha	68	60	65.6	76.8	46.5	40.1	11.3	22.4
Lime sand 16 t/ha	67	64	65.8	80.4	47.3	48.6	11.7	19.7
Lime sand 32 t/ha	66	62	61.8	76.9	39.9	46.9	15.0	21.2
Significance (lime)	ns		**		***		ns	
l.s.d (P=0.05)	-		6.3		9.0		-	
Significance (variety)	ns		***		ns		***	
l.s.d (P=0.05)	-		2.4		-		1.8	
Significance (lime*var)	ns		ns		ns		ns	
l.s.d (P=0.05)	-		-		-		-	

Table 41A. Soil pH ($CaCl_2$) at depth after 12 months (samples from 1 replicate only)

Treatment	Depth (cm)	pH ($CaCl_2$)
Untreated	0-10	5.4
	10-20	5.2
	20-30	5.4
	30-40	5.2
	40-50	5.0
Lime 32 t/ha	0-10	7.4
	10-20	7.3
	20-30	7.1
	30-40	5.8
	40-50	5.5

Table 42A. Effect of liming on nutrient concentrations in youngest mature leaves (YML) and roots of Top Pak carrots at harvest in crop 1. All concentrations expressed on dry weight basis

Treatment	YML Cu	YML Zn	YML Mn	Roots Cu	Roots Zn	Roots Mn
		mg/kg			*mg/kg*	
Untreated	8.8	53.7	177.9	6.7	56.2	45.4
Hydrated lime 3 t/ha	7.9	31.2	90.8	5.4	34.3	18.6
Hydrated lime 12 t/ha	7.5	26.2	75.7	5.1	27.6	15.1
Lime sand 4 t/ha	7.1	35.2	81.8	5.4	35.0	18.4
Lime sand 8 t/ha	7.9	39.9	108.7	5.2	37.9	25.0
Lime sand 16 t/ha	7.4	34.4	100.9	5.3	36.5	22.1
Lime sand 32 t/ha	7.6	31.3	74.1	4.3	33.5	14.0
Significance	***	***	**	***	**	*
l.s.d (P=0.05)	0.73	10.9	62.0	1.02	14.4	20.1

Table 43A. Effect of liming on Cu, Zn and Mn concentrations of YML of potatoes (20 mm tubers stage) and carrot at 78 DAS in crop 2

Treatment	Carrot Cu	Carrot Zn	Carrot Mn	Potato Cu	Potato Zn	Potato Mn
		mg/kg			*mg/kg*	
Untreated	9.6	93.1	408	24.0	78.0	200.0
Hydrated lime 3 t/ha	7.2	37.3	171	18.7	43.0	64.3
Hydrated lime 12 t/ha	6.7	15.1	50	20.3	35.0	20.7
Lime sand 4 t/ha	7.0	37.5	142	16.7	42.3	46.7
Lime sand 8 t/ha	6.2	23.5	39	17.0	41.7	26.3
Lime sand 16 t/ha	6.2	17.3	25	17.7	40.0	21.3
Lime sand 32 t/ha	6.2	16.3	25	18.3	38.0	19.0
Significance	***	***	***	ns	***	***
l.s.d. (P=0.05)	0.89	16.7	77.8	-	14.1	42.3

Table 44A. Effect of lime on nutrient concentrations of Zn and Mn in carrot roots and potato tubers at harvest in crop 2

Treatment	Carrot Zn	Carrot Mn	Potato Zn	Potato Mn
	mg/kg		*mg/kg*	
Untreated	52	61	23	8
Hydrated lime 3 t/ha	27	16	17	8
Hydrated lime 12 t/ha	17	7	16	6
Lime sand 4 t/ha	27	14	17	7
Lime sand 8 t/ha	21	10	17	6
Lime sand 16 t/ha	19	8	17	6
Lime sand 32 t/ha	18	7	16	6
Significance	***	***	***	***
l.s.d (P=0.05)	10	19	2.7	0.8

Table 45A. The effect of lime on concentrations of nutrients in YML of carrot at harvest in crop 3

Treatment	N	P	K	Na	Ca	Mg	S	Cl
				%				
Untreated	2.15	0.36	2.63	2.75	1.39	0.33	0.38	4.46
Hydrated lime 3 t/ha	2.10	0.31	2.42	2.53	1.62	0.30	0.40	4.23
Hydrated lime 12 t/ha	2.13	0.32	2.54	2.62	1.72	0.26	0.46	4.02
Lime sand 4 t/ha	2.11	0.29	2.46	2.61	1.66	0.29	0.38	4.31
Lime sand 8 t/ha	2.04	0.30	2.49	2.63	1.85	0.30	0.39	4.33
Lime sand 16 t/ha	2.05	0.29	2.33	2.58	1.81	0.28	0.39	4.02
Lime sand 32 t/ha	2.13	0.30	2.50	2.60	1.80	0.29	0.40	4.31
Significance	ns	**	ns	ns	*	**	*	*
l.s.d (P=0.05)	-	0.04	-	-	0.24	0.026	0.04	0.26

Table 46A. The effect of lime on concentrations of selected nutrients in YML and root of carrot at harvest in crop 3 (concentrations expressed on a dry basis)

Treatment	YML B (mg/kg)	YML Cu (mg/kg)	YML Fe (mg/kg)	YML Mn (mg/kg)	YML Zn (mg/kg)	Root Ca (%)	Root Mg (%)	Root Mn (mg/kg)	Root Zn (mg/kg)
Untreated	37	5.6	541	114.7	32.8	0.20	0.080	20.4	27.8
Hydrated lime 3 t/ha	36	5.0	383	36.0	17.5	0.24	0.078	5.1	14.2
Hydrated lime 12 t/ha	36	5.8	330	19.0	16.5	0.24	0.078	4.4	12.5
Lime sand 4 t/ha	36	4.5	415	33.0	15.8	0.24	0.078	4.5	13.5
Lime sand 8 t/ha	37	4.2	433	27.8	16.5	0.23	0.075	5.0	13.5
Lime sand 16 t/ha	36	4.2	383	21.8	14.2	0.23	0.072	3.7	11.3
Lime sand 32 t/ha	37	4.8	373	18.0	15.2	0.22	0.072	3.8	12.2
Significance	ns	**	**	***	***	ns	ns	*	***
l.s.d (P=0.05)	-	0.8	83	36.3	7.0	-	-	8.6	2.74

Table 47A. Effect of lime on components of rejects for Top Pak and Bolero in crop 3

Treatment	Undersize (% of total yield)		Forked		Split		Other	
	Bolero	*Top Pak*	*Bolero*	*Top Pak*	*Bolero*	*Top Pak*	*Bolero*	*Top Pak*
Untreated	11.4	11.8	17.9	7.0	0	9.9	1.2	4.1
Hydrated lime 3 t/ha	11.2	9.5	5.2	7.8	0	1.4	6.0	0.6
Hydrated lime 12 t/ha	13.6	11.4	4.8	3.6	0	1.3	0	0
Lime sand 4 t/ha	6.9	11.6	6.2	5.0	0	4.0	0.9	2.8
Lime sand 8 t/ha	5.3	6.0	6.7	5.5	0.3	3.9	0	3.0
Lime sand 16 t/ha	4.2	5.9	5.8	3.6	0.3	4.7	0	0.9
Lime sand 32 t/ha	5.1	5.6	5.1	4.5	0.5	1.3	0.5	0
Significance (lime)	***		*		**		ns	
l.s.d (P=0.05)	3.4		4.0		1.9		-	
Significance (variety)	ns		ns		***		ns	
l.s.d (P=0.05)	-		-		1.0		-	
Significance (lime*var)	ns		ns		ns		ns	
l.s.d (P=0.05)	-		-		-		-	

Acknowledgments

The authors would like to thank K. Gajda and staff of the Medina Research Centre for their technical assistance. We wish to thank M. Ewing, J. Howieson and B. Frayne for their advice on the use of buffers (93PE65). E. Davison is kindly thanked for assisting with pythium identification (93PE79). P. D' Prinzio is thanked for statistical analysis of the data in 92PE57 and 93PE65 . M. Eales is also thanked for assistance with the Westdata® loggers. The management of experiments by staff at Guilderton Farms (L. Biocich, R. Woonings and C. Hoareau) and Kwinana Market Garden (W. Klepic and L. Woonings) is gratefully acknowledged. The financial assistance of the Sumich Group Ltd. and the Horticulture Research and Development Corporation is gratefully acknowledged.

References

Anon (1992). Vegetable seeds review. *Grower* **118** (12), 15.

Anon (1993). Descriptive list of varieties of early and maincrop carrots grown in NIAB trials. NIAB Vegetable growers leaflet No. 5.

Campbell, R. N., Greathead, A. S., Myers, D. F., and de Boer, G. J. (1985). Factors related to control of clubroot of crucifers in the Salinas Valley of California. *Phytopathology* **75**, 665-70.

Chauhan, Y. S., Nene, Y. L., Johansen, C., Haware, M. P, Saxena, N. P., Singh, S., Sharma, S. B., Sahrawat, K. L., Burford, J. R., Rupela, O. P., Kumar Rao, J. V. D. K. and Sithanantham, S. (1988). Effects of soil solarisation on pigeonpea and chickpea. ICTISAT Research Bulletin No. 11.

Cherif, M., and Belanger, R. R. (1992). Use of potassium silicate amendments in recirculating nutrient solutions to suppress *Pythium ultimum* on long English cucumber. *Plant Disease* **76,** 1008-11.

Cohen, Y., and Coffey, M. D. (1986). Systemic fungicides and the control of oomycetes. *Annual Review of Phytopathology* **24,** 311-38.

Davis, R. M. (1991). Investigation into the cause and control of carrot root forking and cavity spot. California Fresh Carrot Advisory Board. 1991 Annual Report. pp. 5-15.

Davis, R. M., Nunez, J. J., Guerard, J. P., and Vivoda, E. (1991). If registered, fungicide could reduce cavity spot of carrots. *California Agriculture* **45**(2) 29-30.

Dick, M. W. (1990). 'Keys to *Pythium*.' (Reading: UK).

Gladders, P., and Crompton, J. G. (1984). Comparisons of fungicides for control of cavity spot in carrots. *Annals of Applied Biology Supplement* **104,** 36-37.

Good, N. E., Winget, G. D., Winter, W., Connolly, T. N., Izawa, S., and Singh, R. M. (1966). Hydrogen ion buffers for biological research. *Biochemistry* **5**, 467-77.

Groom, M. R., and Perry, D. A. (1985). Induction of 'cavity spot-like' lesions on roots of *Daucus carota* by *Pythium violae. Transactions of the British Mycology Society* **84**, 755-57.

Hadfidh, F. T., and Kelly, W. C. (1982). Cavity spot of carrots caused byfeeding of fungus gnat larvae. *Journal of the American Society of Horticultural Science* **107**, 1177-81.

Hooker, W. J. (1981). 'Compendium of Potato Diseases.' (American Phytopathology Society: Minnesota).

Huiskamp, T. (1990). Effects of high cropping frequency on yield and quality of carrots. *Proceedings of the International Horticultural Conference*, Italy pg. 529. (Abstract 184).

Karling, J. S. (1968). 'The Plasmodiophorales'. 2nd Ed. (Hafner Publ. Company: New York) 256 pp.

Katan, J. (1981). Solar heating (solarisation) of soil for control of soilborne pests. *Annual Review of Phytopathology* **19**, 211-36.

Katan, J. (1984). Soil solarisation. *Acta Horticulturae* **152**, 227-36.

Lambert, D. H., and Manzer, F. E. (1991). Relationship of calcium to potato scab. *Phytopathology* **81**, 632-36.

Lorenz, O. A., and Maynard, D. N (1988). 'Knott's Handbook for Vegetable Growers.' 3rd Edition. (John Wiley and Sons: New York).

Lyshol, A. J., Semb, L., and Taksdal, G. (1984). Reduction of cavity spot and root dieback in carrots by fungicide applications. *Plant Pathology* **33**, 193-98.

Maynard, D. N., Gersten, B., Vlach, E. F., and Vernell, H. F. (1961). The effect of nutrient concentration and calcium levels on the occurrence of carrot cavity spot. *Proceedings of the American Society of Horticultural Science* **78**, 339-42.

McKay, A. G., and Galati, A. (1992). Survey looks at cause of carrot yield decline. *Good Fruit and Vegetables* **3** (5), 24-25.

Montfort, F., and Rouxel, F. (1988). Cavity spot of carrots caused by *Pythium violae* Chesters & Hickman: symptomatological and etiological data in France. *Agronomie* **8** (8), 701-06.

Morton, H. V, and Urech, P. A. (1988). History of the development of resistance of phenylamide fungicides. *In* 'Fungicide Resistance in North America.' (Ed. C. J. Delp) pp. 58-60. (APS Press: Minnesota.)

Myers, D. F., and Campbell, R. N. (1981). Clubroot of crucifers in California: soils respond differentially to lime for clubroot control. *Phytopathology* **71**, 1005-6. (Abstr).

Myers, D. F., and Campbell, R. N. (1985). Lime and the control of clubroot of crucifers: Effects of pH, calcium, magnesium, and their interactions. *Phytopathology* **75**, 670-73.

Perry, D. A., and Harrison, J. G. (1979). Cavity spot of carrots. II. The effect ofsoil condition and the role of pectolytic anaerobic bacteria. *Annals ofApplied Biology* **93**, 105-09.

Piggott, T. J. (1986). Vegetable crops. *In* 'Plant Analysis- An Interpretation Manual.' (Eds. D. J. Reuter and J. B. Robinson) pp.161-2. (Inkata Press: Melbourne.)

Ploetz, R. C., and Stempel, L. (1989). Recolonization of fumigated tomato production soil in Dade county by *Pythium* spp. *Proceedings of the Florida State Horticultural Society* **102**, 354-58.

Porter, I. J., and Merriman, P. R. (1985). Evaluation of soil solarisation for control of root diseases of row crops in Victoria. *Plant Pathology* **34**, 108-18.

Pratt, R. G., and Mitchell, J. E. (1973). A new species of *Pythium* from Wisconsin and Florida isolated from carrots. *Canadian Journal of Botany* **51**, 333-39.

Punja, Z. K., and Benard, D. (1992). The etiology and control of cavity spot on fresh market carrots in the Fraser valley of British Columbia. Final report for Science Council B.C., Technology BC Grant.

Scaife, M. A., Burton, A. K., and Turner, M. K. (1980) Cavity spot of carrots - an association with soil ammonium. *Communications in Soil Science and Plant Analysis* **11**, 621-628.

Scaife, M. A., Turner, M. K., Barnes, A., and Hunt, J. (1983). Cavity spot of carrots- observations on a commercial crop. *Annals of Applied Biology* **102**, 567-75.

Schrandt, J. K., Davis, R. M., and Nunez, J. J. (1994). Host range and influence of nutrition, temperature, and pH on growth of *Pythium violae* from carrot. *Plant Disease* **78**, 335-38.

Shlevin, E., Ben-Nun, R., Tzror, L., Nachmias, A., and Ohali, I. (1987). Reduction of 'cavity spots' in carrots by Ridomil applications. *Hassadeh* **67** (11), 2272-74. (Abst).

Stanghellini, M. E., and Tomlinson, J. A. (1987). Inhibitory and lytic effects of a nonionic surfactant on various asexual stages in the life cycle of Pythium and Phytophthora species. *Phythopathology* **77**, 112-14.

Stapleton, J. J., and DeVay, J. E. (1986). Soil solarisation: a non-chemical approach for management of plant pathogens and pests. *Crop Protection* **5**(3), 190-98.

Stapleton, J. J., Quick, J., and DeVay, J. E. (1985). Soil solarisation: effects on soil properties, crop fertilization, and plant growth. *Soil Biology and Biochemistry* **17**(3), 369-73.

Sumner, D. R., and Phatak., S. C. (1988). Efficacy of metham sodium applied through overhead sprinkler irrigation for control of soilborne fungi and root diseases of vegetables. *Plant Disease* **72**, 160-66.

Sweet, J. B., Lake, S. E., Wright, I. R., and Priestley, R. H. (1986). Resistance of carrot varieties to cavity spot disease. *Aspects of Applied Biology* **12**, 235-45.

van der Plaats-Niterink, A. J. (1981). Monograph of the Genus *Pythium*. *Studies in Mycology* No. 21. Centraalbureau voor Schimmelcultures, Baarn, The Netherlands.

Vivoda, E., Davis, R. M., Nunez, J. J. and Guerard, J. P. (1991). Factors affecting the development of cavity spot of carrot. *Plant Disease* **75**, 519-22.

Walker, G. (1988). Control of carrot cavity spot with metalaxyl and phosphorous acid. *Australasian Plant Pathology* **17**, 41-44.

Walker, G. (1991). Effect of metalaxyl and phosphonate on incidence of cavity spot in carrots. *Australasian Plant Pathology* **20**, 21-26.

Watanabe, T., Nagai, Y., and Fukami, M. (1986). Brown-blotted root rot of carrots in Japan (2) Culture and identification. *Annals of the Phytopathology Society of Japan* **52**, 287-91.

Waterhouse, G. M. (1967). Key to *Pythium* Pringsheim. *Mycological Papers, Commonwealth Mycological Institute, Kew* **109**, 1-15.

Wheatley, G. A., Hardman, J. A., and Edmonds, G. H. (1986). Effects of metalaxyl and carbofuran in a fluid-drilling gel on cavity spot incidence and the yield of carrots. *Annals of Applied Biology Supplement* **109**, 38-39.

White, J. G. (1986). The association of *Pythium* spp. with cavity spot and root dieback of carrots. *Annals of Applied Biology* **108**, 265-73.

White, J. G. (1988). Studies on the biology and control of cavity spot of carrots. *Annals of Applied Biology* **113**, 259-68.

White, J. G. (1988). Studies on the biology and control of cavity spot of carrots. *Annals of Applied Biology* **113**, 259-68.

White, J. G., Stanghellini, M. E., and Ayoubi, L. M. (1988). Variation in the sensitivity to metalaxyl of *Pythium* spp. isolated from carrot and other sources. *Annals of Applied Biology* **113**, 269- 77.

6. EVALUATION OF FUNGICIDES FOR LEAF BLIGHT CONTROL IN CARROTS

A. Galati and A. G. McKay

EVALUATION OF FUNGICIDES FOR LEAF BLIGHT CONTROL IN CARROTS

Summary

Leaf blight of carrots is usually caused by the fungal pathogen *Alternaria dauci*. Mechanical harvesting is often hampered when leaves are affected by blight. The commercial survey found leaf blights to be present in most crops during the year, but were most severe in autumn and winter. Leaf spot (*Cercospora carotae*) was found affecting crops during summer but was much less common and damaging than Alternaria. The objective of these experiments was to determine the best possible fungicide or fungicide combinations that the industry may adopt for leaf blight control of carrots. In addition, evaluations were carried out seeking blight tolerant varieties.

Major results

- Difenoconazole (Score®) sprayed at fortnightly intervals, or the combination of chlorothalonil (Bravo®,Rover®)/mancozeb, alternated weekly reduced leaf blight and increased yields by over 150 % compared to unsprayed blight infected crop.
- Dicarboximide fungicides, such as iprodione (Rovral®) vinclozolin (Ronilan®) and procymidone (Sumisclex®) proved ineffective against carrot leaf disease.
- The failure of iprodione (Rovral®) was somewhat surprising because of its reported efficacy against Alternaria. Symptom expression on carrot leaves was consistent with Alternaria however, Cercospora was also identified on leaves. Rovral® may have failed because it was ineffective against Cercospora.
- Timing of sprays at first sign of disease was important for effective disease control. Post-infection sprays of fungicides did give some control of blight, however, fungicides were much more effective when applied at first sign of disease.
- Score® was effective in reducing the severity of scab disease in one experiment.
- Several varieties (Bolero, SPS 567) showed good blight tolerance, compared to the commercial standard Top Pak.
- The commercial crop survey identified the presence of both *A. dauci* and *C. carotae* during the year.

Recommendations

(a) Extension/adoption by industry

Results from these experiments were presented at an industry seminar held in November 1992. A field walk to view a blight experiment (92MD21) was held on Medina Research Centre to show differences in fungicide efficacy. Sumich Group personnel were also shown the benefit of timely blight control programs on their crops (92PE53, 92PE40). Differences in varietal blight tolerance were demonstrated in the field to growers. A press release was circulated to major industry magazines on the importance of timing of first sprays. A farmnote on blight control in carrots was published and an article on blight control was included in a Carrot Association for Research and Development (CARD) newsletter.

(b) Directions for future research

The fungicide Score, could be registered for use on carrot crops, as Ciba Geigy have been supplied with efficacy data. 'Wetters' or 'stickers' which enable better coverage of fungicide on leaf surfaces could be evaluated with fungicides. Continued evaluation of blight tolerant Nantes varieties is required. The adoption of a blight tolerant Nantes carrot to replace commercial variety would lead to a substantial reduction in chemical use.

(c) Financial/commercial benefits

An integrated management program for blight, including effective blight fungicides and the use of blight tolerant varieties are required by industry. A loss in gross income may occur if no or ineffective blight control took place within a crop. For instance, based on results of 92PE40, chlorothalonil alternated with mancozeb produced an export yield of 64 t/ha. The export yield in the unsprayed plots was 24 t/ha. At a price of $0.25 per kg the gross return for carrots sprayed with Bravo/Mancozeb is $16,000 and only $6,000 in the unsprayed plots. The increase in gross return is $10,000, with a chemical cost of $367/ha.

EVALUATION OF FUNGICIDES FOR LEAF BLIGHT CONTROL IN CARROTS

Introduction

Western Australia is the largest exporter of carrots (*Daucus carota*) in Australia. More than 23 000 tonnes were exported during 1991/92 valued at over $12 million. All of this production is located on the sandy soils of the Swan Coastal Plain.

Leaf diseases are important in carrots in Western Australia. Leaf blight (causal organisms *Alternaria* spp.) and leaf spot (*Cercospora carotae*) can weaken leaves, and in severe cases, defoliate the crop. Mechanical harvesting is hampered when leaves are weakened by blight.

A survey of 202 commercial carrot crops found that leaf blights were present in most crops at most times, but were most severe in autumn and winter. The most prevalent fungus at these times of the year was *Alternaria dauci* that often caused severe defoliation. *C. carotae* was commonly found in summer but did not seriously defoliate crops. Growers were not achieving satisfactory control of leaf blight, particularly with the recently adopted hybrid Nantes varieties grown for export (McKay and Galati 1992).

The aim of this series of experiments was to determine the best fungicides or fungicide combinations to control leaf blight of carrots.

1. Experiment 92PE40 - Evaluation of fungicides for control of carrot leaf blight

Aim

The objective of this experiment was to compare a range of fungicides for their effectiveness in controlling leaf blight of carrots on a commercial property.

Materials and Methods

A site was chosen at a commercial carrot growers property, 40 km south of Perth, with a history of leaf blight. Double superphosphate (0.3 t/ha), muriate of potash (0.15 t/ha) and lime sand (5 t/ha) were broadcast and incorporated by rotary hoe across the site.

The Nantes carrot variety Top Pak (South Pacific Seeds) was used because it is the major commercial variety. Pelleted seed was sown on 1 May 1992 with an Agricola Italia® air seeder in 5 double rows per 1.92 m bed. Plots were 6 m long.

Linuron®, Trifluralin® and Gesagard® (prometryne) were applied when necessary to control weeds. The equivalent of 107 kg N /ha, 70 kg P/ha and 161 kg K/ha were applied over the life of the crop.

The experiment was designed so that sprayed plots were spatially separated by an unsprayed bed of crop. This placed sprayed plots under high disease pressure. There were 12 treatments including two unsprayed controls. Treatments were arranged in a randomised block design with 5 replicates. Table 1 lists the fungicides, rate per hectare, spray interval and number of sprays applied in the experiment.

Table 1. Rate per hectare, formulation, spray interval and number of sprays for each fungicide treatment

Treatment ®	Spray interval (days)	Active ingredient	Rate per hectare	Number of sprays
Bravo	14	500 g/ L chlorothalonil	2.6 L	6
Kocide	14	500 g/kg copper as cupric hydroxide	2.0 kg	6
Mancozeb	7	750 g/kg mancozeb	2.2 kg	12
Mancozeb	14	750 g/kg mancozeb	2.2 kg	6
Ronilan	14	500 g/L vinclozolin	1.0 L	6
Rovral	14	250 g/L iprodione	2.0 L	6
Sumisclex	14	275 g/L procymidone	0.5 kg	6
Score	14	250 g/L difenoconazole	0.5 L	6
Bravo/Mancozeb	A			6+6
Rovral/Mancozeb	A			6+6

[A]alternated at 7 day intervals at rates as per single chemical treatment

The first spray was applied 76 days after sowing (DAS). All sprays were applied with a Hardi® back pack with modified hand held mini boom with 5 cone jets. The output at 1 bar was equivalent to 356 L/ha. Each plot was covered twice to achieve a final water volume of 712 L/ha. A wetting agent (Monsoon®), was required only for Sumisclex® and was applied according to label specifications. Most fungicides (Table 1) were sprayed at fortnightly intervals to give a total of 6 sprays over the life of the crop. Mancozeb was also applied weekly to give a total of 12 sprays over the life of the crop. The combinations of Bravo/Mancozeb and Rovral/Mancozeb were alternated weekly so that for example, in the Bravo/Mancozeb treatment, Bravo was sprayed one week then Mancozeb the next.

Twenty leaves (oldest non-senescent leaves) were selected from plots at random 111 DAS (19 August 1992) and 164 DAS (12 October 1992, harvest). Each leaf was scored according to the following rating scheme :

1 = less than 1 % leaf area affected,
2 = 2 - 5 % leaf area affected,
3 = 6 to less than 20 % leaf area affected,
4 = 21 to 40 % leaf area affected with some chlorotic leaves,
5 = greater than 40 % leaf area affected, usually chlorotic and stem lesions present.

Each plot was then given a mean blight score (MBS) :

$$= \frac{\Sigma\text{(rating x number of leaves at that rating)}}{\text{total number of leaves}}$$

Each plot was rated visually at regular intervals (111, 124, 130, 139, 152 and 164 DAS). The rating system was as follows:

1 = no blight present,
2 = some blight present,
3 = moderate blight,
4 = severe blight,
5 = very severe blight, crop defoliated.

At harvest maturity (12 October 1992, 164 DAS), 3 m of row from the middle three rows of each 6 m plot were hand harvested, washed and weighed. The samples were graded into:

export yield (25 to 50 mm crown diameter and greater than 150 mm length); marketable short (25 to 50 mm crown diameter and 100 to 150 mm length); undersized (less than 25 mm crown diameter and less than 100 mm length); oversized (more than 50 mm crown diameter); forked and other (misshapen and split). Each sample was regraded and on the second grading they were categorised for the diseases, cavity spot and scab, which were present in the crop at low levels. Leaves were also weighed. Ten plants were sampled at random from each plot to determine the average number of leaves per plant at harvest.

Samples of infected leaves were taken from the crop for pathogen identification. Leaves were placed on moist filter paper in petri dishes. The petri dishes were incubated under natural light at room temperature to induce sporulation.

The results were analysed by analysis of variance using GENSTAT software.

Results

The Bravo/Mancozeb and Score treatments produced the highest total yields at 96 and 93 t/ha respectively. Total yield in the Bravo/Mancozeb plots was 57 % greater than in the unsprayed treatment (Table 2). Score and Bravo/Mancozeb fungicides produced the highest export yields. Ronilan, Rovral, Sumisclex and untreated plots had the lowest export yields (Table 2). Export yield in the Bravo/Mancozeb plots was 168 % more than in unsprayed treatments. Carrots that are classed as marketable short are usually sold on the local market. The yield of marketable shorts was significantly higher in the unsprayed, Kocide, Mancozeb 7, Ronilan, Rovral and Sumisclex treatments (Table 2).

There was significant differences in the leaf yield ($P<0.001$) across fungicide treatments (Table 2). The combination of Bravo/Mancozeb, Bravo, Score and Kocide produced higher leaf yield compared with other fungicide sprays.

Table 2. The effect of fungicides on the leaf yield, total yield, export yield and yield of marketable shorts for Top Pak carrots harvested on 12 October 1992

Treatment	Leaf yield (t/ha)	Total yield (t/ha)	Export yield (t/ha)	Marketable short yield (t/ha)
Bravo 14	10.3	83.1	48.7	24.4
Kocide 14	10.6	78.2	37.4	31.3
Mancozeb 14	9.9	83.6	50.7	23.0
Mancozeb 7	11.8	82.9	43.6	30.9
Ronilan 14	5.9	58.8	22.4	30.3
Rovral 14	6.8	63.3	25.2	30.0
Score 14	11.9	92.7	60.9	23.9
Sumisclex 14	5.8	59.4	26.4	26.6
Bravo/Mancozeb	12.0	95.6	63.7	21.5
Rovral/Mancozeb	9.8	79.5	43.3	31.1
Unsprayed	6.3	60.8	23.8	29.9
Significance	***	***	***	**
l.s.d (P=0.05)	1.76	8.75	9.72	6.39

*** = P<0.001, ** = P<0.01.

The categories of rejects are listed in Table 3. The percentage of forking across the site was less than 2 %, with no differences between treatments. Other rejects (eg misshapen and split) were similar across treatments. Ronilan, Rovral, Sumisclex, Rovral/Mancozeb and unsprayed treatments had less than 2 % of yield classed as oversized. The remaining treatments, with better blight control, had significantly higher proportion of oversized carrots. Ronilan, Rovral and Sumisclex and unsprayed treatments had a larger proportion of undersized carrots (Table 3).

Table 4 shows the effect of fungicides on blight severity over time. At harvest, plots treated with Score or the combination of Bravo/Mancozeb had significantly less disease compared to other treatments.

Table 3. The effect of fungicides on percentage of rejects (expressed as a % of the total yield) of Top Pak carrots harvested on 12 October 1992

Treatment	Undersize (%)	Oversize (%)	Forked (%)	Other[A] (%)
Bravo 14	2.1	6.0	3.1	0.9
Kocide 14	4.3	4.6	2.2	0.9
Mancozeb 14	5.4	2.9	2.9	0.7
Mancozeb 7	2.1	4.7	2.9	0.4
Ronilan 14	8.6	0.6	1.2	0.2
Rovral 14	10.3	0	1.9	0.5
Score 14	4.5	2.9	0.6	0.5
Sumisclex 14	7.7	1.6	1.0	0.5
Bravo/Mancozeb	2.7	6.8	1.4	0.4
Rovral/Mancozeb	3.8	0.4	1.4	0.7
Unsprayed	6.5	2.3	2.3	0.5
Significance	***	**	ns	ns
l.s.d (P=0.05)	3.81	4.28	-	-

[A]misshapen, split

Table 4. Effect of fungicides on visual blight ratings over time for Top Pak carrots

	Days after sowing					
Treatment	111	124	130	139	152	164
Bravo 14	2.7	2.4	2.4	2.8	2.4	2.1
Kocide 14	2.4	2.8	3.4	3.6	3.1	2.3
Mancozeb 14	2.3	2.7	3.0	3.0	3.3	2.7
Mancozeb 7	2.5	2.3	2.3	2.9	2.4	2.1
Ronilan 14	3.3	3.4	3.7	4.0	4.1	3.8
Rovral 14	2.9	3.2	3.8	3.8	3.9	3.5
Score 14	2.3	1.8	2.2	2.2	1.8	1.4
Sumisclex 14	3.1	3.3	3.7	4.0	3.9	4.0
Bravo/Mancozeb	2.0	1.8	1.6	1.7	1.5	1.4
Rovral/Mancozeb	2.3	2.8	2.8	2.7	2.9	3.2
Unsprayed	3.3	3.8	4.0	4.5	4.2	4.6
Significance	***	***	***	***	***	***
l.s.d (P=0.05)	0.51	0.52	0.64	0.64	0.53	0.51

The number of leaves per plant at harvest was determined to compare leaf loss between treatments. Score, Bravo/Mancozeb, Bravo, Kocide and Mancozeb 7 had a significantly higher number of leaves at harvest compared to other treatments, including unsprayed plots (Table 5).

Mancozeb 14, Ronilan, Rovral, Sumisclex and unsprayed plots had higher mean blight scores over both sampling times. All treatments, except the Bravo/Mancozeb and Score showed increased blight scores from 111 to 164 DAS (Table 5).

Table 5. Effect of fungicides on mean blight scores for Top Pak carrots at 111 and 164 DAS and number of leaves per plant at 164 DAS

Treatment	111 DAS Blight score	164 DAS Blight score	164 DAS Leaves/plant
Bravo 14	3.0	3.6	8.4
Kocide 14	3.5	3.5	8.2
Mancozeb 14	3.6	4.4	7.4
Mancozeb 7	3.5	3.9	8.9
Ronilan 14	3.6	4.5	6.1
Rovral 14	3.5	4.4	6.9
Score 14	3.2	3.1	9.0
Sumisclex 14	3.9	4.5	6.2
Bravo/Mancozeb	3.2	2.6	9.2
Rovral/Mancozeb	3.4	4.3	8.0
Unsprayed	4.0	4.3	6.7
Significance	***	***	***
l.s.d (P=0.05)	0.43	0.60	1.11

Mild symptoms of scab disease were detected at this site but did not seriously affect marketability of the crop. There were significant differences (P<0.001) among fungicide treatments in the incidence of scab. Carrots treated with Score had a significantly lower incidence of scab compared to all other treatments (Table 6). Only 2% of yield was affected by scab in the Score treated plots compared to 33 % in unsprayed plots.

There were no significant differences among fungicide treatments for cavity spot incidence in the crop. Symptoms were very mild with an average of 6 % of the total yield affected.

Plant densities were not affected by fungicide treatments. The average density across all treatments was 71 plants/m^2.

Table 6. Effect of fungicides on the incidence of scab (expressed as a % of the total yield) for Top Pak carrots harvested on 12 October 1992

Treatment	Scab (% of total yield)
Bravo 14	33.4
Kocide 14	21.4
Mancozeb 14	38.2
Mancozeb 7	34.5
Ronilan 14	27.5
Rovral 14	28.8
Score 14	2.2
Sumisclex 14	36.8
Bravo/Mancozeb	35.9
Rovral/Mancozeb	35.4
Unsprayed	32.6
Significance	***
l.s.d (P=0.05)	13.74

Discussion

Bravo/Mancozeb or Score alone provided excellent control of carrot leaf blight and produced significantly higher total and export yield compared to other fungicide treatments or unsprayed plots. Bravo, Kocide and Mancozeb at either 7 or 14 days were the next best treatments. The fungicides Ronilan, Rovral, Sumisclex and the Rovral/Mancozeb combination failed to control blight.

The results of this experiment show that failure to adequately control blight can result in large reductions in yield. In this experiment, Ronilan and Sumisclex at 14 days intervals were ineffective against leaf blight. Carrot producers should not include such fungicides in a regular spray program against leaf blight.

Score (Ciba Geigy Pty Ltd) is a triazole fungicide that is commercially available for early blight control in potatoes. Score applied every 14 days was as effective as the Bravo/Mancozeb treatment that received a weekly fungicide application. In addition Score was more active than Bravo at fortnightly intervals and Score was also the only chemical that controlled the low level of scab.

The possibility of registering Score for use on carrots needs to be considered. The activity of Score against scab disease needs to be confirmed. The symptoms of scab have been reported to be caused by *Alternaria radicina* and *A. dauci* and can develop from seed contamination of these pathogens (Grogan and Snyder 1952). Under field conditions in Western Australia, *Fusarium* spp. were regularly isolated from scab lesions. Score reduced the incidence of scab. However it is reported as being only weakly systemic in plants.

The experiment showed that under high disease pressure applying effective fungicides at regular intervals is an integral part of disease control. Gillespie and Sutton (1979) suggest applying the first spray when 1 in 4 from 50 sampled leaves were affected by blight. Our observations suggest that for blight susceptible varieties under high disease pressure, waiting until this stage may be too late. Under these circumstances a blight control program should commence at the first sign of disease.

The failure of Rovral alone or in combination with Mancozeb in this experiment could possibly be because *Cercospora carotae* was also present and that Rovral failed to control it. Disease symptoms at the site were however consistent with Alternaria infection and the failure of Rovral therefore remains unexplained.

Varietal tolerance to leaf blight has been evaluated in many countries (Angell and Gabelman 1968; Strandberg *et al.* 1972; Lebeda *et al.* 1988). Varietal screening for disease tolerance in Western Australia has identified promising Nantes varieties with high levels of Alternaria tolerance that, if commercially suitable, could reduce the requirement of fungicidal blight control programs.

The current recommendation for carrot blight control under conditions of high disease pressure is to spray the alternating combination of Bravo and Mancozeb at 7 day intervals from the first sign of disease. Kocide could be substituted for Mancozeb on properties that have high crop manganese levels.

---

2. Experiment 92MD21 - Control of advanced stage of carrot leaf blight infection with fungicide sprays

Aim

The objective of this experiment was to compare the efficacy of fungicide combinations in a crop that was already seriously infected by leaf blight prior to fungicide programs commencing.

Materials and Methods

The trial was conducted at the Medina Research Centre, 40 km south of Perth. Double superphosphate (0.5 t/ha), muriate of potash (0.15 t/ha) and 0.15 t/ha of a trace element mix were broadcast and incorporated by rotary hoe across the site. Nemacur ® (fenamiphos) was applied to the site at a rate of 24 L/ha for nematode control.

Pelleted seed of the Nantes carrot variety Top Pak (South Pacific Seeds) was sown on 19 June 1992 with an Agricola Italia® precision seeder with 5 single rows per 1.5 m bed. Plots were 6 m long.

Gesagard® (prometryne) was applied to control weeds. A total of 790 kg/ha of urea, 440 kg/ha of muriate of potash and 220 kg/ha of magnesium sulphate was applied over the life of the crop.

The experiment was designed such that treated plots were separated by an unsprayed bed of carrots 1.5 m wide on either side and 1.0 m of unsprayed carrots on the end of treatment plots. This placed sprayed plots under high disease pressure. There were 12 treatments including two unsprayed controls. Treatments were arranged in a randomised block design with 6 replicates. Table 7 lists the fungicides, application rates, spray interval and number of sprays applied in the experiment.

Carrot leaves with typical *Alternaria dauci* lesions were collected from a commercial carrot crop. A subsample was taken for pathogen identification in the laboratory. Leaves were macerated and evenly distributed across the site on 20 August 1992 (62 days after sowing [DAS]).

The first spray was applied 110 DAS. In this experiment the level of infection in the crop was severe with a minimum of 3 in 4 leaves heavily affected by blight before the first treatment sprays were applied.

Table 7. Product rate, formulation, spray interval and number of sprays for each fungicide treatment

Treatment ®	Spray interval (days)	Active ingredient	Product rate per hectare	Number of sprays
Bravo	7	500 g/L chlorothalonil	2.6 L	6
Kocide	7	500 g/kg copper as cupric hydroxide	2.0 kg	6
Mancozeb	7	750 g/kg mancozeb	2.2 kg	12
Bravo	14	500 g/L chlorothalonil	2.2 L	6
Rovral	14	250 g/L iprodione	2.0 L	6
Score	14	250 g/L difenoconazole	0.5 L	6
Bravo/Mancozeb	A			6+6
Rovral/Mancozeb	A			6+6
Bravo/Kocide	A			6+6
Bravo + Synertrol Oil	14			6

[A]alternated at 7 day intervals at rates as per single chemical treatment

Sprays were applied with a plot sprayer. The output at 1 bar was equivalent to 383 L/ha. Each plot was covered twice to achieve a final water volume of 766 L/ha. Fungicides were sprayed at fortnightly intervals so that 6 sprays were applied over the life of the crop. Bravo, Kocide and Mancozeb were also applied weekly so that 12 sprays were applied over the life of the crop. The combinations of Bravo/Mancozeb, Rovral/Mancozeb and Bravo/Kocide were alternated weekly so that for example, in the Bravo/Mancozeb treatment, Bravo was sprayed one week, then Mancozeb the next. In an additional treatment, Synertrol Oil, a vegetable oil based wetting agent was also applied at fortnightly intervals with Bravo (Table 7).

Each plot was rated at harvest maturity for blight. The rating system was as follows:

1 = no blight present,
2 = some blight present,
3 = moderate blight,
4 = severe blight,
5 = very severe blight, crop defoliated.

At harvest maturity (24 November 1992, 158 DAS), 3 metres of row from the middle three rows of each 6 metre plot were hand harvested, washed and weighed. The samples were graded into: export yield (25 to 50 mm crown diameter and greater than 150 mm length); marketable short (25 to 50 mm crown diameter and 100 to 150 mm length) and rejects (undersized, forked). Leaves were also weighed from each plot.

Samples of infected leaves were taken from the crop for pathogen identification. Leaves were placed on moist filter paper in petri dishes. The petri dishes were incubated under natural light at room temperature to induce sporulation. The results were analysed by analysis of variance using GENSTAT software.

Results

All fungicides treatments produced higher yields compared to the control treatment (Table 8). The total yield was over 80 t/ha across treatments. Total yields were highest in the Kocide 7, Bravo 14, Score 14, Bravo/Mancozeb, Bravo and Synertrol and Bravo/Kocide treatments. The export yield was highest in the Score 14 and Bravo/Mancozeb treatments. The yield of marketable shorts was lowest in the Score 14 and Bravo/Mancozeb treatments (Table 8).

Bravo sprayed every 14 days was as effective as Bravo at 7 days and the Bravo/Mancozeb fungicide combination. In a situation where leaf infection had already taken place, a spray interval of 7 days did not lead to a further improvement in yield. The treatment of Synertrol Oil plus Bravo did not produce significantly better yields than Bravo sprays at 14 day intervals (Table 8).

The leaf yield was significantly different across fungicide treatments (Table 8). Leaf yield was lowest in the unsprayed plots, Rovral/Mancozeb, Rovral 14 and Mancozeb 7 treatments. Visual blight ratings are a measure of disease severity and in this experiment blight were most severe in the unsprayed plots, Rovral/Mancozeb and Rovral 14 treatments. Bravo plus Synertrol Oil, Score 14, Bravo 7, Bravo 14, Bravo/Mancozeb had the lowest blight ratings at harvest.

The major cause of rejection on this site was forking and undersized carrots and ranged among 6 and 18 t/ha among treatments. Planting density was not affected by fungicide sprays. The average density was 81 plants/m^2.

Table 8 Effect of fungicides on leaf yield, visual blight rating, total yield, export yield, marketable short yield and rejects at harvest for the variety Top Pak

Treatment ®	Leaf yield (t/ha)	Visual blight rating	Total yield (t/ha)	Export yield (t/ha)	Marketable short yield (t/ha)	Rejects[A] (t/ha)
Bravo 7	10.5	2.3	93.7	67.5	9.4	16.8
Kocide 7	11.5	2.7	100.1	77.9	9.3	12.9
Mancozeb 7	8.4	2.8	88.7	66.7	5.8	16.2
Bravo 14	11.2	2.3	98.0	75.6	7.0	15.4
Rovral 14	9.8	3.9	91.1	73.8	10.8	6.5
Score 14	12.9	2.1	106.8	91.0	5.7	10.1
Bravo/Mancozeb	11.6	2.0	98.0	86.2	4.4	7.4
Rovral/Mancozeb	8.8	3.7	82.5	64.5	7.8	10.2
Bravo/Kocide	11.2	2.3	97.1	74.3	8.8	14.0
Bravo 14 + Synertrol	12.3	1.8	98.4	70.3	9.9	18.2
Unsprayed	8.5	4.2	84.1	61.8	7.4	14.9
Significance	***	***	**	*	*	*
l.s.d (P=0.05)	1.73	0.6	11.9	16.8	3.8	8.0

[A]includes undersized and forking as major rejects

Discussion

The first fungicide spray was not applied until blight was well advanced in this crop. Fungicides active against leaf blight did not work as effectively once heavy infection had taken place. Bravo/Mancozeb, Score, Bravo 14, Kocide 7 and Bravo/Kocide gave reasonably good disease control in this situation. However in previous experiments (92PE40), when the first spray was applied at the first sign of disease, these fungicides were more effective against blight. Most of the fungicides and/or combinations of fungicides provided some control. The combinations of Rovral and Rovral/Mancozeb were not as effective against blight under high disease pressure. The failure of Rovral in this experiment could be because *Cercospora carotae* was also present in the crop. Disease symptoms, were, however, consistent with Alternaria infection.

Early sprays would reduce the spread of early infections before they became widespread and before dense plant canopies prevent good spray coverage.

Fungicide sprays such as Bravo/Mancozeb, Bravo 14, Bravo/Kocide gave adequate disease control under conditions of high disease pressure. Ideally carrot blight spray programs would be more effective if sprays were applied at the first sign of disease.

3. Experiment 91MD12 - Control of carrot leaf blight by scheduled and weather timed fungicide applications

Aim

Sutton and Gillespie (1979) found that the number of fungicide sprays applied to control carrot blight was reduced to among 1 to 4 per crop (compared to 5 to 7 sprays in a normal spray program) by withholding sprays until weather conditions were favourable for blight development.

The objectives of this experiment were to :
i) compare the efficacy of currently registered chemicals to some alternatives for blight control.
ii) compare the efficacy of two fungicides, Bravo® and Score® under weather timed and scheduled spray conditions in an attempt to reduce the number of sprays required to control leaf blight.

Materials and Methods

A site was chosen at the Medina Research Centre with no recent history of carrots. The soil type was a Spearwood sand with a soil pH (1:5 water) 7.66, bicarbonate extractable phosphorus of 160 mg/kg, bicarbonate extractable potassium of 54 mg/kg and organic carbon content of 0.71 %.

Superphosphate (1 t/ha), muriate of potash (120 kg/ha), magnesium sulphate (50 kg/ha) and 100 kg/ha of a trace element mixture were broadcast and incorporated by rotary hoe across the site. Nemacur® (fenamiphos) was applied at a rate of 24 L/ha for nematode control.

Pelleted seed of the Nantes carrot variety Top Pak (South Pacific Seeds) was sown on 19 April 1991 with a Stanhay® precision seeder with 5 single rows per 1.5 m bed. Plots were 6 m long.

Linuron® (linuron) was applied across the site at a rate of 1 kg/ha in 200 L water after seeding to control weeds. Some thinning of seedlings was required 38 days after sowing (DAS).

A total of 750 kg/ha urea, 400 kg/ha muriate of potash and 150 kg/ha of magnesium sulphate was applied in 10 equal fortnightly dressings commencing at 33 DAS. The crop was irrigated from overhead sprinklers at 140 % Class A pan evaporation applied in two applications per day when pan evaporation exceeded 5 mm per day.

Carrot leaves, infected with the fungus *A. dauci* were collected from a commercial carrot crop, macerated and evenly distributed across the site 91 DAS.

The experiment was designed so that the unsprayed plots were separated (30 m) from the treated plots. This was done to reduce the effect of variable inoculum load from treated plots onto unsprayed (control) plots.

Each of the six replicates blocks were separated by an empty 1.5 m bed to minimise disease spread between plots. There was a 1 m buffer on either end of each plot within a replicate block. Table 9 lists the details of treatments applied.

All plots were sprayed at 111 DAS when 1 in 4 leaves (25 %) from 50 leaves (blight severity of 1-2 %) were found to have even the slightest sign of blight infection. The time interval between sprays was dependant on label recommendations ie 7 to 14 day intervals. Weather timed treatments were sprayed only when the environmental conditions were suitable for blight development according to Sutton and Gillespie (1979). When blight severity was 1 to 2 %, fungicides were applied before forecast rain or before the next night when the forecasted minimum temperature was 16°C or higher. The minimum interval between sprays was 10 days.

Table 9. Fungicide treatments, application rate, active ingredient, application times and number of sprays used in this experiment

Treatment	Fungicide ®	Active ingredient	Application rate	Application times	Number of sprays
Schedule (S)	Mancozeb	mancozeb	2.3 kg/ha	111, 119, 126, 133, 143 and 150 DAS[A]	6
Schedule (S)	Ronilan	vinclozolin	1.0 kg/ha	111, 126, 133, 143 and 150 DAS	5
Schedule (S)	Rovral	iprodione	1.0 kg/ha		
Schedule (S)	Sumisclex	procymidone	0.5 kg/ha		
Schedule (S)	Bravo	chlorothalonil	1.7 kg/ha		
Schedule (S)	Score	difenoconazole	0.5 L/ha		
Weather (W)	Bravo	chlorothalonil	1.7 kg/ha	111, 123, 137 and 150 DAS	4
Weather (W)	Score	difenoconazole	0.5 L/ha		

[A]DAS = days after sowing

Twenty leaves (oldest-non senescent leaves) were randomly selected from plots on August 18 and 28 and September 2, 9, 16 and 23 (121, 131, 136, 143, 150 and 157 DAS) and rated for blight. Data is presented for 157 DAS only (harvest).

Each leaf was scored according to the following rating scheme :

1 = less than 1 % leaf area affected,
2 = 2 - 5 % leaf area affected,
3 = 6 to less than 20 % leaf area affected,
4 = 21 to 40 % leaf area affected with some chlorotic leaves,
5 = greater than 40 % leaf area affected, usually chlorotic with stem lesions present.

Each plot was then given a mean blight score (MBS) :

$$= \frac{\Sigma(\text{rating x number of leaves at that rating})}{\text{total number of leaves}}$$

A growth measurement of the experiment was required to allow covariate analysis because control plots were spatially separated from treated plots. On 20 June 1991 (62 DAS) one metre by three middle rows were sampled from each plot (0.5 m from either end of the plot). Roots and leaves were weighed. The growth measurement was completed prior to inoculation with infected leaves.

At harvest maturity (23 September 1991, 157 DAS), the middle three rows by four metres of each five metre plot was hand harvested, washed and weighed. The samples were graded into total marketable (25 to 50 mm crown diameter and greater than 100 mm length) and rejects (includes forked, undersized, split and misshapen carrots). Leaves (fresh) were also weighed and leaf yield (tonnes per hectare) was calculated.

Differences between unsprayed and treated plots were tested using an analysis of covariance with the growth measurement at 62 DAS as the covariate using GENSTAT version 5 software.

Temperature (°C minimum and maximum) and rainfall (mm) data was recorded on a weather station situated less than 100 m from the site (Table 11).

Results

All fungicides used in this experiment produced higher leaf yields, total and marketable yields than the unsprayed plots (Table 10).

Score W, Bravo W, Score S, Bravo S and Mancozeb S treatments produced the highest total yields, marketable yields, leaf yields and had the lowest mean blight scores (Table 10). Unsprayed treatments had the lowest total yield at 53 t/ha. The unsprayed plots had 70 % less marketable yield compared to the Bravo S treatment. Ronilan S, Sumisclex S and unsprayed plots produced the lowest marketable yields. Rovral S, Ronilan S, Sumisclex S and the untreated plots had high mean blight scores at harvest.

In this experiment, Score (a triazole fungicide) was as effective as Bravo against leaf blight under weather timed or scheduled conditions. Mancozeb was also effective against blight, but was applied weekly compared to other treatments.

Table 10. Effect of fungicides on leaf yield, total and marketable yield, total rejects and mean blight score at harvest maturity (157 DAS) for Top Pak carrots. Data adjusted by covariance analysis. S = scheduled sprays, W = weather timed sprays.

Treatment ®	Leaf yield (t/ha)	Total yield (t/ha)	Marketable yield (t/ha)	Total rejects (t/ha)	Mean blight score (157 DAS)
Mancozeb S	6.2	66.5	59.7	6.8	3.1
Ronilan S	5.1	62.1	54.8	7.3	3.6
Rovral S	5.4	64.1	59.0	5.1	3.3
Sumisclex S	5.9	63.6	58.0	5.6	3.3
Bravo S	5.9	67.1	62.3	4.8	3.0
Score S	5.6	66.5	60.8	5.7	2.7
Bravo W	5.4	66.6	60.8	5.8	3.1
Score W	6.3	69.0	62.1	6.9	3.2
Unsprayed	4.1	53.5	43.6	9.9	3.7
Significance	***	***	***	***	*
l.s.d (P=0.05)	0.7	4.2	4.0	3.4	0.49

*** = P<0.001, * = P<0.05

The major categories of rejection were forking, undersized, splitting and misshapen carrots. The unsprayed treatments produced nearly 10 t/ha of rejects, but this was not significantly different to Mancozeb S, Ronilan S or Score W. Planting density was not affected by fungicide treatments and averaged 65 plants/m^2.

Discussion

The was no differences in yield between the scheduled and weather timed spray regime for either Bravo or Score. There was only a difference of one spray between schedule and weather timed sprays and application times were similar, because of the high incidence of rainfall during the latter stages of crop development (Table 11). Gillespie and Sutton (1979) found 1-5 fewer spray applications were required than in regular schedules. The difference would depend on seasonal variation.

The Gillespie and Sutton (1979) prediction scheme for blight was dependant on *A. dauci* infection indices. Infection by *A. dauci* is a function of surface wetness duration and mean air temperature during the wetness period. Under local conditions, the wetness of the leaf is due to both rainfall and overhead irrigation. If rainfall is inadequate then overhead irrigation is required. The second criteria is to spray when the forecast minimum is more than 16°C. During this experiment there was no nights with a forecast minimum of more than 16°C. It was an extremely cold season and the average minimum temperature was 8.5°C (Table 11). It is difficult to use weather timed sprays in Western Australia because of our reliance of overhead irrigation in winter on light textured soils with low water holding capacity.

Table 11. Minimum, maximum temperature and rainfall data from 104 DAS until harvest maturity (157 DAS) for the experiment

Date	Days after sowing	Minimum (°C)	Maximum (°C)	Rainfall (mm)
Aug 1	104	13.5	18.7	14.0
2	105	9.8	16.7	15.3
3	106	15.5	18.5	7.0
4	107	15.5	17.0	13.2
5	108	9.5	15.6	4.6
6	109	3.3	18.2	0.0
7	110	6.0	18.8	0.0
^8	111	9.7	17.8	0.0
9	112	9.0	22.0	0.0
10	113	7.2	24.1	0.0
11	114	7.2	20.0	0.0
12	115	6.0	17.5	0.0
13	116	2.5	18.8	0.0
14	117	2.8	21.0	0.0
15	118	3.5	23.5	0.0
16	119	10.0	21.5	0.0
17	120	11.5	20.6	0.0
18	121	13.0	18.0	17.6
19	122	12.9	19.7	2.6
^20	123	14.2	19.8	0.8
21	124	12.8	20.0	0.0
22	125	14.2	18.4	5.6
23	126	4.5	18.7	0.0
24	127	3.5	20.4	0.0
25	128	3.8	22.3	0.0
26	129	13.5	19.8	7.4
27	130	7.8	17.4	5.0
28	131	8.8	18.4	3.0
29	132	8.0	17.6	1.8
30	133	3.8	19.0	0.0
31	134	3.6	19.3	1.0
Sept 1	135	6.3	18.2	1.0
2	136	9.5	17.2	0.2
^3	137	13.0	19.4	1.0
4	138	11.5	20.8	3.2
5	139	8.0	22.0	0.2
6	140	7.2	20.0	0.2
7	141	12.0	19.0	4.6
8	142	12.2	15.8	4.2
9	143	3.4	17.5	15.4
10	144	2.5	19.2	0.0
11	145	3.2	20.0	0.0
12	146	11.5	20.5	4.6
13	147	13.0	19.0	10.4
14	148	12.9	18.0	29.4
15	149	8.0	14.6	12.8
^16	150	3.0	17.8	1.6
17	151	9.5	17.7	0.0
18	152	13	18.4	11.0
19	153	8.5	19.4	4.2
20	154	5.4	20.2	0.0
21	155	5.2	20.0	0.0
22	156	4.5	19.4	0.0
23	157	4.5	22.0	0.0
Average		**8.5**	**19.2**	**3.76**

^denote date of weather timed application

It is probably more important that the spray intervals are not too wide during the blight season. The continuous growth of young carrot leaves may result in inadequate protection of foliage if intervals between sprays are too wide. All the currently registered fungicides act as protectants and not eradicants. They act by protecting the foliage by interfering with spore germination.

Once the disease is present the fungicide will not kill the fungus or its spores.

Conditions are often conducive to blight development in carrots during autumn in Western Australia. Once blight appears in crops regular application of protective fungicides would appear to be the most useful means of disease control for growers.

---

4. Experiment 92PE53 - Leaf blight of carrots-control with fungicides

Aim

The aim of this observation was to compare the effectiveness of a range of fungicides with activity against blight fungi (*Alternaria dauci* and *Cercospora carotae*).

Materials and Methods

The observation was conducted as part of a commercial carrot crop on a property 100 km north of Perth. The Nantes carrot variety Top Pak (South Pacific Seeds) was sown on 12 May 1992 with an Agricola Italia® precision seeder with 5 double rows per 1.92 m wide bed. Treatments were unreplicated and plots were 10 m long.

There were 6 fungicide treatments plus 2 unsprayed treatments. The first spray was applied at the first sign of blight [70 days after sowing (DAS)]. The fungicides were applied at either weekly or fortnightly intervals. Table 12 lists the rate, spray interval, number of sprays and active ingredient for each treatment.

Table 12. Rate, formulation, spray interval and number of sprays applied for each fungicide treatment

Treatment ®	Active ingredient	Spray interval	Rate per hectare	Number of sprays
Bravo	500 g/L chlorothalonil	14	2.6 L	6
Mancozeb	750 g/kg mancozeb	7	2.0 kg	12
Rovral	250 g/L vinclozolin	14	2.0 L	6
Antracol	700 g/kg propineb	7	2.0 kg	12
Bayleton	500 g/kg triadimefon	7	0.5 kg	12
Benlate	500 g/kg benomyl	14	1.0 kg	6

All sprays were applied with a Hardi® back pack with modified hand held mini boom (5 cone jets, size 20 nozzles). The output at 1 bar was equivalent to 356 L/ha and each plot was covered twice to achieve a final water volume of 712 L/ha.

The experimental area was surrounded by a buffer of unsprayed crop to to place sprayed plots under high disease pressure.

Each plot was visually rated for blight severity at harvest according to the following scale:

1 = no blight present,
2 = some blight present,
3 = moderate blight,
4 = severe blight,
5 = very severe blight, crop defoliated.

At harvest maturity (13 October 1992, 154 DAS), six 0.5 m samples from the middle three rows of each plot were hand harvested, washed and weighed. The samples were graded into: export yield (25 to 50 mm crown diameter and greater than 150 mm length); marketable short (25 to 50 mm crown diameter and 100 to 150 mm length); and rejects (undersized, oversized, forked, misshapen and split). Each sample was regraded and on the second grading they were categorised for the carrot diseases, cavity spot and scab, which were present in the crop at low levels. Leaves were also weighed. Ten plants were sampled at random from each plot to determine the average number of leaves per plant at harvest.

Results and Discussion

Bravo, Mancozeb and Antracol produced total yields of over 90 t/ha (Table 13). These treatments produced a 10 t/ha yield increase compared to unsprayed plots. The export yield was over 80 t/ha for the Bravo, Mancozeb and Antracol treatments. Rovral, Bayleton and the unsprayed treatments had over 10 t/ha classed as marketable short. In turn, these treatments also had the lowest export yields. The proportion of rejects in all treatments was low, ranging from 2 to 7 t/ha (Table 13).

Table 13. The effect of fungicides on the total and export yield, marketable short yield and rejects for Top Pak carrots

Treatment ®	Total yield (t/ha)	Export yield (t/ha)	Marketable short yield (t/ha)	Rejects[A] (t/ha)
Bravo	93.1	84.0	6.8	2.3
Mancozeb	95.4	83.6	6.6	5.0
Rovral	81.5	66.7	11.4	3.2
Antracol	94.6	80.5	7.3	6.8
Bayleton	85.3	71.0	11.3	3.0
Benlate	88.8	77.7	8.7	2.2
Unsprayed	84.4	68.6	12.3	3.5

[A]undersized, oversized, forked, split, misshapen roots

The leaf yield for the unsprayed treatment was 8 t/ha. Rovral and Bayleton treatments produced leaf yields close to 9 t/ha while the Bravo, Mancozeb and Antracol treated crop produced leaf yields greater than 11 t/ha (Table 14). Rovral, Bayleton and unsprayed treatments had fewer leaves per plant at harvest compared to other treatments. Rovral, Bayleton and the unsprayed treatment had higher blight scores (more severe blight) than other treatments (Table 14).

Table 14. The effect of fungicides on the leaf yield, number of leaves per plant and visual blight rating of Top Pak carrots at harvest

Treatment ®	Leaf yield (t/ha)	Number of leaves per plant	Visual blight rating
Bravo	11.4	6.9	1.7
Mancozeb	12.4	6.6	1.8
Rovral	8.9	5.7	3.8
Antracol	11.6	7.0	1.7
Bayleton	9.3	5.4	3.5
Benlate	10.6	6.9	2.0
Unsprayed	8.4	4.7	3.8

Cavity spot was detected at low levels in this crop (less than 0.2 %). Mild symptoms of scab were also detected in the crop (Table 15). Mancozeb treatment had 20 % of the yield affected by scab, however this result is from only one plot. In replicated field work (92PE40) higher scab levels were not observed with spray treatments of Mancozeb.

Table 15. The effect of fungicides on the incidence of scab (expressed as a % of the total yield) for Top Pak carrots at harvest

Treatment ®	Scab (% of total yield)
Bravo	7.1
Mancozeb	20.3
Rovral	11.0
Antracol	7.1
Bayleton	10.6
Benlate	8.4
Unsprayed	8.7

In conclusion, the fungicides Bravo, Mancozeb and Antracol were the most effective against leaf blight in this observation. These three treatments produced the highest total, export and leaf yields, as well as the lowest visual blight ratings. Mancozeb and Antracol were applied weekly and Bravo was sprayed fortnightly.

The effectiveness of Antracol should be confirmed in replicated field experiments. A spray program of Antracol (12 sprays at 7 day intervals) would cost $298 per hectare compared to $215 for Bravo (6 fortnightly sprays) at 1993 prices. The efficacy of Antracol at wider spray intervals would also be worthy of examination. Antracol (Bayer) is registered for control of early blight of potatoes that is caused by *Alternaria solani,* however it is not registered for use on carrots. Antracol is also active against Septoria disease of celery. Septoria fungi are closely related to Cercospora. *C.*

carotae also can cause leaf spot in carrots and has been found in association with *Alternaria dauci* in severely blighted carrots in Western Australia.

This observation supports related field experiments that showed both Bravo and mancozeb were effective in controlling carrot leaf blight. In other work, alternating Bravo and Mancozeb gave better disease control than programs based a single chemical.

Acknowledgments

Thanks to K. Gajda for technical assistance. E. Melvin-Carter is thanked for assistance in planning and conducting 91MD12. Thanks also to the staff of Guilderton Farms for their assistance in the management of 92PE53 and to the staff at Medina Research Centre especially J. Berston, for managing 91MD12 and 92MD21. W. Klepic and staff at Kwinana Market Garden are acknowledged for their assistance in managing 92PE40. S. Dhaliwal is thanked for statistical analysis of 91MD12. The financial support of this work by the Sumich Group Ltd and the Horticulture Research and Development Corporation is gratefully acknowledged.

References

Angell, F. F., and Gabelman, W. H. (1968). Inheritance of resitance in carrot, *Daucus carota* var. *sativa*, to the leaf spot fungus, *Cercospora carotae*. *Proceedings of the American Society of Horticultural Science* **93**, 434-37.

Gillespie, T. J., and Sutton, J. C. (1979). A predictive scheme for timing fungicide applications to control alternaria leaf blight in carrots. *Canadian Journal of Plant Pathology* **1**, 95-99.

Grogan, R. G., and Snyder, W. C. (1952). The occurrence and pathological effects of *Stemphylium radicinum* on carrots in California. *Phytopathology* **42**, 215-18.

Lebeda, A., Coufal, J., and Kvasnicka, P. (1988). Evaluation of field resistance of *Daucus carota* cultivars to *Cercospora carotae* (leaf spot). *Euphytica* **39**, 285-88.

McKay, A., and Galati, A. (1992). Survey looks at cause of carrot yield decline. *Good Fruit and Vegetables* **3**(5), 24-25.

Strandberg, J. O., Bassett, M. J., Peterson, C. E., and Berger, R. D. (1972). Sources of resistance to *Alternaria dauci*. *HortScience* **7**(3), 345.

Sutton, J. C., and Gillespie, T. J. (1979). Weather-timed sprays for carrot blight control. MAFF AGDEX 258/635.

7. INVESTIGATIONS INTO THE CAUSE AND CONTROL OF CARROT SCAB

A. Galati, A. G. McKay and E. Melvin-Carter

INVESTIGATIONS INTO THE CAUSE AND CONTROL OF CARROT SCAB

Summary

A disorder of carrots, known in Western Australia as 'scab', was characterised by thin corky black lesions on the eyes or the secondary root nodes of roots. Symptoms of this scab were distinct from those of other carrot scabs caused elsewhere by *Xanthomonas carotae* or *Streptomyces scabies*. At the commencement of this project, little was known about the scab observed in W.A.

As part of this project, laboratory screenings were carried out on commercial seed lines for the presence of potentially pathogenic fungi. Field and pot experiments followed with fungicide treatments on infected seed lines. Variety trials conducted over the course of the project showed possible varietal susceptibility to scab. Scab virtually disappeared with the industry adoption of Nantes varieties. It was therefore decided that further work on scab was of low priority.

Major results

- In the commercial survey, scab was most often associated with certain seed sources of the carrot variety Western Red.
- Seed testing of 19 commercial seed lines revealed that some of these had high infections of *Alternaria radicina*, a primary pathogen of carrot.
- A glasshouse experiment with an *A. radicina* infected seed line produced scab symptoms in sterilised soil.
- Isolations from scab lesions on field grown carrots consistently produced *Fusarium* spp.
- Metham sodium fumigation before planting increased the incidence of scab in Western Red in a rotation experiment.
- Inconsistent scab levels and results were achieved in other field and pot experiments reflecting the lack of understanding of scab epidemiology.
- There were significant varietal differences in apparent scab susceptibility. However, seed borne inoculum could not be discounted as a source of disease, as there was some question to the efficacy of thiram applied as a seed dust treatment.
- In some Nantes variety carrot crops scab was associated with severe outbreaks when there was no evidence of seed fungal contamination.
- Difenoconazole (Score®) decreased the incidence of scab disease in one field experiment.

Recommendations

(a) Extension/adoption by industry

Seed companies were informed of the apparent link between fungal contamination of seed and scab. However, since Nantes varieties replaced Western Red for export production, the disease has only occasionally been seen as a problem in commercial crops. Results of field and glasshouse work were reported to growers and industry at a seminar in March 1991. An article was also written about scab for the horticulture industry magazine, 'Horticulture Today'.

(b) Directions for future research

Scab symptoms were associated with severe leaf blight in some commercial crops and in two field experiments. Future work could examine the link between leaf blight and scab development.

(c) Financial/commercial benefits

Fungal contamination of seed may be an important source of inoculum for blight and scab, although the role of seed borne inoculum in the development of scab is not yet clearly understood. Both blight and scab can reduce ecomomic returns, blight by reducing yields and scab by reducing marketability. Some severe losses due to scab were observed in Western Red crops. The introduction of Nantes varieties saw a reduction in the incidence of scab, although scab in these varieties was still associated with severe blight infection. Control of seed borne pathogens in the production and treatment of seed is a prerequisite for the production of healthy productive carrot crops.

INVESTIGATIONS INTO THE CAUSE AND CONTROL OF CARROT SCAB

Introduction

A disease of carrots known locally as 'scab' has caused losses in commercial crops according to a survey conducted in 1990/91 (90PE8). Infection usually takes place on the lateral or secondary root nodes and thin, corky black lesions develop.

The causal organism of carrot scab is unclear because of the range of pathogens associated with the disease. Ark and Gardener (1944) isolated *Xanthomonas carotae* from scab lesions, however this symptom (shallow scabby lesions that often bear grey masses of bacterial ooze) was not consistent with those observed here. Ramsey (1937) and Ramsey and Wiant (1941) isolated *Fusarium* spp. from carrots from California.

Grogan and Kendrick (1952) isolated a variety of organisms associated with scab, but none that were pathogenic. Grogan *et al.* (1961) attributes the cause of scab to environmental and genetic factors because scab developed on carrot roots grown in sterilised soil. These authors failed to induce symptoms following inoculation with *Xanthomonas* and *Fusarium* spp.

Guba *et al.* (1961) isolated *Fusarium, Penicillum* and *Alternaria* from scab lesions but inoculation of sterile carrot slices did not readily produce the same symptoms. They suggested the symptom was physiological in origin.

Mildenhall and Williams (1970) isolated *Rhizoctonia* and *Fusarium* from scab lesions, but found that only *Rhizoctonia* isolates produced typical scab symptoms.

A *Streptomyces* sp. was associated with outbreaks of scab in the Netherlands (Janse 1988) and the United States (Hanson and Lacy 1990). However, symptoms described by these workers were unlike those reported here. In addition, isolation for *Streptomyces* spp. have failed to recover such species from scab lesions.

The other pathogen associated with scab is *Alternaria radicinia.* Many have isolated this fungus from scab-like lesions eg Grogan and Snyder (1952) and Maude (1966).

Collyer and Harrison (1971) found *Fusarium* were frequently isolated from carrot roots where injury to the fibrous roots had occurred. Although the *Fusarium* had sometime appeared to be the primary pathogen, it had also been found as a secondary invader following *Alternaria radicina* infection.

In the survey of commercial carrot crops, scab-like lesions were found on carrot roots (McKay and Galati 1992). One Western Red crop, which was badly affected by scab (82 % of roots with symptoms), was grown from seed infected with the fungus *Alternaria radicinia.* Isolations from the roots of that crop and from many other crops, have consistently produced *Fusarium* spp., predominantly *Fusarium oxysporum* and *F. solani.*

Alternaria radicina (Meier, Dreschler & Eddy) and *Alternaria dauci* (Kühn, Groves & Skolko) are well documented as seed borne pathogens of carrot. *A. radicina* is the causal organism of black rot disease of carrots, a disease that may occur in the field but is considered more serious under storage conditions (Smith *et al.* 1966). The symptoms of black rot are not consistent with those of scab observed in Western Australia. *A. dauci* is the primary pathogen responsible for leaf blight disease of carrots (Hooker 1944).

Fusarium spp. have been isolated from carrot seed (Nath *et al.* 1970), but seed borne *Fusarium* spp. have not been reported as a primary pathogen of carrot. However soil borne *Fusarium* spp. are associated with crown rots or cankers in carrots in the field or in storage (Sherf and MacNab 1986).

In this series of experiments, laboratory, glasshouse and field experiments were carried out to determine the cause and control method for carrot scab.

---

1. Experiment 91PE91 - Screening carrot seed for pathogenic fungi

Aim

Seed testing of some commercial carrot varieties was required to determine whether there was an association between seed borne organisms and scab incidence in the field. The objective of this work was to screen commercial carrot seed lots for the presence of fungi.

Materials and Methods

Nineteen commercial carrot seed lots were checked for pathogens during 1990-91. The seed was initially screened by the moist blotter technique (400 seeds checked, 10 seeds per 9 cm petri dish) according to International Seed Testing Association (ISTA 1966) test conditions. Plates were incubated at 18°C for 7 to 10 days under 12 hours of fluorescent light. Each plate was examined with a stereomicroscope for seed borne fungi. Seed from each batch was also placed onto PCNB (Nash and Snyder 1962), a selective medium for the isolation of *Fusarium* spp. Plates were incubated according to ISTA test conditions. Scrapings from seed allowed for initial identification of species and some fungi were subcultured for further identification to species level. No attempt was made to identify *Alternaria* spp. on PCNB because these had previously been identified to species level from the moist blotter test.

Results

Only two commercial seed lines were found to be highly contaminated by *Alternaria radicina* (Table 1). These seed lines were associated with yield losses caused by scab in commercial crops (Table 3). The levels of infection across seed lots ranged from 0 to 25 % for *A. radicina* and 0 to 5 % for *A. dauci* (Table 1). Two seed lots had *A. radicina* infection levels greater than 21 %. These were 22 % and 22.7 % (Table 3).

Table 1. Level of infection (%) by seed borne fungi among 19 commercial seed lots. Infection levels determined by blotter method

Level of infection (%)	*A. dauci*	*A. radicinia*	*A. alternata*	*S. botryosum*	*B. cinerea*
			number of seed lots		
0	11	5	4	6	7
0.25-5	8	10	9	7	5
6-10	-	1	1	2	1
11-15	-	1	-	1	-
16-20	-	-	1	-	-
>21	-	2	4	2	1

The secondary fungi, *S. botryosum* ranged from 0 to 29 % and *B. cinerea* ranged from 0 to 58 % incidence across seed lots (Table 3).

Fusarium fungi were not detected in over 68 % of seed lots and only one seed lot had greater than 21 % infection by *Fusarium* spp. (Table 2).

Table 2. Level of infection (%) by *Fusarium* spp. Infection levels determined by PCNB agar method for 19 commercial carrot seed lots

Level of infection (%)	*Fusarium* spp.
	number of seed lots
0	13
0.25-5	5
6-10	-
11-15	-
16-20	-
>21	1

Table 3. Percentage infection of commercial lines of carrot seed by fungi. Infection levels determined by blotter method

Seed line	*A. dauci* (%)	*A. radicinia* (%)	*A. alternata* (%)	*S. botryosum* (%)	*B. cinerea* (%)
1[A]	1.3	22.7	2.3	2.5	1.2
2	1.0	2.0	73.8	28.8	57.5
3[A]	1.3	22.0	57.5	24.5	10.0
4[A]	3.0	14.0	22.0	13.0	2.0
5	0	0	0	0.2	0
6	0	0	0.5	0.2	0
7	0.5	0.5	0.2	4.5	0
8	0.2	4.0	0.2	0	0
9	0	0.8	2.0	0.1	0
10	0	0	0.2	0	0
11	0	6.0	0.8	0.2	0
12	0	0	1.0	5.5	0
13	0	0.8	0.5	0.5	2.2
14	0	2.8	19.8	6.3	2.2
15	0	0.2	10.0	2.3	2.8
16	0	0	0	0	0
17	4.0	1.0	24.0	0	4.0
18	0.3	3.0	0	0	0
19	0	0.3	0	0	0

[A]denotes scab present in commercial carrot crops.

Table 4. Percentage infection of commercial lines of carrot seed by fungi. Infection levels determined by PCNB agar method

Seed line	*Alternaria* and *Stemphylium* spp. (%)	*Fusarium* spp. (%)
1	31.0	0.2
2	13.8	25.5
3	24.5	0.8
4	18.5	0.8
5	1.2	0
6	1.5	0
7	0.5	0
8	3.2	0
9	2.5	0
10	1.5	0
11	4.8	0
12	8.7	0
13	3.0	0
14	21.0	1.0
15	0.8	0
16	0	0
17	4.0	0
18	6.3	0
19	0	0.2

Discussion

Three seed lots from 19 had high levels of contamination by *A. radicina,* and one seed lot of 19 had a high level of contamination by *Fusarium* spp. Tahvanen (1978) recorded 58 and 52 % of the 57 commercial seed lots were infected by *A. radicina* and *A. dauci*. The incidence of these pathogens across seed lots averaged 6 % for *A. radicina* and 7.2 % for *A. dauci.* Scott and Wenham (1973) found 22 and 8 % of imported carrot seed lines infected by *A. radicina* and *A. dauci* respectively. The incidence of *A. radicina* ranged from 0-26 % and 0-1 % for *A. dauci* in seed tested in New Zealand (Soteros 1979).

As a precautionary measure, all seed lines should be treated by seed merchants before commercial release. Thiram can be applied as a dust or a soak. Maude (1966) found the best results with a hot water soak in 0.2 % thiram for 24 hours, as a standard treatment for all commercial seed.

Strandberg (1984) found *A. dauci* was not completely eradicated from carrot seed by fungicide dusts or soaks. He also found the most effective fungicides were thiram or iprodione applied as a 24 hour soak, which allowed *A. dauci* to persist on 0.4 and 0.01 % of the treated seed respectively, from an original infection level of 24 %. Although the work was done with *A. dauci,* it is realistic to expect that similar levels of infection could exist for *A. radicina* after fungicide treatment. Pryor *et al.* (1994) concluded that iprodione and thiram treatments (0.2 % a.i at 30°C) were not as effective as a hot water (50°C for 30 min) or hot sodium hypochlorite (0.1 or 1 % at 50°C for 30 min) treatments for the eradication of *A. radicina.* However, the seed in the iprodione and thiram treatments were soaked for 4 and 8 hours only, and not 24 hours as attempted by other workers such as Maude (1966) or Strandberg (1984).

Further work with seed lines with high fungal infection levels is required under sterile glasshouse conditions to determine relationship between seed infection and scab development on carrot roots.

---

2. Experiment 90GL37 - Examining the cause of scab disease of carrots in the glasshouse

Aim

This glasshouse experiment was designed to test the hypothesis that seed contamination by *A. radicina* pre-disposes carrots to infection by *Fusarium* spp. and the development of scab.

Materials and Methods

The experiment was a factorial design (2 x 2) with 10 replicates. The treatments were:

1. Unsterilised soil and untreated, infected seed
2. Unsterilised soil and Thiram® treated seed
3. Steam sterilised soil and untreated, infected seed
4. Steam sterilised soil and Thiram® treated seed.

Soil from a recently harvested scab affected carrot crop was collected from Guilderton, 100 km north of Perth. The soil was air dried and mixed and then one half of the soil was steam sterilised for two hours. The number of Fusarium colonies in soil before and after steam sterilisation was determined according to the method of Snyder *et al.* (1959) and Nash and Snyder (1962). No Fusarium propagules were found in sterilised soil while unsterilised soil contained an average of 80 propagules/ml.

Forty PVC pots (50 cm length x 15 cm diameter) and bottom cap with four 0.5 cm drainage holes, were disinfected with a 2.5 % sodium hypochlorite solution. The pots were then filled with either sterilised or unsterilised soil.

Superphosphate (equivalent rate calculated on a surface area basis) at 825 kg/ha, muriate of potash (120 kg/ha), manganese sulphate (25 kg/ha), magnesium sulphate (50 kg/ha), iron sulphate (18 kg/ha), zinc sulphate (16 kg/ha), borax (18 kg/ha) and sodium molybdate (2 kg/ha) were incorporated to a depth of 10 cm into each pot.

The variety Western Red (Lefroy Valley Seed- Lot no. 89T9161) which had a high incidence of scab in commercial carrot crops was used in this experiment.

The seed was checked for pathogens by the moist blotter technique (400 seeds were checked, 10 seeds per petri dish) according to International Seed Testing Standards (1966). *A. radicina* was present on 23 % and *A. dauci* on 1.3 % of the seed. Two hundred seeds were soaked in Thiram® as described by Maude (1966). The thiram soaked seed was then checked for pathogens and 0.5 % *A. radicina* contamination was detected on the seed.

Carrots were grown in pots in a controlled temperature glasshouse. Pots were watered to field capacity before sowing. Ten seeds were sown per pot to a depth of 1 cm on 22 February 1991. Seedlings were thinned to three carrots per pot at emergence. Pots were randomised on benches in a glasshouse. Sterile resin beads were placed on the soil surface to minimise risk of soil splash from pot to pot.

Ammonium nitrate at an equivalent surface area rate of 20 kg/ha was applied to each pot 21 days after sowing. Carrots were then maintained with liquid 'NPK' (12:6:6) type fertiliser (Aquagreen® TE concentrated liquid plant food). In total, the equivalent of 330 kg N/ha, 170 kg P/ha and 230 kg K/ha were applied to each pot.

The carrots were harvested, washed and examined for scab on 7 August 1991. Sections (12 per agar plate) from scab lesions for each treatment were placed onto petri dishes containing various media including SPA (bacterial agar), PDA, WA and 3P. Infected carrots were stored in sterile plastic bags in a cool room at 1°C. Isolations were repeated on three occasions from each treatment.

The data was analysed by Chi squared analysis. The data was then grouped and analysed by Chi square analysis to determine the effect of seed source and soil treatment on the incidence of scab disease.

Results and Discussion

Pot experiment

Chisquare analysis of the data showed significant differences among the four treatments ($P<0.05$). The incidence of scab was highest in carrots grown in sterilised soil with untreated seed (Table 5). No scab was recorded on carrots grown in unsterilised soil with treated seed. Ten percent of carrots were affected by scab in the sterilised soil and treated seed treatment. The incidence of scab in this treatment may be caused by pathogens remaining on seed even after fungicide soaks or seed dressings (Strandberg 1984), as 0.5 % of the seed still carried *A. radicina* after treatment.

Table 5. The effect of soil sterilisation and seed treatment on the number and percentage of Western Red carrots affected by scab

Treatment	Total number of carrots	+ scab no. of carrots	+ scab % of carrots	- scab no. of carrots	- scab % of carrots
sterilised soil x treated seed	29	3	10	26	90
sterilised soil x untreated seed	30	13	43	17	56
unsterilised soil x treated seed	30	0	0	30	100
unsterilised soil x untreated seed	29	6	21	23	79
Significance			$P<0.05$		

The chisquare table for the main treatments showed 32 % of all carrots grown from untreated seed developed scab lesions, compared to only 5 % from treated seed (Table 6). Scab developed in 27 % of carrots grown in sterilised soil compared to only 10 % in unsterilised soil.

Table 6. Number and % of carrots affected by scab in sterilised and unsterilised soil, treated and untreated seed

Treatment	+ scab no. of carrots	+ scab % of carrots	- scab no. of carrots	- scab % of carrots	Significance
sterilised soil	16	27	43	73	
unsterilised soil	6	10	53	90	$P<0.031$
treated seed	3	5	56	95	
untreated seed	19	32	40	68	$P<0.001$

Organisms isolated
A number of fungal organisms were isolated from scab lesions (Table 7). *Fusarium* spp. were also isolated from carrots from the sterilised soil with untreated seed treatment. *Fusarium* spp. were isolated at every isolation from carrots grown in unsterilised soil with untreated seed.

Table 7. Pathogens isolated from carrot scab lesions

Treatment	Fungi isolated
sterilised soil x untreated seed	*Rhizoctonia, Fusarium* spp., *A. alternata, Stemphylium botyrosum, A. radicina*
sterilised soil x treated seed	*Fusarium* spp.
unsterilised soil x treated seed	no scab
unsterilised soil x untreated seed	*Fusarium* spp.

Rhizoctonia spp., *Penicillum* spp. and *A. alternata* were isolated from scab lesions from carrots grown in sterilised soil with untreated seed. *Alternaria radicina* was isolated on one occasion (7/12 cultures) but these were mixed with fusarium isolates (Table 7). Bacterial organisms were not isolated from lesions.

These results suggest that scab is a seed borne disease because:
- the highest incidence of scab were from carrots grown from untreated seed, and
- the highest incidence of scab was from carrots grown in sterilised soil.

Soil sterilisation may have removed organisms antagonistic to the seed born pathogens and allowed for successful disease development. However, it is difficult to determine the causal pathogen of scab because of the range of organisms isolated.

Pathogenicity tests with pure isolates singularly and in combination, would help to determine the cause of scab. A study of the combination of *Alternaria radicina* and *Fusarium* spp. should be given high priority.

---

3. Experiment 91PE66- Seed treatments for controlling carrot scab - second experiment

Aim
In this experiment, two seed lines contaminated with either Alternaria and Fusarium fungi were treated with seed fungicides that have specific activity against different groups of fungi with the aim of determining the causal pathogen of scab.

Materials and Methods
Ten seed treatments (Table 8) were replicated 6 times in a randomised block design on a Karrakatta sand 100 km north of Perth.

Five single rows on a 1.92 m wide bed at a intrarow spacing of 3.5 cm was sown to a depth of 1 cm on 30 December 1991 (final density of 76 plants/m^2).
Two carrot seed lots (cv Western Red) naturally infested with *A. radicina* and *Fusarium* spp. were used in this experiment. Table 8 lists the fungicide treatments and the method employed for each treatment. Germination and pathogen levels were checked for each treatment according to International Seed Testing Standards (1966).

At harvest maturity, 2.5 m from the middle rows of each plot was sampled, washed and graded. Data was analysed by analysis of variance (GENSTAT software). Data was expressed as percentage of yield affected by scab.

Table 8. Seed fungicide treatment and method used in this experiment

Treatment	Method	Reference
A. radicina infected seed[A]	-	-
A. radicina infected seed + early Thiram dust	5 g thiram per kg of seed 1 week before sowing	Maude 1966
A. radicina infected seed + late Thiram dust	5 g thiram per kg of seed at sowing	Maude 1966
A. radicina infected seed + Thiram soak	24 hour soak at 30°C in a 0.2 % thiram suspension	Maude 1966
A. radicina infected seed + Rovral® soak	24 hour soak at 30°C in a 0.5 % iprodione suspension	Strandberg 1984
A. radicina infected seed + Benlate® soak	24 hour soak at 24°C in a 0.5 % benomyl suspension	Barbetti 1984; Strandberg 1984
A. radicina infected seed + Alcohol soak	10 second soak in 70 % ethanol	Barbetti 1984
Fusarium spp. infected seed[B]	-	-
Fusarium spp. infected seed + Benlate ® soak	24 hour soak at 24°C in a 0.5 % benomyl suspension	Barbetti 1984; Strandberg 1984
Fusarium spp. infected seed + Alcohol soak	10 second soak in 70 % ethanol	Barbetti 1984

[A]Level of infection 20 % prior to treatment, [B]Level of infection 25 % prior to treatment

Results and Discussion

A high level of scab developed on all treatments at this site (site average 56 % of the total yield). The incidence of scab was not significantly different among seed treatments (Table 9). It is possible that scab developed from an exogenous source or that scab developed on some treatments and spread to neighbouring plots.

Table 9. The effect of seed treatment on the final yield affected by scab (% of the total yield) and % germination after seed fungicide treatment

Treatment	Scab (% of total yield)	% germination after seed fungicide treatment
A. radicina infected seed[A]	59.5	89.0
A. radicina infected seed + early Thiram dust	62.2	91.0
A. radicina infected seed + late Thiram dust	57.5	93.0
A. radicina infected seed + Thiram soak	43.8	95.0
A. radicina infected seed + Rovral® soak	62.7	87.0
A. radicina infected seed + Benlate® soak	42.5	91.0
A. radicina infected seed + Alcohol dip	49.2	93.0
Fusarium spp. infected seed[A]	60.0	84.0
Fusarium spp. infected seed + Benlate® soak	49.7	88.0
Fusarium spp. infected seed + Alcohol dip	75.0	83.0
Significance	ns	ns
l.s.d (P=0.05)	-	-

[A]no seed treatment

Laboratory seed germination was not effected by seed treatment (Table 9). Table 10 shows fungi incidence after seed fungicide treatments. Some fungi were still found after treatment, a result also found by Strandberg (1984). The mechanism of scab development and control requires more attention.

Table 10. Incidence of pathogens after seed treatment

Treatment	*A. dauci*	*A. radicina*	*A. alternata*	*S. botryosum*	*Fusarium* spp.
			% of seed infected		
A. radicina infected seed	1.0	15.0	4.0	3.0	0.25
A. radicina infected seed + early Thiram dust	0	0	0	0	0
A. radicina infected seed + late Thiram dust	0	1.0	0	0	0
A. radicina infected seed + Thiram soak	0	0	0	0	0
A. radicina infected seed + Rovral® soak	0	0	0	0	0
A. radicina infected seed + Benlate® soak	0	0	0	0	0
A. radicina infected seed + Alcohol soak	0	6.0	4.0	0	0
Fusarium spp. infected seed[A]	0	4.0	50.0	4.0	25.0
Fusarium spp. infected seed + Benlate® soak	0	1.0	8.0	2.0	0
Fusarium spp. infected seed + Alcohol soak	0	1.0	8.0	6.0	0

[A]Original seed batch assessed on PCNB agar

4. Experiment 91GL21 - Seed treatments for controlling carrot scab - second experiment

Aim

We hypothesise that seed fungicide treatments will reduce the incidence of scab. In this experiment, we test the efficacy of seed fungicide treatments against carrot scab under glasshouse conditions. This experiment was conducted in conjunction with a field experiment that contained similar treatments (91PE66).

Materials and Methods

Carrots were grown in pots in a controlled temperature glasshouse. Seven seed treatments (including two untreated controls) were replicated 9 times in a randomised block design. Table 11 shows the seed fungicide treatments and the reference to the method used in this experiment.

Table 11. Seed fungicide treatment and method used in this experiment

Treatment	Method	Reference
A. radicina infected seed[A]	-	-
A. radicina infected seed[A]	-	-
A. radicina infected seed + Thiram soak	24 hour soak at 30°C in a 0.2 % thiram suspension	Maude 1966
A. radicina infected seed + Rovral® soak	24 hour soak at 30°C in a 0.5 % iprodione suspension	Strandberg 1984
A. radicina infected seed + Benlate® soak	24 hour soak at 24°C in a 0.5 % benomyl suspension	Barbetti 1984; Strandberg 1984
Fusarium spp. infected seed[B]	-	-
Fusarium spp. infected seed + Alcohol soak	10 second soak in 70 % ethanol	Barbetti 1984

[A]Level of infection 20 % prior to treatment, [B]Level of infection 25 % prior to treatment

Soil was taken to a depth of 15 cm from a site with no history of vegetable production (virgin Karrakatta sand). The soil was air dried, mixed and steam sterilised for 2 hours.

A 2.5 % sodium hypochlorite solution was used to disinfect 63 PVC pots [(50 cm length x 15 cm diameter) and bottom cap with four 0.5 cm drainage holes]. The pots were each filled with 12 kg of soil. A fertiliser mix equivalent to 1.4 t/ha superphosphate, 120 kg/ha potassium chloride and 150 kg/ha of trace element mix consisting of 25 kg/ha manganese sulphate, 50 kg/ha magnesium sulphate, 18 kg/ha borax, 18 kg/ha iron sulphate, 16 kg/ha zinc sulphate and 2 kg/ha sodium molybdate were incorporated into each pot to a depth of 10 cm. The pots were watered to field capacity prior to seeding.

Ten seeds per pot were sown to a depth of 1 cm on 3 January 1992. When carrots reach the first true leaf stage, the seedlings were thinned to three per pot. Sterile resin beads were applied to the soil surface to reduce evaporation.

The carrots were maintained with a stock solution of Aquagreen® TE concentrated liquid NPK (12:6:6) fertiliser. Each pot was irrigated to free drainage daily or more frequently when required.

At harvest (10 June 1992), carrots were weighed and scored for scab incidence.

Results and Discussion

In this experiment, on average, 5 % (8 from 189) of carrots developed scab-like lesions. One of 27 carrots were affected by scab in the *A. radicina* infected seed line, 4 of 27 carrots in the *Fusarium* spp. infected seed line and 3 of 27 carrots in the *Fusarium* spp. infected seed line + alcohol soak treatment. The level of scab infection was too low in this experiment to allow meaningful interpretation of results.

---

5. Experiment 92MD35 - Seed treatments for controlling carrot scab - third experiment

Aim

We hypothesise the incidence of scab will be reduced in infected seed lines by seed fungicide treatments. We also hypothesise that the incidence and severity of scab will be more severe with the application of metham sodium, because the soil fumigant will remove organisms antagonistic to the seed borne pathogens from soil and enhance disease development.

Materials and Methods

Seed to which various treatments had been applied (Table 12) was sown into areas at the Medina Research Centre, with and without prior treatment with metham sodium. The experiment was a split-plot randomised block design with 4 replications. Main plots were plus or minus metham sodium while seed treatments were sub-plots (Table 12). Each plot was 2 m long and 1.5 m wide with 5 single rows per plot. Metham sodium (500 L/ha) was applied on the appropriate plots to moist soil and rotary hoed to a depth of 20 cm. A low pressure spray boom applied the metham sodium in front of rotary hoe blades giving immediate incorporation.

The equivalent of 1 t/ha superphosphate, 120 kg/ha muriate of potash and 150 kg/ha trace elements were applied to the site prior to sowing. Commencing from emergence, topdressings of 75 kg/ha urea, 60 kg/ha of muriate of potash and 20 kg/ha magnesium sulphate were broadcast fortnightly. The equivalent of 5 kg/ha of borax was applied at 8, 10 and 14 weeks after sowing. The site was irrigated by overhead sprinklers daily according to class A pan evaporation figures.

Table 12. Seed fungicide treatment and method used in this experiment

Seed treatment	Method	Reference
A. radicina infected seed[A]	-	-
A. radicina infected seed + early Thiram dust	5 g thiram per kg of seed 1 week before sowing	Maude 1966
A. radicina infected seed + late Thiram dust	5 g thiram per kg of seed at sowing	Maude 1966
A. radicina infected seed + Thiram soak	24 hour soak at 30°C in a 0.2 % thiram suspension	Maude 1966
A. radicina infected seed + Rovral® soak	24 hour soak at 30°C in a 0.5 % iprodione suspension	Strandberg 1984
A. radicina infected seed + Benlate® soak	24 hour soak at 24°C in a 0.5 % benomyl suspension	Barbetti 1984; Strandberg 1984
Fusarium spp. infected seed[B]	-	-
Fusarium spp. infected seed + Benlate® soak	24 hour soak at 24°C in a 0.5 % benomyl suspension	Barbetti 1984; Strandberg 1984
Clean seed line[C]	-	-

[A]Level of infection 20 % prior to treatment, [B]Level of infection 25 % prior to treatment, [C]0% infection

The variety Western Red (Lefroy Valley Seeds) naturally infested with *A. radicina* or *Fusarium* spp. was used in this experiment. Seed was sown two weeks after metham sodium application with an Earthway® hand seeder to a depth of 1 cm on 2 December 1992.

The incidence of disease during growth was checked weekly for the first sign of disease. At harvest maturity (20 April 1993), 50 roots were sampled at random from each plot and examined for scab.

Results and Discussion

Carrots were examined for scab each week from emergence. In this experiment, scab was not detected at any stage. The crop was not harvested until 139 days after sowing, which was about 3 weeks after the normal commercial maturity. On average, scab affected 56 % of total yield in another experiment (91PE66) on a commercial property with similar seed treatments. Environmental conditions apparently did not favour scab development at the site of the current experiment.

Acknowledgments

K Gajda is thanked for assisting with laboratory work. Thanks also to J. Berston and D. Pitman and other staff members of the Medina Research Centre for their assistance in managing 92MD35. The seed companies are thanked for donating commercial seed batches for screening in 91PE91. The financial support of the Sumich Group Ltd and the HRDC is gratefully acknowledged.

References

Ark, P. A., and Gardner, M. W. (1944). Carrot bacterial blight as it affects the roots. *Phytopathology* **34**, 416-20.

Barbetti, M. J. (1984). Seed treatment for control of subterranean clover root rot. *Australasian Plant Pathology* **13**, 43-45.

Collyer, J. E., and Harrison, D. E. (1971). Carrot rots in Victoria. *Vegetable Growers Digest* **31**, 20-23.

Galati, A., and McKay, A. (1993). The export carrot industry. *Journal of Agriculture, Western Australia* **34**(2), 48-51.

Grogan, R. G., and Kendrick, J. B. (1952). Carrot root scab - disease complex (Abst) *Phytopathology* **42**, 9-10.

Grogan, R. G., and Snyder, W. C. (1952). The occurrence and pathological effects of *Stemphylium radicinum* on carrots in California. *Phytopathology* **42**, 215-18.

Grogan, R. G., Zink, F. W., and Kimble, K. A. (1961). Pathological anatomy of carrot root scab and some factor effecting its incidence and severity. *Hilgardia* **31**, 53-67.

Guba, E. F., Young, R. E., and Ui, T. (1961). Cavity spot disease of carrot and parsnip roots. *Plant Disease Reporter* **45**, 102-05.

Hanson, L. E., and Lacy, M. L. (1990). Carrot scab caused by *Streptomyces* spp. in Michigan. *Plant Disease* **74**, 1037 (Abst.).

Hooker, W. J. (1944). Comparative studies of two carrot leaf diseases. *Phytopathology* **34**, 606-12.

International Seed Testing Association (1966). International rules for seed testing. *Proceedings of the International Seed Testing Association* **31**, 1-152.

Janse, J. D. (1988). A Streptomyces species identified as the cause of carrot scab. *Netherlands Journal of Plant Pathology* **94**, 303-06.

Maude, R. B. (1966). Studies on the etiology of blackrot, *Stemphylium radicinum* (Meier Drechsl. and Eddy) Neer., and leaf blight *Alternaria dauci* (Kühn) Groves and Skolko, on carrot crops and on fungicide control of their seedborne infection phases. *Annals of Applied Biology* **95**, 321-27.

McKay, A. G., and Galati, A. (1992). Survey looks at causes of carrot yield decline. *Good Fruit and Vegetables* 3(5), 24-25.

Mildenhall, J. P., and Williams, P. H. (1970). Rhizoctonia crown rot and cavity spot of muck-grown carrots. *Phytopathology* **60**, 887-90.

Nash, S. M., and Snyder, W. C. (1962). Quantitative estimations by plate counts of propagules of the bean root rot fusarium in field soils. *Phytopathology* **52**, 567-72.

Nath, R. P., Neegaard, P., and Mather, S. B. (1970). Identification of Fusarium species on seeds as they occur in blotter test. *Proceedings of the International Seed Testing Association* **35**, 121-44.

Pryor, B. M., Davis, R. M., and Gilbertson, R. L. (1994). Detection and eradication of *Alternaria radicina* on carrot seed. *Plant Disease* **78**, 452-56.

Ramsay, G. B. (1937). Fruit and vegetable diseases on the Chicago market in 1936. *Plant Disease Reporter Supplement* **101**, 81-96.

Ramsay, G. B., and Wiant, J. (1941). Market diseases of fruit and vegetables. *U. S. Department of Agriculture Miscellaneous Publication* **440**, 1-70.

Scott, D. J., and Wenham, H. T. (1973). Occurrence of two seed-borne pathogens, *Alternaria radicina* and *Alternaria dauci* on imported carrot seed in New Zealand. *New Zealand Journal of Agricultural Research* **16**, 247-50.

Sherf, A. F., and MacNab, A. A. (1986). 'Vegetable Diseases and Their Control'. (John Wiley & Sons: New York).

Smith, M. A., McColloch, L. P., and Friedman, B. A. (1966). Market diseases of asparagus, onions, beans, peas, carrots, celery, and related vegetables. USDA Agriculture Handbook No. 303.

Snyder, W. C., Nash, S. M., and Trujillo, E. E. (1959). Multiple clonal types of *Fusarium solani phaseoli* in field soil. *Phytopathology* **49**, 310-12.

Soteros, J. J. (1979). Detection of *Alternaria radicina* and *A. dauci* from imported carrot seed in New Zealand. *New Zealand Journal of Agricultural Research* **22**, 185-90.

Strandberg, J. O. (1984). Efficacy of fungicides against persistence of *Alternaria dauci* on carrot seed. *Plant Disease* **68**, 39-42.

Tahvonen, R. (1978). Seed-borne fungi on parsley and carrot. *Journal of the Scientific Agricultural Society of Finland* **50**(2), 91-102.

8. THE RESPONSE OF NANTES CARROTS TO NITROGEN FERTILISER RATE AND REGIME

A. G. McKay, A. Galati and I. R. McPharlin

THE RESPONSE OF NANTES CARROTS TO NITROGEN FERTILISER RATE AND REGIME

Summary

Two field experiments were sown on sands at Medina Research Centre to examine the yield and quality responses of Nantes carrots (*Daucus carota* cv Top Pak) to nitrogen (N) fertiliser rate and regime. N regimes included constant (N as equal weekly applications), early (greater proportion of N during early crop stages), late (greater proportion of N in late stages of crop). Petiole nitrate-N and leaf N concentrations were also monitored and related to final root yields.

Major results

Near maximum marketable yield from the summer sowing was achieved with between 100 and 300 kg N/ha applied in the late regime compared with the winter sowing which required 348 kg N/ha for 99% of maximum marketable yield. Slower growth and winter rainfall would probably account for the differences in N requirement between summer and winter sown crops.

Altering N regime had little impact in the winter sowing, but applying a greater proportion of N fertiliser later in the crop (late regime) improved yield and fertiliser N recovery in the summer planting.

At maximum marketable yield levels and with constant weekly N applications, the equivalent of about 40% of applied fertiliser was recovered in the crop (roots + leaves). In both summer and winter plantings, the late regime improved apparent fertiliser recoveries (AFRs) over those from applying constant weekly amounts of N (constant regime). In the winter planting, the late regime averaged a 12% higher AFR than the constant regime while for the summer planting the late regime AFR was 26% higher than that of the constant regime.

Critical petiole-nitrate-N and leaf N concentration ranges declined rapidly over time as the crops grew. Days after sowing are of little value for interpreting leaf analysis results from crops sown at different times of year. A simple growth model based on day-degree summations may provide a basis for interpreting carrot leaf nitrogen analysis results.

Based on this work, an N program for Nantes carrots growing on sand which produces high yield and quality and gives relatively high fertiliser use efficiency would be:

Crop age	Application rate (kg N/ha/week)
Week 1	0
Weeks 2 - 6	10
Weeks 7 - 1 week before harvest	25

Based on this program a summer crop (15 weeks duration) would receive a total N application of 250 kg/ha and a winter crop (20 weeks duration) would receive a total N application of 375 kg/ha.

Recommendations

(a) Extension/adoption by industry

The results of this work were extended to growers at a field day at Medina Research Centre, an industry seminar, and through newsletter articles e.g. 'Nantes carrots need fine tuning.' West Coast Vegetables 1995 1(2). Results are also used as the basis for export carrot nitrogen recommendations made by Agriculture W.A. extension staff and horticultural consultants.

(b) Directions for future research

Further work is needed on the efficiency of N use in irrigated crops growing on sands over underground water reserves. Efficient irigation scheduling also needs urgent consideration. Efficient irrigation hold the key to efficient crop N use.
A simple day-degree based growth model would provide a useful basis from which to compare carrot crops growing at different times of year. The effect of N (as urea in this case) in causing root forking also needs clarification.

(c) Financial/commercial benefits

Nitrogen (N) is under the spotlight in carrot cropping because this nutrient is generally highly deficient in sands and because it is easily washed past plant roots by irrigation water or rainfall and can contaminate groundwater.

For the winter planting and with the constant regime, to produce 95 and 99 % of maximum yield, 248 and 348 kg of N /ha respectively were required over the life of the crop. The percentages of fertiliser recovered in the crop (roots + leaves) were 48 % and 42 % respectively.

As more N fertiliser is applied, the percentageof fertiliser taken up by the crop decreases. So the dilemma arises. In order to get the extra 4 % of yield to go from 95 to 99 % of maximum the grower needs to apply an extra 100 kg of N/ha of which the crop only takes up 30 kg leaving an extra 70 kg of N/ha which may end up polluting groundwater. Applying extra nitrogen to ensure maximum yield is easy to justify on economic grounds, however it is the sustainability issues which are of paramount importance to the vegetable industry in this instance.

THE RESPONSE OF NANTES CARROTS TO NITROGEN FERTILISER RATE AND REGIME

Introduction

Carrots are grown on the sandy soils of the Swan Coastal Plain near Perth in Western Australia. Exports account for over 70 % of total production with 29,800 tonnes of carrots exported mainly to south-east Asia in 1993/94. Environmental considerations mean that growers need to avoid excessive use of nitrogen (N) fertiliser in order to minimise the risk of nitrate enrichment of groundwater.

In 1991 the export carrot industry changed from Western Red to Nantes varieties. In the past, Western Red had been supplied with less than optimum (for yield) fertiliser N to limit top growth and facilitate mechanical harvesting. Hybrid Nantes varieties produce smaller tops and also appear to have higher yield potentials (Phillips 1988) and consequently may have higher N requirements. However it is still important not to oversupply N even for Nantes carrots because it may cause lodging of the tops and clogging of top-lifting harvesters.

Fallon and Hawson (1973) found that 256 and 280 kg N/ha was required to maximized yields of Western Red growing on sandy soil in 2 experiments. Phillips (unpublished data) estimated that 279 kg N/ha maximised the export yield of Western Red growing on a Spearwood sand. Optimum N fertiliser rates depend on many factors including soil type, site history, variety, fertiliser regime, irrigation practices and rainfall. Consequently optimum rates of N fertiliser for a particular crop cannot be accurately predicted.

Plant analysis by laboratory methods has proved useful with other crops for monitoring N status however there is a 1 to 2 week interval between crop sampling and the delivery of results More recently "in field" sap nitrate analysis has shown promise for monitoring the N status of potatoes (Williams and Maier 1990). Carrot growers may benefit by using the sap nitrate test kits because the result would allow immediate adjustment of N fertiliser programs.

1. *Experiment 92MD24 - The response of winter sown Nantes carrots to nitrogen fertiliser rate and regime*

Aim

This experiment was designed to test the hypothesis that plant tissue analysis could be used to test the N status of a carrot crop and that sap nitrate levels were correlated to laboratory analysis. The effect of N regime on carrot yield, quality and N fertiliser recovery was also examined.

Materials and Methods

Site details and crop management

The experiment was conducted at the Medina Research Centre, 40 km south of Perth. The soil type was a Spearwood sand Uc 4.13 (Northcote 1979). Table 1 lists the preplanting soil test details of the site. Fenamiphos (Nemacur®) was used for nematode control. Superphosphate (500 kg/ha), muriate of potash (120 kg/ha), magnesium sulphate (50 kg/ha) and 100 kg/ha of a standard trace element mix were broadcast and rotary hoed across the site.

Table 1. Soil (0-15 cm) characteristics of the site

pH (1:5 $CaCl_2$)	6.7
Extractable[A] phosphorus	56 mg/kg
Extractable[A] potassium	29 mg/kg
Organic carbon	0.45 %
Nitrate-N	4 mg/kg
Ammonium-N	3 mg/kg
Electrical conductivity	0.035 dS/m

[A] 0.05 M bicarbonate extractable (after Colwell 1963)

Each plot was 6 m long with 5 rows per 1.5 m wide bed. Pelleted seed of the variety Top Pak (South Pacific Seeds) was sown with an Agricola Italia® air seeder on the 22 July 1992, with a target denstiy of 70 plants/m^2. Linuron was applied at label rates to control weeds and chlorothalonil (Bravo®) was applied regularly to control leaf blight (*Alternaria dauci).*

Experimental design

There were 14 treatments (Table 2) and 4 replicates per treatment . The plots were arranged according to a randomised block design with 8 rates of N (0, 100, 200, 300, 400, 600, 800 and 1000 kg/ha) applied as urea in 18 equal weekly dressings (constant regime). Six further treatments were included to examine the effect of N regime at 200 and 300 kg N/ha. The arbitrary regimes were named constant, early, growth and late (see Fig. 1 and Table 2).

Table 2. Detail of nitrogen treatments

Treatment (kg N/ha)	Time of N application
0	Nil applied N
100, 200, 300, 400, 600, 800 and 1000 constant	Applied in 18 equal weekly dressings commencing two weeks after sowing
200 and 300 early	78 % of N applied in first 9 weeks, 22 % in weeks 10-19
200 and 300 late	22 % of N applied in first 9 weeks, 78 % in weeks 10-19
200 and 300 growth	60 % of N applied in first 9 weeks, 40 % in weeks 10-19

A total of 221 kg of potassium/ha as potassium sulphate (41.5 % K) was applied to the crop in 18 equal weekly dressings. Two additional dressings of magnesium sulphate at 50 kg/ha were applied at 8 and 12 weeks after sowing.

Urea and sulphate of potash were dissolved in water to produce separate stock solutions. A measured amount of each stock solution was then added to a watering can and made up to a final volume of 7 L before applying to each plot. Immediately after fertiliser application the plots were irrigated to apply 4 mm of water.

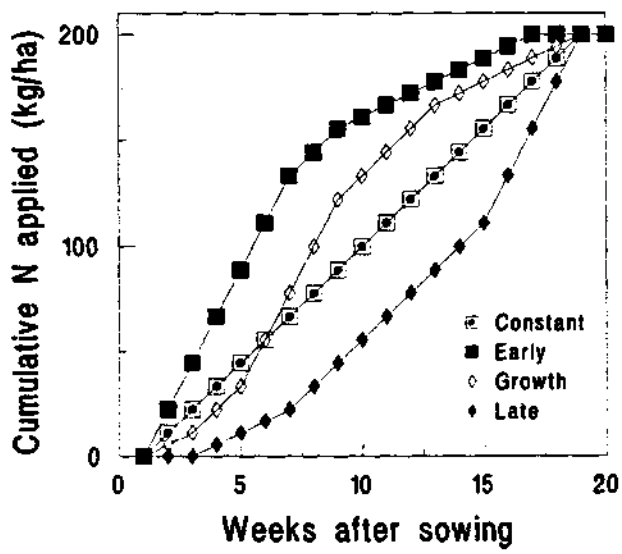


Fig. 1. Cumulative N applied in the 4 fertiliser regimes for the 200 kg N/ha rate.

Irrigation

Irrigation was applied with impact sprinklers at 9 by 12 m spacing and scheduled according to the previous days Class A pan evaporation. Rates of irrigation ranged from 80 % of Class A pan evaporation up to the 4-true leaf stage increasing to 100 % at the 8 leaf stage and then to 120 % when full ground cover was reached. Two waterings per day were applied when evaporation exceeded 5 mm/d. Irrigation adequacy was monitored at intervals with a soil capacitance probe (Environscan®).

Measurements

Forty youngest fully expanded leaves (YFEL) were sampled from the three middle rows of each plot between 8 and 9 am at 63, 77, 93, 105, 119 and 140 days after sowing (DAS). Twenty leaves were oven dried for nitrogen laboratory analysis of total N and nitrate-N. The sap nitrate-N concentration in fresh petioles was detemined from the remaining 20 leaves using a Nitrachek® meter to read Merkoquent® nitrate test strips. Nitrate standards were used to calibrate the test strips prior to measurement of nitrate. The petioles of the YFEL were removed from leaves, cut into sections and sap was extracted from a subsample using a garlic press. Diluted (1:20) sap was applied to the nitrate sensitive square of the Merkoquent® test strip and after one minute a meter reading was taken. Two to three strips were measured per replicate. Undiluted sap concentrations were measured when diluted sap produced 'lo' readings on the meter. The remaining petiole sample was dried and retained for laboratory analysis of total N and nitrate-N.

In addition, sap nitrate concentrations were measured daily for a week (112 to119 DAS) for the 200, 400 and 800 kg N/ha treatments to examine the effect of time of N application on sap nitrate-N concentrations. Each plot was sampled between 8.00 and 9.00 am each day and 20 leaves were sampled per plot in 3 replicates. Three metres of row from the middle three rows from each 6 m plot was hand harvested at maturity (140 DAS). The samples were weighed and graded into the following categories;

export yield : 25 to 50 mm crown diameter and greater than 150 mm length,
marketable short yield : 25 to 50 mm crown diameter and 100-150 mm length,
undersize : less than 25 mm crown diameter and less than 100 mm length,
oversize : more than 50 mm crown diameter, and,
other rejects such as forking, misshapen, and split roots.

Leaf yield from each plot was also recorded and the the average root length was estimated by measuring 20 randomly selected roots from each plot. In addition, a subsample of leaves and roots was taken from each plot and fresh and dry weights were determined for calculation of crop N uptake. Soil profile samples were collected from 3 replicates of the 0, 200, 400 and 800 kg N/ha treatments for the determination of soil nitrate-N and ammonium-N concentrations. From each plot, 3 core samples were taken and bulked at depths of 0-15 cm, 15-30 cm, 50 cm, 100 cm and 150 cm. Soils were cooled and analysed immediately after sampling.

Results were analysed by analysis of variance using GENSTAT statistical software.

Results

Effect of N rate on yield

A rational (quadratic/linear) function described the response of total yield to applied N (Fig. 2). The addition of nitrogen increased the total yield from 40.9 t/ha where no nitrogen was applied up to a maximum of 128.4 t/ha with 763 kg/ha of N (Fig. 2). To produce 90 % (115.6 t/ha) and 95 % (122.0 t/ha) of maximum yield, 222 and 325 kg N/ha respectively were required.

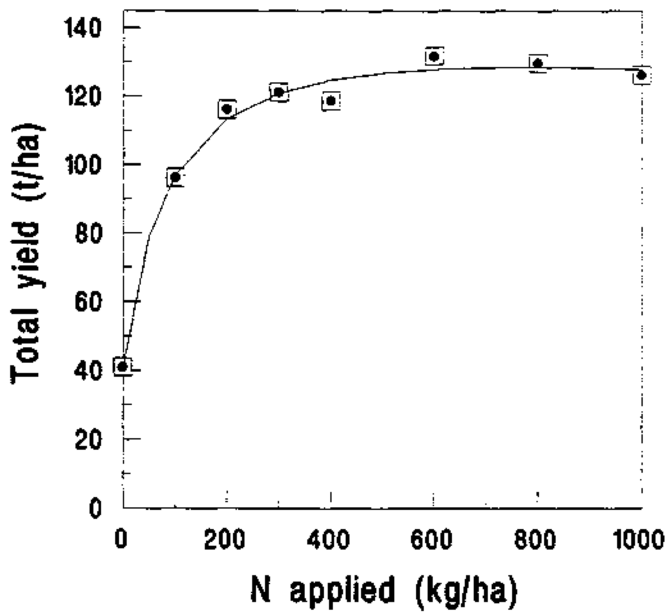


Fig. 2. The response of total carrot yield to applied nitrogen. Fitted function $Y = 149.9 - 109/(1+ 0.0111 x) - 0.0131 x$. $R^2 = 0.982$ where Y = total yield (t/ha) and x = nitrogen rate (kg N/ha).

Marketable yield responded similarly to applied N although the marketable yield declined more markedly above 600 kg N/ha (Fig. 3). Marketable yield increased from 34.4 t/ha with nil applied N reaching a maximum of 120.3 t/ha with 423 kg N/ha. Ninety % (108 t/ha), 95 % (114 t/ha) and 99 % (119.1 t/ha) of maximum marketable yield were produced with 188, 248 and 348 kg N/ha respectively.

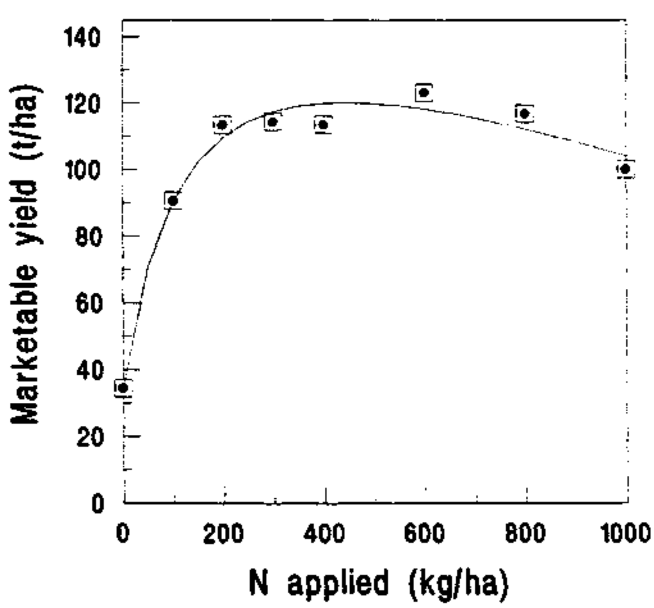


Fig. 3. The effect of nitrogen on marketable yield for Top Pak carrots. Fitted function $Y= 180.8- 146.2/(1+0.00735 x) - 0.0591 x$. $R^2 = 0.962$ where Y = marketable yield and x = nitrogen rate (kg N/ha).

Leaf yield increased with increased nitrogen rate. Leaf yield increased from 4.9 t/ha with nil applied N reaching 27 t/ha with 600 kg N/ha (Table 3).

The yield of oversize carrots increased with increasing N rate (Table 4). The nil N treatment produced the highest yields of marketable short and undersize roots (Tables 3 and 4). The yield of forked roots tended to increase with increasing N rate (Table 4) but was highly variable and the effect was not significant ($P>0.05$). The yield of split roots increased ($P<0.01$) at the highest N rate (Table 4).

Table 3. The effect of N rate on leaf yield, average root length, plant density, yield and marketability of carrots

Treatment (kg N/ha)	Leaf yield (t/ha)	Average root length (cm)	Density (plants/m^2)	Total yield (t/ha)	Marketable yield [A] (t/ha)	Export yield (t/ha)	Marketable short yield (t/ha)
0	4.9	13.8	71	40.9	34.4	15.8	18.6
100	10.4	17.1	73	96.2	90.6	81.4	8.6
200	14.9	19.1	67	116.2	113.5	100.1	4.5
300	18.4	18.5	68	121.1	114.5	99.8	6.1
400	20.5	18.7	61	118.7	113.7	87.0	5.7
600	26.7	19.7	63	131.8	123.2	87.7	3.8
800	26.3	19.3	63	129.6	116.8	94.8	3.8
1000	27.7	19.5	61	126.2	100.1	76.8	4.8
Significance	***	***	**	***	***	***	***
l.s.d ($P=0.05$)	4.0	1.4	6.2	14.0	22.4	21.2	3.0

[A]Marketable yield = export yield + marketable short yield + oversize yield

Table 4. The effect of N rate on the yield of various root categories and the root:top ratio of Top Pak carrots

Treatment (kg N/ha)	Undersize (t/ha)	Oversize (t/ha)	Forked (t/ha)	Misshapen (t/ha)	Split (t/ha)	Root:top ratio
0	6.0	0	0.6	0	0	8.4
100	2.5	0.7	2.7	0.4	0	9.2
200	0.7	8.9	1.5	0.5	0	7.8
300	0.9	8.5	3.5	2.2	0	6.6
400	0.1	21.1	4.5	0.4	0	5.8
600	0.3	31.6	7.3	0.0	1.0	5.0
800	1.1	18.3	9.8	0.6	1.3	4.9
1000	0.8	18.6	19.4	0	5.9	4.6
Significance	***	**	ns	ns	**	***
l.s.d ($P=0.05$)	1.9	15.2	-	-	2.7	0.7

The effect of N regime on yield

N regime significantly affected total yield, marketable yield (export+marketable short+oversize) and leaf yield. The early regime produced lower yields than all other regimes (Table 5). There was no difference between constant, late and growth regimes for total and marketable yield (Table 5). At both the 200 and 300 kg N/ha rates leaf yields were highest for the late regime and lowest for the early regime (Table 5).

Table 5. The effect of N regime on total yield, marketable yield and leaf yield

N regime	200 kg N/ha	300 kg N/ha
	Total yield (t/ha)	
Constant	116.2	121.1
Early	91.9	112.6
Late	114.3	125.1
Growth	111.2	128.7
Significance (N rate)	**	
l.s.d (*P=0.05*)	3.8	
Significance (N regime)	***	
l.s.d (*P=0.05*)	8.1	
Significance (rate*regime)	ns	
l.s.d (*P=0.05*)	-	
	Marketable yield (t/ha)	
Constant	113.5	114.5
Early	85.9	110.4
Late	106.5	121.8
Growth	110.6	124.3
Significance (N rate)	*	
l.s.d (*P=0.05*)	0.7	
Significance (N regime)	**	
l.s.d (*P=0.05*)	9.5	
Significance (rate*regime)	ns	
l.s.d (*P=0.05*)	-	
	Leaf yield (t/ha)	
Constant	14.9	18.4
Early	11.1	14.1
Late	17.0	21.9
Growth	14.2	18.2
Significance (N rate)	**	
l.s.d (*P=0.05*)	0.92	
Significance (N regime)	***	
l.s.d (*P=0.05*)	1.7	
Significance (rate*regime)	ns	
l.s.d (*P=0.05*)	-	

N regime had no effect on average root length, plant density, export and marketable short yield or the yield of other root categories including undersize, oversize, forked, misshapen and split roots (data not presented).

Petiole nitrate-N and leaf N concentrations

Sap nitrate-N concentrations in petioles of YFELs decreased rapidly between 63 and 93 DAS (Fig. 4). During this period for the 300 N rate, petiole nitrate-N fell from 1250 mg/L to 50 mg/L. At each sampling date, there were significant differences in sap nitrate-N concentrations among N rates (Table 14A). Increasing N rate generally resulted in higher sap nitrate-N concentrations at each sampling time. Separation between N rates was greatest at 77 DAS (Fig. 4) when carrots averaged 8 true leaves and 18 mm crown diameter.

Sap nitrate-N was well correlated with laboratory measured petiole nitrate-N when measured at 93 DAS. [y= 42.4 + 1091.1x, R^2=0.901 d.f. = 31, where x= laboratory nitrate-N (% d.w.) and y= sap nitrate-N (mg/L)].

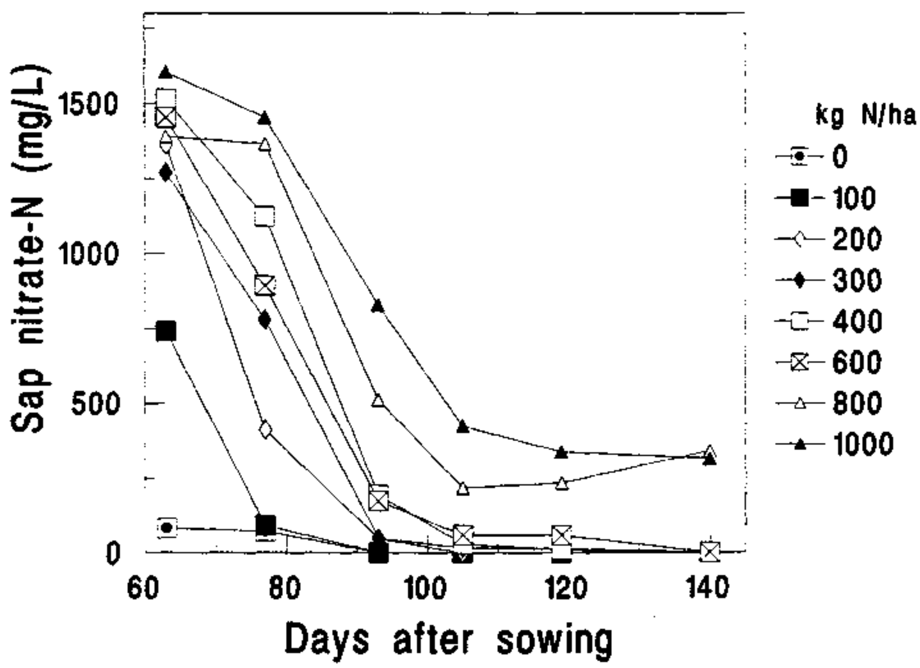


Fig. 4. Sap nitrate-N in the petioles of the youngest fully expanded leaves of Top Pak carrots over time.

Nitrogen concentration in dried youngest fully expanded leaves was affected by N rate at each sampling date. Generally N concentration increased with increasing N rate, however there was a Piper-Steinberg effect from 77 DAS onwards with the nil N treatments having elevated N concentrations (Table 6). N concentrations for each treatment declined over time (Table 6) as did nitrate-N concentrations in dried whole leaves (Table 15A).

Table 6. The effect of N rate on the N concentration (% d.w.) in youngest fully expanded leaves at various times after sowing

N rate (kg N/ha)	63 DAS	77 DAS	93 DAS	105 DAS	119 DAS	140 DAS
			(N % d.w.)			
0	4.38	3.72	3.07	2.98	2.75	2.35
100	4.84	3.31	2.64	2.66	2.50	2.00
200	5.17	3.85	2.74	2.77	2.59	2.20
300	5.23	4.02	2.82	2.90	2.69	2.56
400	5.19	4.52	3.33	3.01	3.02	2.32
600	5.29	4.37	3.41	3.11	3.09	2.45
800	5.36	4.63	3.52	3.63	3.20	2.55
1000	5.36	4.86	3.76	3.70	3.21	2.80
Significance	***	***	***	***	**	***
l.s.d ($P=0.05$)	0.21	0.34	0.30	0.33	0.35	0.29

Table 7 shows the effect of N application on the petiole sap nitrate-N levels at daily intervals commencing the day before a weekly application at 112 DAS. At 113 DAS, 24 hours after N application, sap nitrate-N concentrations had risen, especially for the 200 N treatment (Table 7). After 114 DAS, the concentrations continued to fall in the 200 and 400 N treatments. N concentration in dried YFEL was more stable than sap nitrate-N over this 7 day interval (Table 8).

Table 7. The concentration of sap nitrate-N (mg/L) in petioles each day between 112 and 119 days after sowing for 200, 400 and 800 kg N/ha treatments

Treatment (kg N/ha)	112 DAS	113 DAS	114 DAS	115 DAS	117 DAS	118 DAS	119 DAS
				sap nitrate-N (mg/L)			
200	0	85.3	2.9	0	0	0	0
400	83.3	97.8	30.5	28.4	25.5	50.6	7.0
800	250.0	290.4	270.3	287.7	350.0	304.8	245.7
Significance (N)				**			
l.s.d ($P=0.05$)				275			
Significance (Time)				**			
l.s.d ($P=0.05$)				138			
Significance (N*Time)				*			
l.s.d ($P=0.05$)				353			

Table 8. The effect of N rate on the N concentration (% d.w.) in youngest fully expanded leaves measured daily from 112 to 119 days after sowing

Treatment (kg N/ha)	112 DAS	113 DAS	114 DAS	115 DAS (N % d.w.)	117 DAS	118 DAS	119 DAS
200	2.65	2.56	2.72	2.58	2.67	2.52	2.55
400	3.01	2.95	3.30	2.83	3.07	2.72	3.10
800	3.20	3.12	3.71	3.26	3.01	3.33	3.09
Significance (N)				*			
l.s.d ($P=0.05$)				0.24			
Significance (Time)				*			
l.s.d ($P=0.05$)				0.21			
Significance (N*Time)				ns			
l.s.d ($P=0.05$)				-			

Critical nitrate-N and nitrogen ranges

Relationships between N applied and petiole nitrate-N and leaf N concentrations at each sampling date are listed in tables 9 and 10 respectively. These equations were used to calculate the sap nitrate-N and N concentrations at each sampling time which corresponded to 95 and 99 % of maximum yield at harvest. These ranges (the critical ranges) are plotted in Figs. 5 and 6.

Table 9. The relationships between N applied (x in kg N/ha) and the petiole sap nitrate-N concentration of carrots (Y in mg/L) at various times after sowing. PNY95 and PNY99 are calculated petiole sap nitrate-N concentrations which resulted in 95 and 99 % of maximum yield

Days after sowing	Equation	R^2	PNY_{95} (mg NO_3-N/L)	PNY_{99} (mg NO_3-N/L)
63	$y=34.25 + 506.0 \log x$	0.911	1305	1413
77	$y=-2.72 + 2.66x - 0.0012x^2$	0.912	734	1071
93	$y=18.27 - 0.158x + 0.001x^2$	0.972	57	216
105	$y=19.44 - 0.277x + 0.0007x^2$	0.984	3	70
119	$y=7.32 - 0.174x + 0.0005x^2$	0.978	3	56
140	$y=3.34 - 0.188x + 0.0006x^2$	0.818	6	73

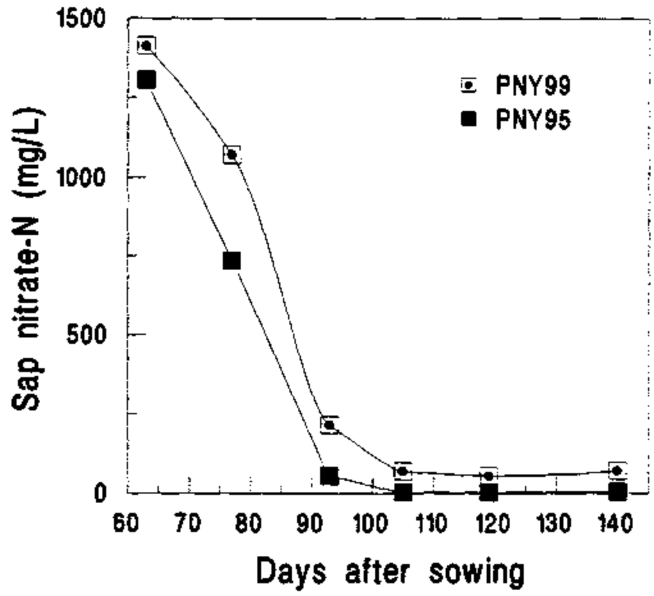


Fig. 5. Critical range for sap nitrate-N in petioles of youngest fully expanded leaves of carrots. PY95 and PY99 are the petiole sap nitrate-N concentrations which resulted in 95 and 99 % of maximum yield respectively.

Table 10. The relationships between N applied (x in kg N/ha) and the N concentration in leaves of carrots (Y in %) at various times after sowing. LNY95 and LNY99 are calculated N concentrations which resulted in 95 and 99 % of maximum yield

Days after sowing	Equation	R^2	LNY_{95} (% N d.w.)	LNY_{99} (% N d.w.)
63	y=4.99 + 0.0004x	0.662	5.12	5.20
77	y=3.52 + 0.0015x	0.809	4.01	4.32
93	y=2.56 + 0.0013x	0.906	2.98	3.25
105	y=2.52 + 0.0012x	0.959	2.91	3.16
119	y=2.49 + 0.0008x	0.859	2.75	2.91
140	y=2.08 + 0.0007x	0.741	2.31	2.45

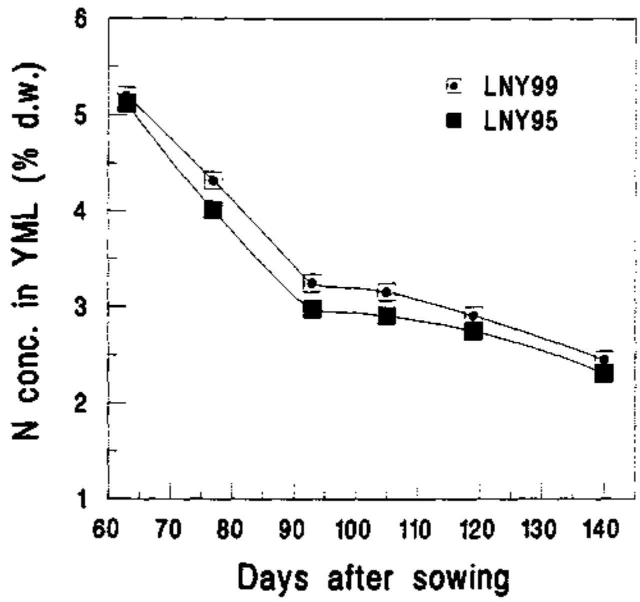


Fig. 6. Critical range for N concentration in the youngest fully expanded leaves of carrots. LNY95 and LNY99 are the N concentrations at each sampling time which resulted in 95 and 99 % of maximum yield respectively.

Fertiliser nitrogen recovery

The apparent fertiliser recovery is expressed as the percentage of fertiliser N recovered in the crop (tops + roots). N in the tops is returned to the paddock where it would become available for future crop uptake or leaching. At this site crop supplied with no fertiliser N took up 37.4 kg N/ha (Table 11). Apparent fertiliser recovery decreased from 65.4 % at 100 N to 41.6 % at 300 N and continued to decline with higher N rates (Table 11). The equation y = 145.4 - 40.8 log x, $R^2 = 0.985$ describes the relationship between N rate (x) and N fertiliser recovery (%).

Table 11. The N content of roots and tops of carrots and apparent N fertiliser recovery

N applied (kg/ha)	Root N content (kg/ha)	Tops N content (kg/ha)	Total N in crop (kg/ha)	Total - nil N (kg N/ha)	Crop N/ Fertiliser N (%)
0	23.4	14.0	37.4	-	-
100	73.5	28.1	102.8	65.4	65.4
200	101.5	39.6	141.1	103.7	51.9
300	116.2	46.2	162.3	124.9	41.6
400	132.6	53.4	186.0	148.6	37.2
600	174.0	66.6	240.6	203.2	33.9
800	189.1	70.7	259.9	222.5	27.8
1000	197.3	74.2	271.5	234.1	23.4

The early N regime had the poorest apparent N fertiliser recovery of 24.7 % at the 300 N rate while 57.1 % of the late regime N was recovered in the crop compared to 41.6 % for the constant N regime (Table 12).

Table 12. The effect of N regime on apparent N fertiliser recovery

N rate and regime	Root N content (kg/ha)	Tops N content (kg/ha)	Total N in crop (kg/ha)	Total - nil N (kg N/ha)	Crop N/ Fertiliser N (%)
200 constant	101.5	39.6	141.1	103.7	51.9
200 early	59.3	22.6	78.9	41.5	20.8
200 growth	91.1	32.6	123.7	86.3	43.2
200 late	110.5	44.5	155.0	117.6	58.8
300 constant	116.2	46.2	162.3	124.9	41.6
300 early	84.3	27.1	111.5	74.1	24.7
300 growth	107.1	41.6	143.0	105.6	35.2
300 late	148.3	60.3	208.6	171.2	57.1

Only low levels of ammonium and nitrate were detected in the soil to a depth of 150 cm at harvest (Table 13). N treatment did not influence the low levels of ammonium-N found in the soil profile while nitrate-N was only above detection limits in the 800 N plots at harvest. These soil samples were collected 7 days after the final N application.

Table 13. Soil ammonium and nitrate concentrations at various depths at harvest. Detection limit for both ammonium and nitrate-N was 0.5 µg/g. Readings < 0.5 µg/g were recorded as 0.25 µg/g

	Soil ammonium-N (µg/g dry soil)					Soil nitrate-N (µg/g dry soil)				
Treatment	0-15 cm	15-30 cm	50 cm	100 cm	150 cm	0-15 cm	15-30 cm	50 cm	100 cm	150 cm
0	0.74	0.70	0.57	0.25	0.25	0.25	0.25	0.25	0.25	0.25
200	0.70	0.63	0.33	0.25	0.25	0.25	0.25	0.25	0.25	0.25
400	0.67	0.63	0.37	0.25	0.25	0.25	0.25	0.25	0.25	0.25
800	0.97	0.80	0.25	0.25	0.25	2.90	4.37	2.22	0.97	1.27
Significance (N)			ns					***		
l.s.d ($P=0.05$)			-					0.708		
Significance (Depth)			***					ns		
l.s.d ($P=0.05$)			0.088					-		
Significance (N*D)			*					ns		
l.s.d ($P=0.05$)			0.17					-		

Using the data from Table 13 and a soil bulk density of 1.5 g/cm^3 to calculate residual N in the form of ammonium and nitrate in the soil revealed that after subtraction of N under the nil plots (17.2 kg/ha) no additional (fertiliser) N was detected under the 200 and 400 N treatments. Similarly, 40.4 kg N/ha of apparent fertiliser N was found under the 800 N plots.

Discussion

Carrot yield was highly responsive to N fertiliser at this site with the nil N crop producing only 32 % of the maximum total yield. Yield response functions predicted

95 and 99 % of maximum marketable yields of 114 and 119 t/ha with 248 and 348 kg N/ha respectively. Forbes and Westgate (1963) found that in 2 seasons out of 3, N rates of 224 and 280 kg N/ha were insufficient to maximise the yield of Chantenay carrots growing through winter on a fine sand in Florida.

Application of an additional 100 kg N/ha to produce an extra 4 % of yield can be justified on economic grounds [100 kg of N (as urea) = $80, additional gross income 5.1 t at $260/t = $1326] however N fertiliser recovery was substantially reduced viz.,
At 95 % max. yield fertiliser recovery = 47.8 %, 118.5 kg N/ha in crop
⇒ 129.4 kg N lost,
At 99 % max. yield fertiliser recovery = 41.7 %, 145.3 kg N/ha in crop
⇒ 202.7 kg N lost.
Hence an extra 57 % of fertiliser N is lost in producing the extra 4 % in yield and the scope for nitrate enrichment of groundwater is increased accordingly. More information on the fate of N lost from this system is required including quantification of N leached and volatilized.

Apart from the early N regime which produced lower yields, varying the N application regime had little effect on yields. A greater proportion of N applied in the early regime would have been subject to leaching from August (171 mm) rainfall reducing yields and N recovery. The late regime had the highest N fertiliser recoveries probably as a result of less rainfall mediated leaching on the greater proportion of N applied during dry late spring conditions (December rainfall 10 mm).

As with other crops such as potatoes (Williams and Maier 1990), sap nitrate-N was well correlated with nitrate-N in dried petioles measured in the laboratory. Measurement of sap nitrate-N concentrations 63 days after sowing allowed detection of only severely N deficient crop which was already obvious from the symptoms of reduced growth and chlorotic old leaves. For the next month sap nitrate-N levels fell rapidly with the critical nitrate-N range falling from 1300 - 1400 mg/L down to 57 - 216 mg/L. At mid-growth when the crop was at the 8-leaf stage the critical range for petiole sap nitrate-N was from 730 - 1070 mg/L. However the sharp decline in the critical nitrate-N range over this period would limit the practical application of these critical ranges.

During the later stages of crop growth the critical sap nitrate-N range steadied such that petioles of crop producing > 99 % of maximum yield contained low (<70 mg/L) but detectable levels of nitrate-N. During this time sap nitrate-N could not be detected in the petioles of Ndeficient crop. Thus it appears possible to monitor N adequacy in the field during the latter stages of carrot crop growth using sap analysis.

Nitrogen concentration in YFEL followed similar trends to sap nitrate-N and, with fast laboratory turn-around, would also be useful for monitoring N status during the latter stages of crop growth.

Conclusions

To produce 90, 95 and 99 % of maximum marketable yield of the Nantes carrot variety Top Pak sown on a sandy soil in winter, 188, 248 and 348 kg N/ha repectively as urea was required when applied in equal weekly applications.

Apart from the lower yields and fertiliser recoveries on the early regime which received 78 % of the N fertiliser in the first 9 weeks, N regime had little effect on yield. There was some indication of higher N fertiliser recoveries in crop grown on the late regime which should be further investigated.

The use of sap analysis and tissue testing for assessing the N status of carrots may, for practical purposes, be limited to the latter stages of crop growth because critical petiole nitrate-N and YFEL N concentration ranges declined rapidly over the early stages of the crop. This would add considerable uncertainty to the interpretation of petiole or leaf N analysis from commercial crops during the early stages of crop growth.

Confirmation of these results is needed along with further work on the fate of applied N fertiliser in relation to crop water use and irrigation drainage.

Appendix

Table 14A. The effect of N rate on the sap nitrate-N concentration (mg/L) in the petioles of YFELs at 6 times.

Treatment	63 DAS	77 DAS	93 DAS	105 DAS	119 DAS	140 DAS
			sap nitrate-N (mg/L)			
0	82.6	72.5	0.0	5.0	0.0	0.0
100	740.6	92.4	0.0	0.0	0.0	0.0
200	1360.7	410.7	47.2	0.0	0.0	0.0
300	1269.2	779.0	47.9	17.4	13.5	0.0
400	1513.8	1123.4	193.3	29.6	9.9	0.0
600	1497.5	997.1	170.5	47.2	54.4	0.0
800	1389.6	1364.7	511.0	217.0	233.3	339.4
1000	1603.6	1453.5	829.6	423.4	337.3	313.2
Significance	***	***	***	***	***	**
l.s.d ($P=0.05$)	263.3	342.8	112.0	100.0	79.5	199.2

2. *Experiment 92MD36 - The response of spring sown Nantes carrots to nitrogen fertiliser rate and regime*

Aim

Carrots are grown on the sandy soils of the Swan Coastal Plain near Perth in Western Australia for export and local markets. There is increasing focus on the offsite effects of horticulture on the Coastal Plain. Guidelines are needed for nitrogen (N) fertiliser management for vegetable cropping to assist in balancing profitability with the risk of nitrate enrichment of groundwater. Growers need to avoid excessive N usage while producing profitable crop yields.

The objective of this experiment was to define the yield response to N fertiliser of Nantes carrots growing through summer. The effect of N regime on yield and N recovery was also examined and critical ranges for leaf N concentration and petiole nitrate-N were estimated.

Materials and Methods

Site details and crop management

The experiment was conducted at the Medina Research Centre, 40 km south of Perth on a Spearwood sand (Uc 4.13, Northcote 1979). The site had a history of vegetable cropping with lettuce the previous crop. Preplanting soil test results are presented in Table 1.

Table 1. Soil (0-15 cm) characteristics of the site

pH (1:5 $CaCl_2$)	7.3
Extractable phosphorus[A]	100 mg/kg
Extractable potassium[A]	15 mg/kg
Organic carbon[B]	0.71 %

[A] After Colwell (1963), [B] After Walkley and Black (1947)

Fenamiphos (Nemacur®) was applied to the site for nematode control. Superphosphate (500 kg/ha), muriate of potash (120 kg/ha), magnesium sulphate (50 kg/ha) and 100 kg/ha of trace element mix were broadcast and rotary hoed across the site before planting.

Pelleted seed of the variety Top Pak (South Pacific Seeds) was sown with an Agricola Italia® air seeder on the 2 December 1992, with a target density of 90 plants/m^2. Each plot was 6 m long with 5 rows per 1.5 m wide bed. Linuron was applied at recommended rates to control weeds and chlorothalonil (Bravo®) was applied when necessary to control leaf diseases.

Experimental design

There were 14 treatments and 4 replicates per treatment (Table 2). Treatments were arranged in a randomised block design with 8 rates of N (0, 100, 200, 300, 400, 600, 800 and 1000 kg/ha) and 6 additional treatments were included to examine the effect of N regime at two rates, 200 and 300 kg N/ha. The arbitrary regimes were named constant, early, growth and late (Table 2). All N was applied as urea.

Table 2. Details of nitrogen treatments

Treatment (kg N/ha)	Time of N application
0	Nil applied N
100, 200, 300, 400, 600, 800 and 1000 constant	Applied in 14 equal weekly dressings commencing two weeks after sowing
200 and 300 early	56 % applied in first 4 weeks, 44 % in weeks 5-14
200 and 300 late	25 % applied in first 5 weeks, 75 % in weeks 6-14
200 and 300 growth	44% applied in first 4 weeks, 56 % in weeks 5-14

Urea and sulphate of potash were dissolved separately in water to produce stock solutions. A sub-sample of each stock solution was then added to a watering can and made up to a final volume of 7 L of water and applied to each plot.

A total of 420 kg/ha of potassium sulphate (41.5 % K) was applied to the crop in 14 equal weekly dressings. Side dressings of magnesium sulphate (150 kg/ha total) and borax (10 kg/ha) were broadcast across the site as the crop grew.

Irrigation

Irrigation was applied with impact sprinklers at 9 by 12 m spacing in 2 irrigations per day. The site received 80 % Class A pan evaporation (from the previous day) for 8 weeks after planting and thereafter received 100 % of pan evaporation. Irrigation adequacy was also monitored with a soil capacitance probe (Environscan®). Irrigation water contained 3 mg/L NO_3- N.

Measurements

Twenty youngest mature leaves (YML) comprising blades + petioles, were collected from the three middle rows of each plot between 8 and 9 am every fortnight commencing 49 days after sowing (DAS) and oven dried at 70°C for laboratory analysis of total N and nitrate-N. At 77 and 105 DAS, the sap nitrate-N concentration in the petioles was determined as follows. The petioles of an additional 20 YML were separated from the blades and cut into sections. A subsample of the petioles was air dried at 70°C and analyzed for total N and nitrate-N in the laboratory. Sap was extracted from the remaining petiole sample with the aid of a garlic press. Nitrate standards were used to calibrate the Nitrachek® meter and Merckoquant® test strips prior to measurement of sap nitrate. Sap was diluted (1:20) in distilled water before applying to the nitrate sensitive square of the Merkoquent® test strip and a meter reading taken after one minute. Two to three strips were measured per replicate.

Plots were harvested 105 days after sowing (DAS). Three metres of row from the middle three rows from each 6 m plot was hand harvested and roots were weighed and graded into the following categories:

Export, 25 to 50 mm crown diameter and greater than 150 mm length,
Marketable, short yield: 25 to 50 mm crown diameter and 100-150 mm length,

Undersize, less than 25 mm crown diameter and less than 100 mm length,
Oversize, more than 50 mm crown diameter, and,
Rejects, such as forked, misshapen, and split roots.

Leaf yield from each plot was recorded. In addition, sub-samples of leaves and roots were taken from each plot to determine fresh and dry weights for calculation of crop N uptake.

The results were analysed by analysis of variance using GENSTAT statistical software. Total and marketable yield curves were analyzed by nonlinear regression using GENSTAT software. Inverse polynomials were fitted to the relationship between N applied and total and marketable yield using GENSTAT software.

Results

Effect of N rate on yield

Nitrogen significantly ($P<0.001$) affected the total yield of carrots (Table 3). A rational function (quadratic/linear) described the relationship between total yield and applied N (Fig. 1). The rate of N required for 90 % of maximum yield (105 t/ha) was 215 kg N/ha, 290 kg N/ha was required for 95 % of maximum yield (111 t/ha), while 390 kg N/ha was required to produce 99 % of maximum yield (115 t/ha).

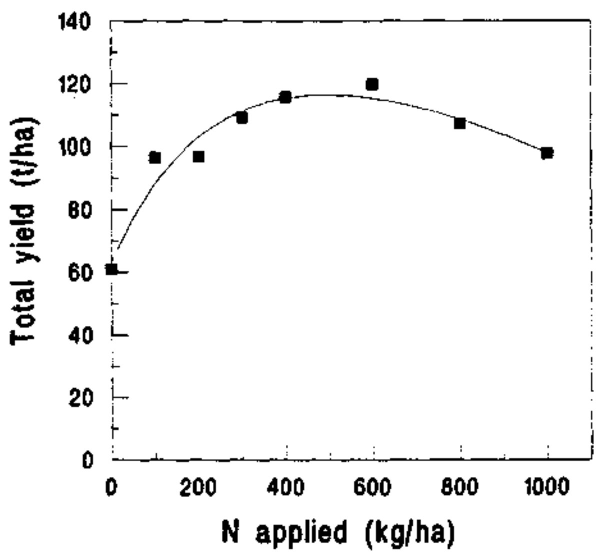


Fig. 1. The response of Top Pak carrot yield to nitrogen. Fitted function $Y = 275-212/(1+0.00204x) - 0.1072x$. $R^2 = 0.897$ where Y = total yield (t/ha) and x = nitrogen rate (kg N/ha).

A third order polynomial function accounted for most of the variation in marketable yield in response to N rate ($R^2 = 0.878$). Maximum marketable yield from this function was 74.9 t/ha with 241.4 kg N/ha applied. Marketable yield declined sharply at high N rates because of increases in rejection from forked roots (Table 4). There was also a small but significant reduction in plant density with high N rates (Table 3).

Leaf yield was increased with increasing N rate from 12 t/ha with nil N to a maximum of over 40 t/ha with 600 kg N/ha (Table 3).

Table 3. The effect of N on leaf yield, plant density, total and marketable yield of Top Pak carrots

Treatment (kg N/ha)	Leaf yield (t/ha)	Density (plants/m^2)	Total yield (t/ha)	Marketable yield (t/ha)[A]	Export yield (t/ha)	Marketable short yield (t/ha)
0	11.6	113	60.9	33.9	17.8	16.1
100	20.0	108	96.4	78.7	52.8	25.9
200	22.1	95	96.7	71.5	51.5	20.0
300	30.6	100	109.2	75.8	48.3	27.6
400	35.4	95	115.7	63.2	42.7	20.5
600	46.0	96	119.8	36.0	24.4	11.5
800	41.7	83	107.4	31.4	22.2	9.2
1000	43.1	90	97.7	21.8	12.8	9.0
Significance	***	*	***	***	***	***
l.s.d (P=0.05)	8.9	14.6	18.1	21.9	16.6	11.1

[A]marketable yield = export yield + marketable short yield

The nil N treatment produced the highest yields of marketable short and undersize roots while higher N rates generally produced greater yields of oversize roots (Table 4). The high N rates produced the highest incidence of 'other' rejects, the major reason for rejection in this category was rots. Rot symptoms were consistent with bacterial soft rot caused by *Erwinia* spp.

Table 4. The effect of N rate on the yield of reject categories

Treatment (kg N/ha)	Undersize (t/ha)	Oversize (t/ha)	Forked (t/ha)	% forked[A]	Misshapen (t/ha)	Other (t/ha)[B]
0	21.4	0	0.9	1.4	1.6	3.0
100	11.9	1.8	0.7	0.8	2.3	1.1
200	5.2	0.7	12.8	12.5	4.3	2.3
300	7.7	9.0	14.2	12.9	0.6	1.9
400	4.7	6.3	29.3	25.3	2.0	10.3
600	5.1	3.8	60.6	50.9	1.1	13.3
800	4.5	7.3	51.2	49.0	2.0	11.0
1000	2.6	2.8	61.5	64.5	1.9	7.1
Significance	***	*	***	***	ns	*
l.s.d (P=0.05)	4.2	5.5	19.5	19.3	-	7.8

[A]Data not transformed [B]mainly rots, splitting, hairy roots..

The effect of N regime on yield

N regime significantly affected total yield, leaf yield, density, export yield, marketable short yield and the yield of forked roots (Table 5). Total yields were highest with the late regime and lowest with the early regime although the late regime total yield was not significantly higher than the constant and growth regimes (Table 5). The late and growth regimes also produced the highest export yields (Table 5). The late regime produced the highest leaf yields (Table 5). The early regime had a lower plant density than the other regimes (Table 5).

The early regime produced a higher (*P<0.001*) incidence of forking than the other regimes. The early regime had 48 % of yield forked compared to 13 % for the constant, 6 % for the growth and only 1.4 % for the late regime. N regime had no effect on the yield of undersize, oversize, misshapen roots or other rejects (data not presented). There were no significant differences between the 200 and 300 kg N/ha rates on root yields while the 300 kg N/ha produced a higher leaf yield than 200 kg N/ha.

Table 5. Effect of N regime on total, marketable, export, marketable short yield, and leaf yield, density and the incidence of forked roots

	200 kg N/ha	300 kg N/ha	N rate means	Signif. (rate of N)	l.s.d (P=0.05)	Signif. (N regime)	l.s.d (P=0.05)	Signif. (rate*regime)
Density (plants/m²)								
Constant	95	100	98					
Early	73	89	81	ns	-	**	10.8	ns
Late	104	109	106					
Growth	96	92	94					
Total yield (t/ha)								
Constant	96.7	109.2	103.0					
Early	84.4	101.9	93.2	ns	-	***	11.1	ns
Late	110.5	114.9	112.7					
Growth	108.1	107.0	107.5					
Marketable yield (t/ha)								
Constant	71.5	75.8	73.7					
Early	34.2	39.1	36.6	ns	-	***	9.7	ns
Late	86.2	94.0	90.1					
Growth	83.6	83.0	83.3					
Export yield (t/ha)								
Constant	51.5	48.3	49.9					
Early	24.5	27.2	25.8	ns	-	***	9.9	ns
Late	64.8	70.7	67.7					
Growth	61.7	65.2	63.4					
Marketable short yield (t/ha)								
Constant	20.0	27.6	23.8					
Early	9.7	11.9	10.8	ns	-	**	6.3	ns
Late	21.4	23.3	22.3					
Growth	21.8	17.8	19.8					
Leaf yield (t/ha)								
Constant	22.1	30.6	26.4					
Early	20.6	27.2	23.9	*	2.2	***	3.9	ns
Late	33.1	35.6	34.3					
Growth	27.5	27.9	27.7					
means	25.8	30.3						
Forked (t/ha)								
Constant	12.8	14.2	13.5					
Early	36.2	53.2	44.7	ns	-	***	11.3	ns
Late	2.2	0.9	1.5					
Growth	4.9	7.1	6.0					

Petiole nitrate-N and leaf N concentrations

Increasing nitrogen rate significantly ($P<0.001$) increased the concentrations of N and NO_3-N in the YML (Tables 6 and 7). The trend over time was for both N and NO_3-N concentrations to decrease across all treatments from 49 until 105 DAS.

Table 6. Nitrogen concentration in YML of carrots at 49, 63, 77, 91 and 105 days after sowing (DAS)

Treatment	49 DAS	63 DAS	77 DAS	91 DAS	105 DAS
			N (% d.w.)		
0	2.77	2.10	2.27	2.12	1.97
100	3.05	2.27	2.18	2.16	2.13
200	3.61	2.63	2.55	2.31	2.21
300	3.83	2.59	2.36	2.18	2.17
400	4.00	2.92	2.62	2.24	2.32
600	4.19	3.19	2.72	2.45	2.66
800	4.12	3.29	2.93	2.81	2.78
1000	4.42	3.38	3.09	2.81	2.80
Significance	***	***	**	***	***
l.s.d (P=0.05)	0.33	0.32	0.40	0.23	0.24

Table 7. Laboratory measured nitrate-N (% dry weight) concentration in YML of carrots at 49, 63, 77, 91 and 105 days after sowing (DAS)

Treatment	49 DAS	63 DAS	77 DAS	91 DAS	105 DAS
			Nitrate-N (% d.b.)		
0	0.010	0.010	0.010	0.010	0.010
100	0.009	0.010	0.013	0.015	0.010
200	0.085	0.023	0.013	0.017	0.010
300	0.128	0.055	0.025	0.020	0.010
400	0.335	0.178	0.053	0.043	0.025
600	0.468	0.275	0.160	0.140	0.090
800	0.499	0.325	0.273	0.219	0.139
1000	0.608	0.370	0.435	0.213	0.215
Significance	***	***	***	***	***
l.s.d (P=0.05)	0.0685	0.081	0.087	0.038	0.044

N and NO_3-N concentrations were also measured by laboratory and by test strip techniques respectively in the petioles of YML at 77 and 105 DAS (Table 8). Sap NO_3-N in the petioles of the YML as measured by test strips was highly correlated to laboratory measured NO_3-N and N in dried YML with R^2 ranging from 0.85-0.97) (Table 9).

Table 8. Nitrogen and NO_3-N concentrations in petioles at 77 and 105 DAS by laboratory and test strip techniques

Treatment	77 DAS N (% d.b.)	77 DAS NO_3-N (% d.b.)	77 DAS sapNO_3-N (mg/L)	105 DAS N (% d.b.)	105 DAS NO_3-N (% d.b.)	105 DAS sapNO_3-N (mg/L)
0	0.75	0.018	0	0.75	0.015	0
100	0.68	0.012	0	0.69	0.010	0
200	0.71	0.022	0	0.74	0.010	0
300	0.69	0.030	16	0.76	0.015	0
400	0.87	0.085	143	0.75	0.013	0
600	0.96	0.238	459	0.92	0.146	333
800	1.08	0.357	606	1.08	0.258	420
1000	1.03	0.390	848	1.13	0.285	390
Significance	***	***	***	***	***	***
l.s.d (P=0.05)	0.162	0.079	172	0.136	0.064	94

Table 9. Correlations between sap NO_3-N and total N and NO_3-N in youngest mature leaves (YML) and petioles (P) of carrot

DAS	y x	Equation	R^2
77	Sap NO_3-N vs P-N (% d.w.)	y =-1379.05 + 1934.36x	0.867
	Sap NO_3-N vs P-NO_3-N (% d.w.)	y = -40.16 + 2069.88x	0.980
	Sap NO_3-N vs YML-N (% d.w.)	y = -2271.75 + 976.70x	0.862
	Sap NO_3-N vs YML -NO_3N (% d.w.)	y = 0.5461 + 2096.60x	0.968
105	Sap NO_3-N vs P-N (% d.w.)	y = -812.21 + 1120.34x	0.918
	Sap NO_3-N vs P-NO_3-N (% d.w.)	y = -9.082 + 1619.79x	0.942
	Sap NO_3-N vs YML-N (% d.w.)	y = -1258.23 + 588.70x	0.906
	Sap NO_3-N vs YML-NO_3-N (% d.w.)	y = -6.801 + 2352.48x	0.848

Sap NO_3-N in mg/L

Critical concentrations of N and NO_3-N for 95-99 % of maximum yield over time in the YML and petiole of carrots are presented in Table 10. At 49 DAS, the critical N concentration range was 3.77-3.95 %, whereas at harvest (105 DAS) the critical range had fallen to 2.26-2.35 %.

Table 10. Critical concentrations ranges for N and NO_3-N in youngest mature leaves (YML) and petioles (P) of carrot over time. All x variables as % d.w. except petiole sap NO_3- N for which units are mg/L

Days after sowing	x	Relationship between x and total yield (y)	R^2	Critical concentration range of x for 95-99 % of maximum yield
49	YML-N	y = 4.38 - exp (-0.003464x)	0.960	3.77-3.95
63	YML-N	y = 2.24 + 0.00131x	0.917	2.62-2.75
77	YML-N	y = 2.22 + 0.00087x	0.914	2.47-2.56
91	YML-N	y = 2.06 + 0.00076x	0.882	2.28-2.36
105	YML-N	y = 2.00 + 0.00089x	0.941	2.26-2.35
49	YML-NO_3-N	y = -0.015 + 0.00066x	0.943	0.177-0.243
63	YML-NO_3-N	y = -0.023 + 0.00042x	0.944	0.099-0.141
77	YML-NO_3-N	y = -0.058 + 0.00043x	0.901	0.066-0.109
91	YML-NO_3-N	y = -0.021 + 0.00025x	0.903	0.052-0.076
105	YML-NO_3-N	y = -0.041 + 0.00032x	0.872	0.052-0.083
77	P-NO_3-N	y = -0.044 + 0.00044x	0.929	0.084-0.128
105	P-NO_3-N	y = -0.041 + 0.00032x	0.872	0.051-0.083
77	P-N	y = 0.668 + 0.00042x	0.823	0.832-0.790
105	P-N	y = 0.657 + 0.00046x	0.892	0.791-0.837
77	P-Sap NO_3-N	y = -134.93 + 0.924x	0.931	133-226
105	P-Sap NO_3-N	y = -75.85 + 0.515x	0.820	73-125

Fertiliser nitrogen recovery

N content by various plant parts increased significantly ($P<0.001$) with rate of applied N (Table 11).

The effect of N rate on apparent fertiliser recovery (AFR) in whole plants and roots is shown in Fig 2. AFR for whole plants decrease linearly with increasing rate of applied N ranging from 0.43 at 100 kg N/ha to 0.23 at 1000 kg N/ha. AFR for roots remained reasonably stable and close to 0.2, declining only at the highest N rate (Fig. 2).

Table 11. The effect of N rate on N content at harvest of whole plants, leaves and roots and apparent fertiliser recovery (AFR) for whole plants and roots

Treatment (kg N/ha)	N content of leaves (kg/ha)	N content of roots (kg/ha)	N content of whole plant (kg/ha)	AFR[A] whole plants	AFR roots
0	36.0	42.6	78.6	-	-
100	47.1	77.6	124.6	0.46	0.18
200	55.8	89.5	145.3	0.33	0.20
300	78.5	120.7	199.2	0.40	0.18
400	101.2	147.8	249.0	0.42	0.24
600	137.6	152.5	290.1	0.35	0.17
800	111.8	178.4	290.2	0.26	0.16
1000	136.5	160.2	296.7	0.22	0.11
Significance	***	***	***		
l.s.d (*P*=0.05)	27.5	44.8	48.8		

[A] AFR = [(N content)-(N content in 0 kg N/ha treatment)]/ N applied

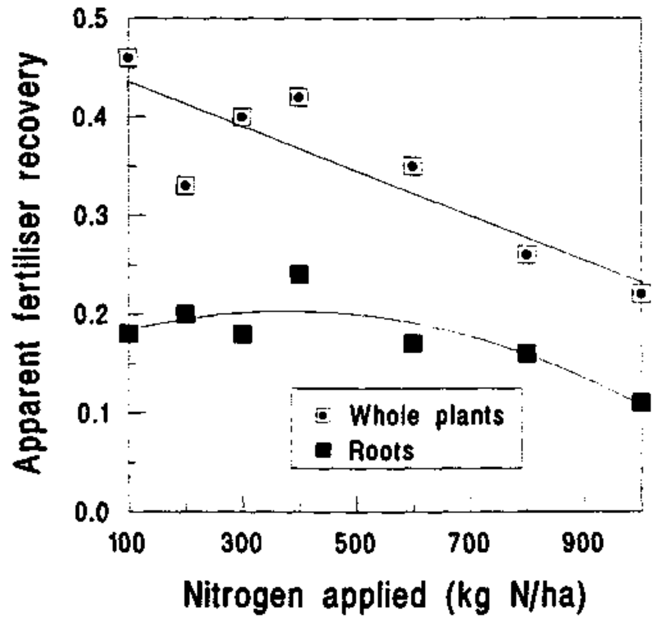


Fig. 2. The effect of applied nitrogen rate on the apparent fertiliser recovery of carrots

Regime had significant effects on leaf and root dry matter contents as well as leaf and root nitrogen concentrations (Table 12). Nitrogen concentrations in leaves and roots were highest with the late regime, intermediate with the constant and growth regimes and lowest with the early regime (Table 12).

Table 12. The effect of N regime on carrot nitrogen concentrations and dry matter contents

N rate and regime	Leaf N (%)	Leaf dry matter (%)	Root N (%)	Root dry matter (%)
200 constant	1.88	14.5	0.89	10.5
200 early	1.47	15.6	0.78	10.9
200 growth	1.57	14.2	0.94	9.8
200 late	2.00	13.5	1.16	9.7
300 constant	1.86	14.0	1.09	10.0
300 early	1.67	14.6	0.90	10.9
300 growth	1.80	14.9	1.07	10.3
300 late	2.19	13.4	1.46	9.9
Signif. (rate)	*	ns	*	ns
l.s.d. (P=0.05)	0.08	-	0.09	-
Signif. (regime)	***	***	***	**
l.s.d. (P=0.05)	0.35	0.52	0.10	0.50
Signif. (rate*regime)	ns	ns	ns	ns

The effect of regime on nitrogen uptake is shown in Table 13. Crop N uptake was highest with the late regime, intermediate with the constant and growth regimes and lowest with the early regime. On average about 62 % of the total crop N was in the roots.

Table 13. The effect of N regime on N uptake and apparent fertiliser recovery (AFR)

N rate and regime	Tops N content (kg/ha)	Root N content (kg/ha)	Total N in crop (kg/ha)	AFR[A] whole plants	AFR roots
200 constant	58.2	90.3	143.0	0.32	0.23
200 early	46.9	75.2	126.1	0.24	0.16
200 growth	59.1	102.9	154.6	0.38	0.30
200 late	88.8	125.5	214.3	0.68	0.41
300 constant	83.9	119.2	194.9	0.39	0.26
300 early	57.9	110.5	187.8	0.36	0.23
300 growth	78.3	116.6	194.0	0.38	0.25
300 late	104.7	166.6	249.5	0.57	0.41
Signif. (rate)	P=0.076	*	***		
l.s.d. (P=0.05)	-	12.4	7.3		
Signif. (regime)	***	***	***		
l.s.d. (P=0.05)	6.1	17.8	14.1		
Signif. (rate*regime)	ns	ns	ns		

[A] AFR = [(N content)-(N content in 0 kg N/ha treatment)]/ N applied

Discussion

The late regime had an apparent fertiliser recovery (leaves and roots) of 62 % (mean of 200 and 300 N rates) while the constant regime averaged 36%. Adjusting N regime thus has considerable scope to improve N use efficiency. At this site, the late regime produced higher yields, less root forking and higher N recoveries than the constant regime. The late regime also produced lower leaf and root dry matter content and higher N concentrations than the constant regime.

While total yields reached maximum at about 500 kgN/ha, marketable and export yields both reached maxima between 100 and 300 kgN/ha. Higher N rates reduced marketable yields mainly through a dramatic increase in the proportion of forked (or stumped) roots and to a lesser degree, in an increase in rots. This may have been related to ammonium toxicity effects on the developing tap root of the carrots.

The early regime produced 48% root forking compared to 13% for the constant regime and 1.4% for the late regime. During the first six-weeks after sowing the constant regime received 14.3 kgN/ha/week, the late regime 10 kgN/ha/week and the early regime 25 kgN/ha/week as urea. These differences caused the observed differences in the incidence of root forking, an effect which may have been exacerbated by the 0.8 Epan crop factor for irrigation scheduling during the early stages of crop growth. This effect of N (urea) on root forking needs further investigation, given that 10-15/kgN/ha/week is within the commercial fertilisation rate range for young carrots. In the earlier winter (July) sown experiment in this series, N rate and regime had N significant effects on root forking although forking tended to increase with very high N rates in that planting.

With the constant weekly regime, 290 kg N/ha produced 95% maximum total yield while 390 kg N/ha was needed to produce 99% of maximum yield. Apparent fertiliser recoveries in the whole crop (leaves and roots) at these N rates were similar and were close to 40%. Thus for the 4% yield between 95 and 99% of maximum an extra 100 kgN/ha was required, of which 40 kgN/ha was recovered in the crop and the remaining 60 kgN/ha is lost, presumably by leaching.

Applying higher N rates early (the early regime) also increased forking dramatically. Altering the N regime for the 200 and 300 kgN/ha rates affected both total and marketable yields. The late N regime gave the highest yields such that 200 N late had total yields higher than 300 N applied under a constant regime. The 200 N late produced an export yield of 64.8 t/ha while 300 N constant produced 48.3 t/ha

Conclusion

Near maximum marketable yield from this summer sowing was achieved with between 100 and 300 kg N/ha applied in the late regime compared with the winter sowing which required 348 kg N/ha for 99% of maximum marketable yield. Slower growth and winter rainfall would probably account for the differences in N requirement between summer and winter sown crops.

Altering N regime had little impact in the winter sowing, but applying a greater proportion of N fertiliser later in the crop (late regime) improved yield and fertiliser N recovery in the summer planting.

At maximum marketable yield levels and with constant weekly N applications, the equivalent of about 40% of applied fertiliser was recovered in the crop.
In both summer and winter plantings, the late regime improved apparent fertiliser recoveries (AFRs) over those from applying constant weekly amounts of N (constant regime). In the winter planting, the late regime averaged a 12% higher AFR than the constant regime while for the summer planting the late regime AFR was 26% higher than that of the constant regime.

Based on this work, an N program for Nantes carrots growing on sand which produces high yield and quality and gives relatively high fertiliser use efficiency would be:

Crop age	Application rate (kg N/ha/week)
Weeks 0-1	0
Weeks 2 - 6	10
Weeks 7 - 1 week before harvest	25

For a summer crop (15 weeks) total N application would be 250 kg/ha and for a winter crop (20 weeks), total N application would be 375 kg/ha.
Leaves are not removed from the paddock when carrots are harvested and hence the fate of N in leaves need to be considered in relation to following crops.
Further work on N use efficiency should be combined with irrigation scheduling work. More consideration of the efforts of N on root forking would be of benefit to growers and should consider N rate and timing, as well as N source, ie ammonium-nitrogen versus nitrate-nitrogen.

Acknowledgements

Thanks to Kris Gajda, Rani Weissberg and the staff of Medina Research Centre for technical assistance.. Staff of the Chemistry Centre of Western Australia are also thanked for conducting the analytical work. South Pacific Seeds are thanked for donating the carrot seed. Financial support from the Sumich Group Ltd and the HRDC is gratefully acknowledged.

References

Colwell, J. D. (1963). The estimation of phosphorus fertiliser requirements of wheat in southern New South Wales by soil analysis. *Australian Journal of Experimental Agriculture and Animal Husbandry* **3**, 190-197.

Fallon, J. P. and Hawson M.G. (1973). Carrot fertiliser trials - Rate and frequency response. *Australian Vegetable Research Newsletter* **29**, 67-68.

Forbes, R. B. and Westgate, P.J. (1963). Carrot fertilization experiments in central Florida. *Proceedings of the Soil and Crop Science Society of Florida* **23**, 99-104.

Northcote, K. H. (1979). A Factual Key for the Recognition of Australian Soils. 4th ed. (Rellim Technical Publications: Glenside, South Australia.)

Phillips, D. R. (1988). Investigation of cultural and management techniques for mechanically harvested export carrots. Final report to Australian Special Rural Research Fund.

Williams, C. M. J. and Maier N. A. (1990). Determination of the nitrogen status of irrigated potato crops II. A simple on farm quick test for nitrate-nitrogen in petiole sap. *Journal of Plant Nutrition* **13**, 985-993.

9. THE EFFECT OF CONTINUOUS CROPPING WITH AND WITHOUT METHAM SODIUM ON THE YIELD AND QUALITY OF CARROTS

A. G. McKay and A. Galati

Summary

Carrots were continuously cropped with and without pre-planting application of the soil fumigant metham sodium for 6 crop cycles on a Karrakatta sand in south-western Australia. In each crop cycle, the yield and quality of the continuously cropped treatments were compared to new land carrots grown on areas which had not previously grown carrots.

Total yields for the continuously cropped treatments declined relative to the new land crop by the 4th crop cycle and had fallen to 75 % of the new land yield by the 6th crop cycle. Export grade yields followed similar trends with the continuously cropped treatment yields declining to 60 % of the new land yield in the 6th crop cycle. The greater decline in export yield was as a result of the combination of lower total yields and a lower proportion of export size roots in the continuously cropped treatments compared to the new land crop. The continuously cropped treatments had higher proportions of marketable short roots in the 4th and 5th crop cycles. Some evidence indicated that differences in phosphorus nutrition between the continuously cropped treatments and the new land treatment may have contributed to the yield differences. The differences in available soil phosphorus status developed because of greater phosphorus removal in the continuously cropped treatments.

Fumigation with metham sodium did not significantly affect total yields and had variable effects on the incidence of root forking. There was no trend for increased forking with time. The incidence of forking averaged about 10 % of total yield across all treatments and crops. Diseases such as cavity spot and scab did not develop to serious levels.

Major results

- Carrot yields were not sustainable under a continuous cropping regime, even with the use of the soil fumigant metham sodium, when compared to carrot yields on new land over 6 crop cycles. Total yields in continuously cropped carrots declined relative to new land crop from the 4th consecutive crop onwards. Export grade yields in continuously cropped carrots declined to 60% of new land yields by the 6th crop.
- Continuously cropped treatments had higher proportions of marketable short roots in the 4th and 5th crop cycles. (Short marketable roots are too short for export but can be sold in pre-packs on the local market).
- The average incidence of root forking peaked in crop 2 and thereafter remained close to 10 % of total yield.
- Metham sodium had little effect on yield and variable effects on root forking though the effects on forking were small.
- Cavity spot disease was detected from the second crop but did not develop to severe levels. The highest infection levels were recorded in the 6th crop but only 4 % of total yield developed severe cavity spot symptoms. The high soil pH may have limited cavity spot development.
- Scab disease was associated with the variety Western Red rather than Top Pak. Fumigation with metham sodium increased the incidence of scab in Western Red in one crop.

Recommendations

(a) Extension/adoption by industry

The non-sustainability of continuous carrot cropping, often because of rising disease levels, has been experienced by some former carrot producers who were forced out of business. The lack of serious disease development on our site limited the extension value of the data. Carrot growers have been made aware of the need to question the continued widespread use of metham sodium.

(b) Directions for future research

Further work is needed on carrot crop sequences and rotations with other vegetables. More information on the effects of metham sodium fumigation is needed given its widespread use in the carrot industry.

(c) Financial/commercial benefits

Guidelines for sustainable (both commercially and enviromentally) carrot cropping systems will have considerable long-term financial benefit to the Australian carrot export industry. This work was the start of the process for developing such 'best practice' guidelines.

Experiment 90MD11 - The effect of continuous cropping with and without metham sodium on the yield and quality of carrots

Introduction

Carrot producers have reported reduced yields on areas where carrots have been continuously cropped or cropped in short rotations with carrots. The intensive nature of vegetable cropping on the sandy soils of the Swan Coastal Plain in Western Australia means that land is often continuously cropped. Furthermore the dominance of carrot production on the sandy soils means that few crops are grown as extensively as carrots and therefore rotation of carrots with other crops is limited.

The soil fumigant metham sodium (active ingredient methyl-isothiocynate) is used by many Western Australian carrot growers with the aim of reducing the incidence of disease and weeds,and improving yields. Metham sodium has been found to reduce soil populations of *Meloidogyne* spp. (root-knot nematode), *Pythium ultimum*, *Fusarium* spp. (Roberts *et al.* 1987) and *Rhizoctonia* spp. (Sumner and Phatak 1988).

The efficacy of fumigants can be variable (Kritzman and Ben-Yephet 1989). The failure of metham sodium in soil can be due to a range of factors such as low soil moisture content, soil temperatures being too high or too low, and high organic matter content (van Berkum and Hoestrous 1979).

In this experiment the yield and quality of carrots grown in soil with no history of carrots, were compared with carrots cropped continuously on areas with and without preplanting metham sodium treatment. Six successive carrot crops were grown in a 4 year period. Yield, quality and disease incidence under the different cropping regimes were compared.

Materials and Methods

Site

The experiment was situated at Medina Research Centre (32°S, 116°E) 30 km south of Perth, Western Australia. The soil was an orange Spearwood sand with the following soil test results before the start of the experiment : pH (1:5 water) of 7.6, organic carbon content of 0.5%, bicarbonate extractable phosphorus (Colwell 1963) and potassium of 63 and 35 mg/kg, respectively. The site had grown lupins and had then been fallow for 2 years. Carrots had never been grown on the site.

Treatments

Table 1 lists the treatments included in the experiment. Treatments were modified slightly as the experiment progressed. The variety Top Pak was grown continuously on areas with and without metham sodium treatment. The variety Western Red was omitted after the third crop, as the export industry had changed exclusively to Nantes varieties.

A 'new land' treatment was included from the second crop cycle, whereby previously fallow areas were planted with their first carrots. A 1:1 carrot/cauliflower rotation was included however an oversight in not planting carrots in one phase of this treatment in crop 4 meant that results of this treatment were only available for carrots in crops 3 and 5.

Metham sodium was applied at 500 L/ha to the appropriate plots by a low pressure spray boom fitted in front of a rotary hoe blade and immediately incorporated to 20 cm before sealing with irrigation. The soil was aerated by cultivation after 10 to 14 days, being left for longer periods at cooler times of year.

Further treatments included incorporating carrot leaves into the soil and the inoculation of soil with scab infected carrots. Carrot leaves were macerated, evenly spread and incorporated by rotary hoeing to a depth of 20 cm in treatment plots before sowing crops 3 and 4. Scab infected carrots from a commercial property were chopped finely, evenly spread and rotary hoed into the appropriate plots prior to sowing crop 2. This treatment was monitored for crops 2 and 3 only.

Table 1. Summary of treatments included in each crop cycle

Code	Treatment	Variety	Crop number 1	2	3	4	5	6
TP + F	Continuous carrot cropping with metham sodium	Top Pak	√	√	√A	√A	√	√
TP - F	Continuous carrot cropping without metham sodium	Top Pak	√	√	√A	√A	√	√
TP + New	New land	Top Pak	√	√	√A	√A	√	√
WR + F	Continuous carrot cropping with metham sodium	Western Red	√	√	√	-	-	-
WR - F	Continuous carrot cropping without metham sodium	Western Red	√	√	√	-	-	-
TP + Cauli	Carrot/cauliflower rotation	Top Pak	-	-	√	-	√	-
WR + Leaves TP + Leaves	Incorporation of carrot leaves	Western Red/Top Pak[B]	-	√	√	-	-	-
WR + Scab TP + Scab	Inoculation with scab infected carrots	Top Pak/Western Red[C]	-	√	√	-	-	-

√ denotes carrots planted, [A]sub-treatments of metalaxyl, [B]Western Red sown in crop 2, Top Pak sown in crop 3, [C]Top Pak sown in crop 2, Western Red sown in crop 3.

Sub-treatments of metalaxyl were also applied to crops 3 and 4. Metalaxyl was applied to selected treatments as a spray of Apron® (350 g metalaxyl/kg) in two 0.5 kg a.i./ha applications, the first immediately after sowing and the second 8 weeks later (Table 1).

Treatments were arranged in a randomised block design with 8 replications. Sowing and harvest dates, and duration of the 6 crops are shown in Table 2.

Table 2. Sowing and harvest dates and duration for each carrot crop

Crop cycle	Planting date	Harvest date	Crop duration (days)
1	27 Jun. 1990	4 Dec. 1990	160
2	1 Mar. 1991	23 Jun. 1991	114
3	31 Oct. 1991	31 Mar. 1992	210
4	19 Jun. 1992	1 Dec. 1992	165
5	5 Feb. 1993	8 Jun. 1993	123
6	3 Aug. 1993	13 Dec. 1993	132

Crop management

Carrot seed was sown using commercial seeding equipment on the dates shown in Table 2. Five single rows were sown on plots 1.5 m wide and 16 m in length. Superphosphate, muriate of potash and trace elements were broadcast and rotary hoed across the site, before each planting at rates shown in Table 3.

Table 3. Pre- and post-planting fertiliser applied to each crop

	Crop number					
	1	2	3	4	5	6
			kg/ha			
Preplant fertiliser						
Sulphur	1400	1400	500	-	-	-
Superphosphate	500	500	500	500	500	500
Muriate of potash	120	120	120	120	120	120
Magnesium sulphate	50	50	50	50	50	50
Manganese sulphate	25	-	25	25	-	-
Ferrous sulphate	18	-	-	18	-	-
Zinc sulphate	16	15	-	16	-	-
Borax	18	15	18	11	11	11
Sodium molybdate	2	-	-	2	-	-
Postplant fertiliser						
Urea	750	600	600	750	750	700
Muriate of potash	600	480	480	600	600	600
Magnesium sulphate	200	160	160	200	200	200

Urea, muriate of potash and magnesium sulphate were topdressed as equal fortnightly applications commencing 1 to 2 weeks after crop emergence. Total postplanting fertiliser rates are shown in Table 3.

The herbicides linuron, trifluralin and prometryne were applied when neccessary and at label rates for weed control. Nemacur® (fenamiphos) at 24 L/ha was applied before planting crops 1, 3 and 5 to prevent nematode infection.

Cauliflower plots received the equivalent total fertiliser rates as the carrots. Chlorthal dimethyl was applied immediately after transplanting the cauliflowers and insects were controlled with registered insecticides.

When necessary, the crop was irrigated at between 80 and 120 % (depending on growth stage) of the previous day's Class A pan evaporation. Irrigation was applied from overhead impact sprinklers delivering 8 mm/h. Two waterings/day were applied when Epan exceeded 5 mm per day.

Harvest

At harvest, 5 x 1 m lengths of row from the middle 3 rows of each plot were hand harvested for yield and quality assessment.. Leaves and roots were weighed and checked for disease. A separate leaf sample of 20 youngest mature leaves was also taken and dried for nutrient analysis. Roots were graded into the following categories:

Export: 25 to 50 mm crown diameter and greater than 150 mm length,
Marketable, short: 25 to 50 mm crown diameter and 100-150 mm length,
Undersized: less than 25 mm crown diameter and less than 100 mm length,
Oversized: more than 50 mm crown diameter,
Other rejects such as forked, misshapen, nodal enlargement, bolted, green shoulder, crown rot, cavity spot and scab.

Statistical analysis

Data was analysed for each crop by analysis of variance using GENSTAT ver. 5 with mean separation by protected l.s.d.

Results and Discussion

Yield

Continuous carrot cropping led to reductions in total and export yields by the fourth consecutive crop compared to cropping new land (Fig. 1). Metham sodium fumigation prior to cropping did little to reverse this trend although in the first crop, metham sodium applied to new land increased total yield by nearly 20 %. The effect of metham sodium was not as pronounced in subsequent crops where total yields from the fumigated treatment were between 1.6 to 7.6 % higher than unfumigated continuously cropped treatments.

From crops 4 to 6, the total yield in the continuous carrot treatments were reduced compared to the new land treatment (Fig. 1). By crop 6, total yield in the continuously cropped treatments had fallen to 74 % of the new land total yield.

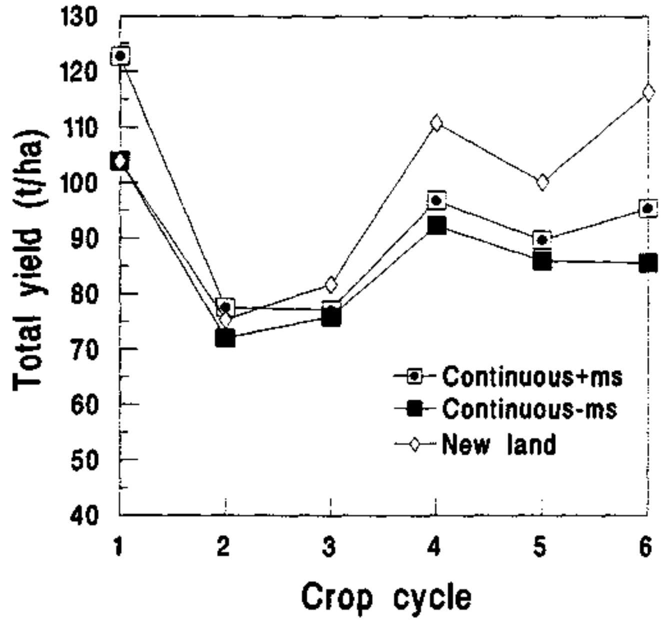


Fig. 1. Comparison of total yield of new land crop versus continuous carrot cropping with and without metham sodium (expressed as % of new land). New land in crop 1 is equivalent to continuous carrots without metham sodium.

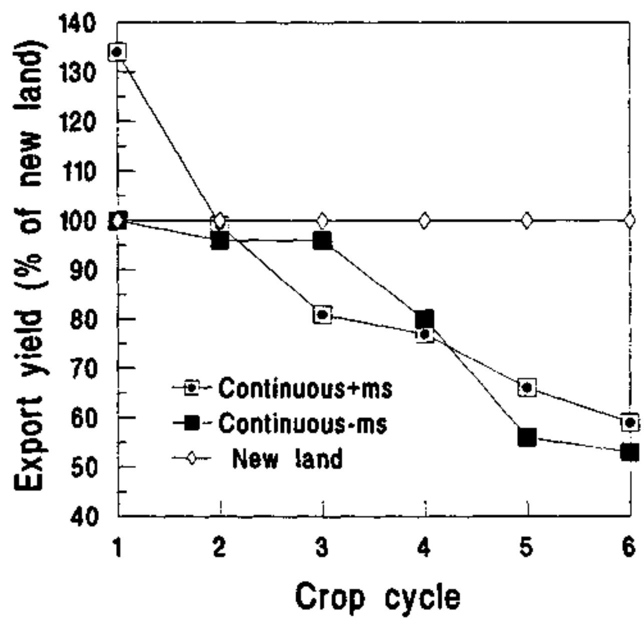


Fig. 2. Comparison of export yield of new land crop versus continuous carrot cropping with and without metham sodium (expressed as % of new land). In crop 1, new land is equivalent to continuous carrots without metham sodium.

Export yields from continuous cropping treatments showed an even greater decline relative to new land crop (Fig. 2). By crop 4, export yields in the continuous carrot treatments were significantly reduced compared to carrots grown on new land. Export yield declined to 60 % of that for the new land crop for continuous carrot treatments by crop 6. Both lower total yield (Table 4a) and lower proportions of export grade roots (Table 4b) contributed to the observed reduction in the export yield of the continuously cropped treatments relative to the new land. When the continuously cropped treatments had lower proportions of export grade roots they did have higher proportions of marketable short and undersize roots (Tables 4c and d.). There was also a tendency for higher levels of root forking in continuously cropped treatments from crop 4 onwards (Table 4e).

No allelopathic or other effects of leaf incorporation on yield were observed in crops 2 and 3 so this treatment was not included in subsequent crops.

Tables 4a-f. Summary of total yield data for the 6 crop cycles and the proportion of export, marketable short, undersize, forked and other rejects (mainly split and misshapen roots).

a.

Treatment	Crop 1	Crop 2	Crop 3	Crop 4	Crop 5	Crop 6
			Total yield (t/ha)			
TP+F	122.7	77.6	77.1	96.8	89.7	68.6
TP-F	103.9	72.1	75.9	92.3	86.0	64.4
New land	103.9	75.4	81.7	110.8	100.2	89.2

b.

Treatment	Crop 1	Crop 2	Crop 3	Crop 4	Crop 5	Crop 6
			% Export			
TP+F	74.1	61.5	45.3	63.8	56.7	48.1
TP-F	65.1	64.5	54.5	69.6	50.2	47.0
New land	65.1	63.9	52.8	72.7	73.2	63.2

c.

Treatment	Crop 1	Crop 2	Crop 3	Crop 4	Crop 5	Crop 6
			% Marketable short			
TP+F	4.6	16.1	22.7	7.2	27.4	28.9
TP-F	9.1	8.3	18.3	9.4	28.5	30.3
New land	9.1	11.0	18.5	6.0	19.0	21.7

d.

Treatment	Crop 1	Crop 2	Crop 3	Crop 4	Crop 5	Crop 6
			% undersize			
TP+F	0.7	1.5	9.9	2.0	6.4	10.1
TP-F	1.6	1.7	9.4	1.6	7.0	8.7
New land	1.6	1.5	6.4	0.8	2.3	5.7

e.

Treatment	Crop 1	Crop 2	Crop 3	Crop 4	Crop 5	Crop 6
			% forked			
TP+F	5.2	16.2	15.7	14.8	8.7	7.2
TP-F	11.2	23.6	9.6	9.8	12.2	4.1
New land	11.2	20.5	14.1	4.5	6.6	2.4

f.

Treatment	Crop 1	Crop 2	Crop 3	Crop 4	Crop 5	Crop 6
			% other rejects			
TP+F	15.2	4.7	6.6	12.1	0.8	6.0
TP-F	13.9	2.1	8.3	10.3	2.2	11.0
New land	13.9	3.3	8.7	14.6	3.0	7.0

Huiskamp (1990) found that cropping carrots on the same land each year for 6 years reduced total yield by an average of 10 % for the 6 year period compared to growing carrots in a 1:1 rotation with other vegetables such as potatoes, Brussels sprouts and onions. Onions and witloof chicory proved to be the best rotation crops in this study however yield and quality ('carrots less smooth, less straight and shorter') were still reduced compared to allowing at least a 5 year interval between consecutive carrot crops.

In crop 1, fumigation had no significant effects on the nutrient concentrations in leaves sampled 83 days after sowing although fumigation tended to increase zinc and manganese concentrations (data not presented). Increases in nutrient availability resulting from fumigation may not be detected by measuring only leaf nutrient concentrations without plant nutrient contents. Therefore an effect of metham sodium fumigation on crop nutrition and hence yield cannot be eliminated. Alternatively, the effect of metham sodium fumigation in increasing the total yield in the first crop may have arisen because of a reduction in the effects of fungal pathogens from previous host crops of lupins on the site. The reduction in root forking with metham sodium fumigation in this first crop supports this.

The reasons for the reductions in yields in continuous cropping treatments compared to new land over time were not clear. The most likely causes are sub-clinical disease effects or crop nutrition effects related to crop history.

Leaf analysis at harvest in crops 5 and 6 revealed only minor differences in nutrient concentrations and none that would support an argument for yield differences (Tables 20 and 22). Soil tests at harvest showed higher levels of extractable phosphorus (P) on new land plots (Tables 19 and 21). McPharlin *et al.* (1994) found a critical soil bicarbonate extractable level of 60 mg/kg for P for carrots growing on a Karrakatta sand of pH (1:5 water) 6.5. No critical soil P concentration is available for carrots growing on the more alkaline Spearwood sands. However potatoes growing on Karrakatta sand have similar soil P critical concentrations to carrots while potatoes on Spearwood sand of pH (1:5 water) 7.8 have a critical soil P concentration of 95 mg/kg (Hegney and McPharlin unpublished data). Thus the critical soil P concentration for carrots growing onSpearwood sand might also be close to 95 mg/kg.

Extractable soil P levels increased over 50 % (from 63 to 95 mg/kg) on the plots which were fallow until the sixth crop cycle and which received 45 kg P/ha at the start of each crop cycle. Extractable soil P concentrations on continuously cropped plots increased only 15 % (from 63 to 74 mg/kg) from the start to the end of the experiment under the same fertiliser P regime.

Reuter and Robinson (1986) reported deficient and adequate carrot leaf P concentrations at harvest of 0.2 and 0.4 % d.w. respectively. Leaf analysis at harvest for crops 5 and 6 showed all treatments with P concentrations which were below 0.2 % d.w. suggesting P status may have been marginal (Tables 20 and 22).

Both roots and leaves were exported from our plots. A carrot crop producing 80 t roots/ha contains about 5 kg P/ha in roots and 25 kg P/ha in leaves (McPharlin *et al.* 1992). In the continuously cropped treatments, the application of 45 kg P/ha/crop was close to a maintenance dressing for bicarbonate extractable soil P. The soil P concentration in the continuously cropped treatments was significantly less that of the new land crops in crop cycles 5 and 6 and was possibly less than adequate for maximum yield. Therefore the total yield differences observed between the continuously cropped treatments and the new land crops may have resulted from differences in available soil P concentrations. Leaf P concentrations and contents during the early stages of crop growth would help test this hypothesis.

Forking

Forking led to a reduction in export yields in all crops, but the incidence did not increase over time. The incidence of forking across the 6 crops was 10 % in new land treatment, 11 % in continuous carrots with fumigation and 12 % in continuous carrots without fumigation. Fumigation had a variable effect on root forking, reducing it in crop 1, tending to reduce it in crop 2, increasing it in crop 4 while not significantly affecting it in crops 3, 5 and 6.

Pythium spp. are often implicated as causal agents of root forking in carrots (Howard *et al.* 1978) and several Pythium species have been associated with root rots in lupins (Weimer 1944). The reduction in forking following metham sodium treatment in the first crop may have resulted from control of *Pythium spp.* built up under the previous lupin crop although this effect was not apparent in the subsequent carrot crops.

Crop 4 was sown during winter when soil temperatures were low and metham is slow to dissipate. It is conceivable that the increase in forking in crop sown on areas treated with metham sodium in crop 4 resulted from damage to the emerging tap root from residual metham in the cold wet soil (Leistra *et al.* 1974).

There are several other known causes of root forking in carrots. Soil compaction (Strandberg and White 1979) and soil saturation (White and Strandberg 1979) have been recorded as causes of carrot root forking in organic soils in North America. These causes of forking were unlikely to been important in our experiment because the site was deep ripped before the start of the experiment to obviate any effect of soil compaction and the sandy soil on the site was well drained and did not remain saturated even after heavy rainfall. Root knot nematode(*Meloidogyne* spp.) penetration of the early forming taproot can also cause forking of carrots (Vrain 1982, Belair 1987). Fenamiphos (Nemacur®) was used on our site to control nematodes and no galling or other evidence of nematodes was observed.

Forking is a problem in several regions of North America where carrots are cropped intensively on organic soils. Pythium fungi have been implicated as causing root forking in carrots (Howard *et al.* 1978). Metalaxyl reduced the incidence of root dieback in field experiments from 97 % of carrots in the control to 15 % (Lyshol *et al.* 1984). In this experiment, when used, metalaxyl had inconsistent effects on forking, reducing it in crop 4 but not in crop 3.

Metham sodium can reduce populations of fungi such as *Pythium* spp. in soil (Roberts *et al.* 1987), but there are reports that the effect of fumigants are not long lasting. White (1986) found that soil sterilised with methyl bromide was free from Pythium at sowing but there was evidence of re-invasion by harvest. Ploeth and Stempel (1989) detected two *Pythium* species at 60 and 80 days after planting in fumigated soil. If Pythium spp. were solely responsible for root forking in our experiment more consistent control with metham sodium might have been expected.

Cavity spot

Cavity spot was detected at low levels in the second crop and persisted at low levels (< 5 % of the total yield) in crops 3 and 4. Little cavity spot was detected in crop 5 perhaps because this crop was harvested in winter when cavity spot is least severe in Western Australia (McKay and Galati 1992). In crop 6, cavity spot infected about 25 % of the total yield with no significant differences among treatments. Even then only 4 % of the yield was classed as having severe cavity spot symptoms.

Huiskamp (1990) found that cavity spot levels increased with intensive cropping. Cavity spot incidence in carrots measured over 6 years was lower if the preceding crop was onions, but was similar to continuous carrots if the preceding crop was potatoes or Brussels sprouts (Huiskamp 1990). In our study, cavity spot did not develop to moderate levels until the sixth crop and then no treatment differences were observed.

Results from a commercial survey (90PE8) have shown that carrots growing on soils of high pH generally produce a lower incidence of cavity spot than low pH soils. This site had a soil pH of close to 8 in water and this may have limited cavity spot development.

Scab

The results from crops 2 and 3 showed that scab was generally associated with Western Red rather than Top Pak. Inoculation of soil with scab infected carrots did not produce disease in the crop of Top Pak grown on these plots in the second crop. *Fusarium spp.* were invariably isolated from scab lesions.

Fumigation with metham sodium increased ($P<0.001$) the incidence of scab in Western Red in the second crop. If infected seed is the source of scab infection, then fumigation may have enhanced the development of scab by removing soil organisms that were antagonistic to the development of scab. At planting, seed was dusted with thiram to eradicate seed borne pathogens. However, seed dusting treatments are not effective in eradicating seed borne pathogens (Strandberg 1984) so that seed may still have been a source of scab inoculum.

Further work should be conducted on crop rotation impacts on the yield, quality and disease of carrot crops, together with further studies on the effects of metham sodium fumigation.

Acknowledgments

The authors express their thanks to K. Gajda for his technical assistance and to the staff at Medina Research Centre, especially D. Pitman for their assistance with field work. South Pacific Seeds and Lefroy Valley Seed Co. are thanked for providing seed of Top Pak and Western Red respectively. Financial support from the Sumich Group Ltd. and the Horticulture Research and Development Corporation is gratefully acknowledged.

References

Belair, G. (1987). A note of the influence of cultivar, sowing date and density on damage to carrot caused by *Meloidogyne hapla* in organic soils. *Phytoprotection* **68** (1), 71-4.

Guyton, R. F., Thompson, J. R., Kimoto, R., and Kratky, B. A. (1989). Root-knot nematode populations and carrot yield following five forage legumes and continuous carrots. *Horticultural Science* **24**(1), 71-3.

Howard, R. J., Pratt, R. G., and Williams, P. H. (1978). Pathogenicity to carrots of Pythium species from organic soils of North America. *Phytopathology* **68,** 1293-96.

Huiskamp, T. (1990). Effects of high cropping frequency on yield and quality of carrots. *Proceedings of the International Horticultural Conference*, Italy p. 529. (Abstract 184).

Kritzman, G., and Ben-Yephet, Y. (1989). Effect of metham sodium on several bacterial diseases. *Acta Horticulturae* **255,** 49-54.

Leistra, M. (1974). Predictions on effectiveness and after-effects of metham sodium by stimulating soil fumigations. *Netherlands Journal of Plant Pathology* **80,** 61-71.

Lyshol, A. J., Semb., L., Taksdal., G. (1984). Reduction of cavity spot and root dieback in carrots by fungicide applications. *Plant Pathology* **33**, 193-98.

McPharlin, I. R., Aylmore, P. M. and Jeffery, R.C. (1992). Response of carrots (*Daucus carota* L.) to applied phosphorus and phosphorus leaching on a Karrakatta sand, under two irrigation regimes. *Australian Journal of Experimental Agriculture* **32,** 225-232.

McPharlin, I. R., Jeffery,R. C. and Weissberg, R. (1994). Determination of the residual value of phosphate and soil test phosphorus calibration for carrots on a Karrakatta sand. *Communications in Soil Science and Plant Analysis* **25**, 489-500.

Netzer, D., and Kenneth, R. G. (1969). Persistence and transmission of *Alternaria dauci* (Kühn) Groves & Skolko in the semi-arid conditions of Israel. *Annals of Applied Biology* **6**, 289-94.

Ploetz, R. C., and Stempel, L. (1989). Recolonisation of fumigated tomato production in Dade county by *Pythium* spp. *Proceedings from the Florida State Horticulture Society* **102**, 354-58.

Reuter, D. J. and Robinson, J. B. (1986). Plant Analysis. An Interpretation Manual. *Inkata* Press, Melbourne. p161.

Roberts, P. A., Magyarosy, A. C., Matthews, W. C., and May, D. M. (1988). Effects of metam sodium applied by drip irrigation on root-knot nematode, *Pythium ultimum* and Fusarium sp. in soil and on carrot and tomato roots. *Plant Disease* **72** (3), 213-17.

Strandberg, J. O. (1984). Efficiency of fungicides against persistence of *Alternaria dauci* on carrot seed. *Plant Disease* **68**, 39-42.

Strandberg, J. O., and White, J. M. (1979). Effect of soil compaction on carrot roots. *Journal of the American Society of Horticulture Science* **104** (3), 344- 49.

Sumner, D. R., and Phatak, S. C. (1988). Efficacy of metam-sodium applied through overhead sprinkler irrigation for control of soilborne fungi and root diseases of vegetables. *Plant Disease* **72**, 160-66.

Van Berkum, J. A., and Hoestra, H. (1979). Practical aspects of the chemical control of nematodes in soil. *In* 'Soil Disinfestation'. (Ed. D. Mulder). Chapter 6, pp 53-134. (Elsevier Scientific Publishing Company: Amsterdam).

Vrain, T. C. (1982). Relationship between *Meloidogyne hapla* density and damage to carrots in organic soils. *Journal of Nematology* **14**, 50-57.

Weimer, J. L. (1944). Some root rots and a foot rot of lupines in the southeastern part of the United States. *Journal of Agricultural Research (Wash.)* **68**, 441-457.

White, J. G. (1986). The association of *Pythium* spp. with cavity spot and root dieback of carrots. *Annals of Applied Biology* **108**, 265-73.

White, J. M., and Strandberg, J. O. (1979). Physical factors affecting carrot root growth: water saturation of soil. *Journal of the American Society of Horticulture Science* **104** (3), 414-16.

Appendix

Results of individual crops

Crop 1

Top Pak produced higher total and marketable yields than Western Red which may in part be as a result of higher plant densities for Top Pak (Table 5). Fumigation with metham sodium did not significantly affect total yield but it did increase export yields (Table 5). Metham sodium increased export percentage from 65 to 74 % in Top Pak and from 52 to 61 % in Western Red. Export yields were increased with the fumigation treatment such the main effect of fumigation was to increase export yield from 59.8 t/ha to 76.4 t/ha. Non-fumigated plots had a higher percentage of rejects than fumigated plots ($P<0.01$). The major effect of fumigation was to reduce root rejection due to forking (Table 6).

Fumigation had no effect on the yield of marketable short carrots (Table 5). Top Pak which is shorter than Western Red, had a higher yield of marketable short carrots.

Table 5. The effect of metham sodium on the leaf yield, plant density, and total, export and marketable short yields for Top Pak and Western Red carrots in crop 1

Treatment	Leaf yield (t/ha)	Density (plants/m^2)	Total yield (t/ha)	Export yield (t/ha)	Marketable short yield (t/ha)
TP + F	17.1	76	122.7	90.9	5.6
TP - F	17.3	73	103.9	67.6	9.5
WR + F	48.6	65	102.1	62.0	2.6
WR - F	49.4	67	99.9	52.0	2.1
Significance (fumigation)	ns	ns	ns	**	ns
l.s.d (P=0.05)	-	-	-	10.5	-
Significance (variety)	***	*	*	***	*
l.s.d (P=0.05)	3.1	8.0	10.6	10.5	4.0
Significance (fum*var)	ns	ns	ns	ns	ns
l.s.d (P=0.05)	-	-	-	-	-

*** = $P<0.001$, ** = $P<0.01$, * = $P<0.05$, ns = $P>0.05$, + F = with metham sodium, - F = without metham sodium.

Table 6. The effect of metham sodium on the total rejects and components of total rejects for the varieties Western Red and Top Pak in crop 1

Treatment	Total rejects	Forked	Under-size	% of total yield Over-size	Mis-shapen	Crown rots	Bolted	Other[A]
TP + F	21.1	5.2	0.7	4.9	4.5	0.3	0	5.3
TP - F	26.7	11.2	1.6	4.0	2.2	1.4	0.7	5.6
WR + F	36.8	7.7	1.1	12.4	3.4	0.1	7.0	5.1
WR - F	46.0	14.4	2.8	11.0	6.3	0.2	7.3	4.0
Significance (fumig.)	**	**	ns	ns	ns	*	ns	ns
l.s.d (P=0.05)	4.9	4.0	-	-	-	0.5	-	-
Significance (variety)	***	ns	ns	***	ns	*	***	ns
l.s.d (P=0.05)	4.9	-	-	3.2	-	0.5	1.1	-
Significance (fum*var)	ns	ns	ns	ns	*	ns	ns	ns
l.s.d (P=0.05)	-	-	-	-	3.2	-	-	-

*** = P<0.001, ** = P<0.01, * = P<0.05, ns = P>0.05, + F = with metham sodium, - F = without metham sodium. [A]splitting, insect damage, nodal enlargement, green shoulders

The major causes of rejection in Western Red were bolting and oversized carrots. Oversize carrots accounted for over 10 % of the total yield of Western Red (Table 6).

The incidence of crown rot was affected by variety and fumigation. In non-fumigated plots 1.4 % of yield of Top Pak was affected by crown rot compared to 0.3 % of yield in fumigated plots. The fungi *Fusarium* spp., *Rhizoctonia* spp. and *Sclerotina* spp. were isolated from crown rot lesions.

Fumigation had no effect on leaf yield or plant density (Table 5). The two varieties had significantly different (P<0.001) leaf yields. The difference in leaf yield was enhanced by the presence of bolters in the Western Red (Table 6). Hybrid Nantes lines such as Top Pak have smaller tops than Western Red and the difference was exacerbated in this case because of the greater propensity of Western Red to bolt.

Plant densities were significantly different between varieties (P<0.05). Top Pak had a higher density (74 plants/m^2) than Western Red (66 plants/m^2).

No symptoms of diseases such as cavity spot were found on carrots from this crop.

Crop 2

Fumigation with metham sodium did not significantly affect total yield, export or leaf yield in the second crop (Table 7). Also there was no difference in yield between the 'new land' and the continuous carrots treatments (Table 7).

There were significant (P<0.05) effects of fumigation on plant density and the yield of marketable short roots. Fumigation increased the density of Top Pak and this higher density probably accounted for the increase in marketable short roots (Table 7).

Table 7. The effect of cropping treatment on leaf yield, density, total, export, and marketable short yield of Western Red and Top Pak carrots in crop 2

Treatment	Leaf yield (t/ha)	Density (plants/m^2)	Total yield (t/ha)	Export yield (t/ha)	Marketable short yield (t/ha)
TP + F	12.5	57	77.6	47.7	12.5
TP - F	11.4	50	72.1	46.5	6.0
WR + F	26.0	51	75.3	44.9	2.1
WR - F	26.0	49	71.2	45.1	1.5
WR + Leaves	25.4	50	72.9	46.6	2.7
TP + Scab	11.5	53	72.4	48.4	9.5
TP + New	12.0	52	75.4	48.2	8.3
Significance	***	*	ns	ns	***
l.s.d (P=0.05)	2.2	4.5	-	-	2.9

*** = P<0.001, ** = P<0.01, * = P<0.05, ns = P>0.05

Fumigation had no effect on the proportion of rejects produced in crop 2 (Table 8) however Western Red a had significantly higher proportion of rejects than Top Pak.

There were no significant differences among treatments in the incidence of forking and undersized carrots (Table 8).

Scab was only detected in treatments planted to Western Red. Fumigated plots of Western Red had 13 % of the total yield affected by scab while only 4 % in the unfumigated plots of Western Red showed scab symptoms. The leaf incorporated plots of Western Red had 4 % of total yield affected by scab (Table 8). A t-test using proportions (results not shown) showed highly significant varietal and fumigation effects on the incidence of scab.

Table 8. The effect of cropping treatment on reject incidence for Top Pak (TP) and Western Red (WR) carrots in crop 2

Treatment	Total rejects	Under-size	Forked	Over-size	Scab	Cavity spot	Mis-shapen	Other[A]
				% of the total yield				
TP + F	22.4	1.5	16.2	1.4	0	0.4	2.0	0.8
TP - F	27.4	1.7	23.6	0.2	0	0	1.4	0.4
WR + F	37.7	1.5	14.2	2.3	13.1	0.6	0.2	5.8
WR - F	34.6	2.4	19.1	3.2	3.6	1.4	1.9	3.0
WR + Leaves	32.2	1.0	14.5	5.3	3.6	1.2	0.9	5.6
TP + Scab	20.3	1.7	16.4	1.2	0	0.1	0.6	0.2
TP + New	25.3	1.4	20.5	0.4	0	0.2	2.0	0.7
Significance	**	ns	ns	***	***	ns	ns	**
l.s.d (P=0.05)	11.8	-	-	2.4	6.3	-	-	3.6

*** = P<0.001, ** = P<0.01, * = P<0.05, ns = P>0.05, [A]splitting, insect damage

Western Red again had a higher proportion of oversize carrots than Top Pak (Table 8). Cavity spot was detected at very low levels in this crop (Table 8).

The total and marketable yields of Western Red from plots with leaves incorporated were not significantly different to other treatments planted to Western Red (Table 7).

Crop 3

Cropping treatments had no effect on total yields in crop 3. There were significant treatment differences in the leaf yield, plant density and yield of marketable shorts in the third crop (Table 9). Most of these differences were attributable to the differences between Top Pak and Western Red. Though there were no significant differences in export yield, it was noteworthy that the new land and the crop following cauliflower tended to have the highest export yields and the fumigated treatment the lowest (Table 9). Metalaxyl sub-treatments had no effect on carrot yield, yield of size categories or disease in crop 3 (data not presented).

Table 9. The effect of cropping treatment on total, export and marketable short yield, leaf yield and plant density for the varieties Top Pak and Western Red in crop 3

Treatment	Leaf yield (t/ha)	Density (plants/m^2)	Total yield (t/ha)	Export yield (t/ha)	Marketable short yield (t/ha)
TP + F	12.9	78	77.1	34.9	17.5
TP - F	13.3	80	75.9	41.4	13.9
WR + F	24.7	61	73.5	40.1	5.4
WR - F	27.2	66	77.0	40.4	6.9
TP + Leaves	14.0	87	80.8	36.7	20.1
WR + Scab	26.2	68	80.2	39.4	8.8
TP + New	14.3	79	81.7	43.1	15.1
TP + Caulis	13.4	73	79.4	42.8	14.8
Significance	***	***	ns	ns	***
l.s.d (P=0.05)	3.1	9.3	-	-	2.9

*** = P<0.001, ** = P<0.01, * = P<0.05, ns = P>0.05

Table 10. The effect of cropping treatment on the incidence of rejects for Top Pak and Western Red carrots in crop 3

Treatment	Total rejects	Under-size	Forked	Over-size	Scab	Cavity spot	Mis-shapen	Other[A]
				% of total yield				
TP + F	32.2	9.9	15.7	0.3	0.3	2.1	3.4	0.5
TP - F	27.3	9.4	9.6	0	0.1	6.1	1.5	0.6
WR + F	39.2	5.4	11.4	3.0	6.5	5.6	7.0	0.3
WR - F	38.8	3.6	19.4	2.0	2.2	4.2	7.4	0.0
TP + Leaves	30.5	13.0	11.2	0	0.2	2.5	3.5	0.1
WR + Scab	39.5	5.4	13.0	2.8	5.1	5.2	7.9	0.1
TP + New	29.2	6.4	14.7	0	0.4	3.0	4.6	0.1
TP + Caulis	28.6	6.8	14.1	0	1.3	2.2	3.7	0.5
Significance	ns	***	ns	**	*	ns	**	ns
l.s.d (P=0.05)	-	4.0	-	2.2	4.5	-	3.7	-

*** = P<0.001, ** = P<0.01, * = P<0.05, ns = P>0.05, [A]splits and rots

The incidence of cavity spot was up to 6 % in crop 3 however there was no differences among treatments (Table 10). There were significant differences among treatments for the incidence of scab disease. In general, treatments which included the variety Western Red, had a significantly higher incidence of scab. Carrots grown on areas where the previous crop was cauliflower did not differ in yield and quality to carrots grown on areas that had a previous carrot cropping history or new land.

Crop 4

In contrast to previous crops the yield of carrots grown on new land in crop 4 was significantly higher than the yield from the continuously cropped treatments. The difference in export yield resulted from the combination of higher total yield and reduced rejection due to forking on new land. The reason for the higher total yield on new land is not clear, however it may be due to a higher level of available nitrogen or phosphorus in soil which was previously fallowed. This may have enhanced early crop growth and subsequently been expressed in root yield. Leaf yield for the new land treatment was higher than that from the unfumigated plots which supports this hypothesis (Table 11).

Table 11. The effect of cropping treatment on the leaf yield, density, total, export and marketable short yield in crop 4

Treatment	Leaf yield (t/ha)	Density (plants/m^2)	Total yield (t/ha)	Export yield (t/ha)	Marketable short yield (t/ha)
TP + F	15.1	68	96.8	61.8	7.0
TP - F	14.3	67	92.3	64.2	8.7
TP + New	15.9	69	110.8	80.6	6.7
Significance	**	ns	***	***	ns
l.s.d. (P=0.05)	1.1	-	7.0	8.3	-

*** = P<0.001, ** = P<0.01, * = P<0.05, ns = P>0.05

In crop 4 the proportion of rejects was significantly different among treatments (Table 12). The incidence of forking was highest in fumigated crop and lowest in the new land crop (Table 12). New land carrots had a significantly higher incidence of misshapen roots though this only accounted for 1.3 % of total yield (Table 12). Cavity spot affected less than 6 % of the total yield in this crop and there were no differences among treatments (Table 12).

Table 12. The effect of cropping treatment on incidence of rejects for the variety Top Pak at harvest in crop 4

Treatment	Total rejects	Under-size	Forked	Over-size	Scab	Cavity spot	Mis-shapen	Split
				% of the total yield				
TP + F	28.9	2.0	14.8	3.3	0.3	6.5	0.2	1.9
TP - F	20.9	1.6	9.8	3.3	0.8	4.0	0.3	1.1
TP + New	19.9	0.8	4.5	5.1	1.5	5.3	1.3	1.4
Significance	*	ns	***	ns	ns	ns	***	ns
l.s.d (P=0.05)	7.0	-	4.2	-	-	-	0.6	-

*** = P<0.001, ** = P<0.01, * = P<0.05, ns = P>0.05

Metalaxyl had no effect on total or marketable yields in the fourth crop. However, metalaxyl did reduce the incidence of forking (Table 13). There were no significant interactions between main cropping treatments and the metalaxyl subtreatment. Metalaxyl had no effect (P=0.81) on the incidence of cavity spot.

Table 13. The main effect of metalaxyl on the incidence of root forking in crop 4

Subtreatment	Forked (% of total yield)
- metalaxyl	11.5
+ metalaxyl	7.9
Significance	*
l.s.d (P=0.05)	3.4

Crop 5

In the 5th crop cycle carrots grown on new land produced the highest export yields, followed by the carrot/cauliflower rotation. The continuously cropped treatments produced the highest yields of short marketable roots (Table 14). There were also significant differences ($P<0.001$) in total yields in this planting, with the new land treatment producing higher yields than the other treatments (Table 14).

Table 14. The effect of cropping treatment on density, total, export and marketable short yield for Top Pak carrots in crop 5

Treatment	Density (plants/m^2)	Total yield (t/ha)	Export yield (t/ha)	Marketable short yield (t/ha)
TP + F	96	89.7	50.9	24.6
TP - F	101	86.0	43.2	24.5
TP + New	87	104.8	76.7	16.2
TP + Caulis	90	92.7	60.2	19.0
Significance	ns	***	***	**
l.s.d. (P = 0.05)	-	7.7	8.9	5.2

*** = $P<0.001$, ** = $P<0.01$, * = $P<0.05$, ns = $P>0.05$

Fumigation did not increase yields compared to the non-fumigated treatment on continuously cropped soil. No diseases were present in this crop. The incidence of forking was 12 % of the total yield in non fumigated continuously cropped plots, compared to 6.6 % in the new land treatment, but this result was not significant (Table 15).

Table 15. The effect of cropping treatment on reject incidence for Top Pak carrots in crop 5

Treatment	Undersize	Forked	Other[B]
	% of total yield		
TP + F	6.4	8.7	0.8
TP - F	7.0	12.2	2.2
TP + New	2.6	6.6	2.1
TP + Caulis	3.8	8.3	2.2
Significance	***	ns	ns
l.s.d (P=0.05)	2.1	-	-

*** = $P<0.001$, ns= $P>0.05$, [A] Marketable % = Export % + Marketable short %
[B]misshapen, splitting

Crop 6

The new land treatment produced significantly higher total and export yields than the continuous carrot treatments (Table 16). The percentage of total yield affected by forking was significantly greater ($P>0.01$) in the fumigated continuously cropped treatment than in the non-fumigated continuously cropped treatment and the new land treatment (Table 17). There were no treatment effects on other reject categories.

Table 16. The effect of cropping treatment on leaf yield, density, total, export and marketable short yield for the variety Top Pak in crop 6

Treatment	Leaf yield (t/ha)	Density (plants/m^2)	Total yield (t/ha)	Export yield (t/ha)	Marketable short yield (t/ha)
TP + F	19.6	102	68.6	33.0	19.8
TP - F	17.4	101	64.4	30.3	19.5
TP + New	21.2	106	89.2	56.4	19.4
Significance	***	ns	***	***	ns
l.s.d (P=0.05)	1.9	-	10.5	8.8	-

*** = P<0.001, ns = P>0.05

Table 17. The effect of cropping treatment on the incidence of rejects for the Top Pak carrots in crop 6

Treatment	Undersize	Forked	Split	Other[A]
		% of total yield		
TP + F	7.9	10.0	3.5	1.9
TP - F	9.0	5.6	7.4	1.9
TP + New	5.7	4.8	3.5	1.1
Significance	ns	**	ns	ns
l.s.d (P=0.05)	-	3.3	-	-

** = P<0.01, ns = P>0.05, [A]misshapen and oversized roots

Cavity spot disease developed more in this December harvested crop than any of the previous crops in this experiment and although the new land crop had a 30 % lower incidence than continuous cropping differences were not significant (P>0.05) (Table 18). Cavity spot was not included in the assessment of export yields. If it were, export yields would be reduced by up to 10 % assuming carrots displaying slight symptoms could be marketed.

Table 18. Percentage of carrots (by number) affected by cavity spot disease in crop 6

Treatment	Slight	Moderate	Severe	Total
		% carrots with cavity spot[A]		
TP + F	14.3	5.6	4.4	24.4
TP - F	15.2	4.9	4.3	24.4
TP + New	10.6	4.0	3.8	18.3
Significance	ns	ns	ns	ns
l.s.d (P=0.05)	-	-	-	-

[A]carrots regraded for cavity spot independent of marketability

Soil and leaf analysis results for crops 5 and 6

Table 19. Soil test results for soil (0-15cm) taken at harvest for crop 5.

Treatment	Bicarbonate extractable P (mg/kg)	Bicarbonate extractable K (mg/kg)	Organic carbon (%)	pH (1:5 water)
TP +F	73	40	0.53	7.7
TP-F	74	44	0.51	7.8
TP+New	95	44	0.48	8.1
Significance	*	ns	*	*
l.s.d (P = 0.05)	14	-	0.02	0.3

Table 20. Nutrient concentrations in youngest mature leaves of carrots at harvest in crop 5. All concentrations expressed on dry basis.

Treatment	N (%)	P (%)	K (%)	Mg (%)	Ca (%)	Na (%)	Cl (%)	S (%)	Cu (mg/kg)	Mn (mg/kg)	Zn (mg/kg)	Fe (mg/kg)	B (mg/kg)
TP+F	2.5	0.18	2.8	0.24	1.95	2.24	4.0	0.40	6.1	127	18	433	31
TP-F	2.6	0.19	3.0	0.23	1.85	1.94	3.7	0.37	6.2	77	17	345	31
TP+New	2.6	0.19	2.9	0.22	2.04	1.88	3.9	0.36	5.3	50	15	283	31
Significance	ns	ns	ns	ns	ns	**	ns	*	**	**	ns	*	ns
l.s.d (P=0.05)	-	-	-	-	-	0.18	-	0.03	0.5	38	-	85	-

Table 21. Soil analysis at harvest for crop 6

Treatment	Bicarbonate extractable P (mg/kg)	Bicarbonate extractable K (mg/kg)	Organic carbon (%)	pH (1:5 water)
TP + F	74	86	0.59	7.6
TP - F	74	78	0.59	7.7
TP + New	95	70	0.59	7.9
Significance	**	ns	ns	ns
l.s.d (P = 0.05)	10	-	-	-

Table 22. Nutrient concentrations in youngest mature leaves of carrots at harvest for crop 6. All concentrations expressed on dry basis.

Treatment	N (%)	P (%)	K (%)	Mg (%)	Ca (%)	Na (%)	Cl (%)	S (%)	Cu (mg/kg)	Mn (mg/kg)	Zn (mg/kg)	Fe (mg/kg)	B (mg/kg)
TP+F	2.1	0.18	3.1	0.33	2.49	1.47	4.07	0.38	5.2	114	21	511	34
TP-F	2.0	0.17	3.1	0.33	2.86	1.50	4.34	0.39	5.1	87	20	645	34
TP+New	2.0	0.17	2.7	0.33	2.76	1.41	4.11	0.36	4.1	43	16	446	34
Significance	ns	ns	**	ns	*	ns	ns	ns	***	**	*	ns	ns
l.s.d (P=0.05)	-	-	0.21	-	0.24	-	-	-	0.3	38	4	-	-

10. THE EFFECT OF PLANT DENSITY AND TIME OF HARVEST ON THE YIELD AND QUALITY OF NANTES CARROTS

A. G. McKay and A. Galati

THE EFFECT OF PLANT DENSITY AND TIME OF HARVEST ON THE YIELD AND QUALITY OF NANTES CARROTS

Summary

Two field experiments were planted to study the effects of plant density and harvest time on the yield and quality of Nantes carrots. Both site 1 (high yielding) and site 2 (low yielding) were located on a property 100 km north of Perth under centre-pivot irrigation on coastal plain sands. Each experiment had three harvest times, one being at the commercial harvest time and the other being two weeks earlier and two weeks later than commercial harvest.

Major results

- Optimum plant density depended on yield and changed with time of harvest as yields increased with later harvest. Across the 6 harvests (2 sites x 3 harvests), the plant density for optimising export yield increased from 44 to 70 plants/m^2 as optimum export yield increased from 14 to 83 t/ha.
- The incidence of cavity spot disease increased with later harvest and to a lesser degree as plant density decreased. Cavity spot incidence was correlated to average root weight ($R^2 = 0.65$) across all density and harvest treatments at site 2. This indicated that root surface area and/or physiological maturity related to root size may be a determinant in the development of cavity spot symptoms.
- Avoiding cavity spot by planting at lower plant densities to enable earlier harvest of desired size range carrots appeared to have little practical use, particularly as yields are compromised in doing so.

Recommendatons

(a) Extension/adoption by industry

Results of this work were conveyed to industry at a formal grower seminar held at Mandogalup and sponsored by the Carrot Association for Research and Development. Follow-up extension articles were published in a grower newsletter and Agriculture WA extension staff worked with some individual growers to improve their attainment of target plant populations with consistent intrarow spacings.

(b) Directions for future research

A follow-up survey of commercial crop densities and variations in intrarow spacings would be useful. Note: Later model precision airseeders (the Agricola Italia is now the W.A. industry standard) have much improved seed placement.

Methods to minimise variation in intrarow spacing and plant density could be investigated in order to improve the ability of producers to grow to specification and better satisfy market demands.

Some simple modelling could be used to predict optimum plant densities for yield and returns based on predicted harvest times.

(c) Financial/commercial benefits

Having plant densities higher or lower than optimum reduced gross returns although the greatest impact on gross returns was for harvest time. Later harvests produced higher returns although in crops such as at site 2 where cavity spot evidence was high from the late harvest, there would be a trade-off between increased yield and increased level of rejection because of disease.

Maximum returns could be achieved across a reasonable range of plant densities under the arbitrary price structure used largely because of the presence of both small and large fractions in the crop.

Introduction

A survey of commercial carrot crops in Western Australia during 1990-91 found large variation in plant densities among crops. Plant densities ranged from 16 to 152 plants/m^2 and this variation contributed to low total yields and increased proportions of undersize and oversize roots in many crops (McKay and Galati 1992).

Carrot size grades are based on root length and diameter, and plant densities must be selected to provide maximum numbers of carrots within the size required for market. Maximisation of marketable yield can only be accomplished if optimum densities with consistent interplant spacing are achieved. New precision air seeders and seed with high pecentage germination mean the variation in interplant spacing can be minimised.

Row arrangement, plant density and harvest date have all been found to affect root size of carrots. Mack (1980) found that, for a given plant density, there was an increase in total yield as row spacings were decreased from 60 to 15 cm.

In more detailed work, Salter *et al.* (1979, 1980) examined the effect of row arrangement (eg 2, 3, 4, 5 or 10 rows per 1.52 m wide bed) on carrot yield. In contrast to Mack (1980), they found that varying row spacings of less than 37.5 cm had little effect on root yield but rather that plant density and time of harvest were the most important variables controlling root yield. Salter *et al.* (1980) also noted that UK carrot producers had already adopted a range of row spacings and arrangements suited to available seeders and harvesters. They concluded that carrot producers could use any row arrangement within reasonable limits as long as optimum density was maintained.

Carrots grown at lower densities reach marketable size in less time than carrots grown at higher plant populations. Robinson (1969) showed how important time until harvest maturity was for producing maximum yield. Carrots sown on a 5.1 x 5.1 cm grid (337 plants/m^2) produced higher yields than carrots sown on a 10.2 x 10.2 cm grid (87 plants/m^2). However, carrots at the higher density reached marketable size 25 days after those at the lower density.

Bussell (1973) studied the effect of plant density and time of harvest on yield of 'finger' (13 to 18 mm diameter) carrots and found that maximum yield was reached 3 weeks earlier at low (533 plants/m^2) than high densities (2 500 plants/m^2). Webster (1969) examined a range of in-row spacings (2.5 to 7.5 cm) for Chantenay carrots and found the maximum yields of marketable sized roots were achieved when spacings were between 3.75 and 6.25 cm depending on season. Warne (1951) found that the yield of carrots was highest in 45 cm rows at an in-row spacing of 2.5 cm (89 plants/m^2) compared to other spacings (5, 10 and 15 cm in row spacings). Phillips (1990) recommended a plant density of 67 plants/m^2 for the Autumn King variety Western Red growing in Western Australia. Export carrot production in Western Australia is now based exclusively on Nantes varieties about which there is little information on optimum densities for maximising the yield of size grades suitable for export markets.

1. Experiment 92PE32 - The effect of plant density on the yield and quality of Nantes carrots sown in autumn

Aim

The objective of this experiment was to examine the relationships between plant density and yield, size distribution and length of Nantes carrots at three harvest times. Two nitrogen (N) rates were also included as sub-treatments for consideration of any plant density by nitrogen interactions.

Materials and Methods

The experiment was conducted on a Spearwood sand (Uc 4.13, Northcote 1979) on a commercial property, 100 km north of Perth. Soil (0-15 cm) from the site tested before planting gave the following results:

pH (1:5 water) = 7.2,
Bicarbonate extractable phosphorus = 85mg/kg,
Bicarbonate extractable potassium = 54 mg/kg
Organic carbon = 0.4 %.

Seven plant densities and two nitrogen subtreatments were replicated 4 times in a randomised split-block design. The target densities in this experiment were 20, 40, 60, 80, 100, 120 and 140 plants/m^2. Subtreatments consisted of either the commercial fertiliser rate of 280 kg N/ha (low N) or this rate plus an additional 100 kg N/ha (high N). This additional N was applied as ammonium nitrate in 5 equal fortnightly dressings from emergence.

Pelleted seed of the Nantes variety Top Pak (South Pacific Seeds) were sown with an Agricola® precision air seeder on 4 May 1992. The 3 lowest densities were sown at a higher rate and thinned by hand at the 3-leaf stage. Five twin rows per 1.92 m wide bed (wheel centre to wheel centre) were sown and each plot was 10 m long. Densities were calculated on an area basis including tractor wheelings as part of the area.

Fertiliser P (84kg/ha), K (440 kg/ha), other nutrients and overhead irrigation were applied as per the surrounding commercial crop. Good control of weed and diseases was achieved with applications of registered herbicides and fungicides although blight (*Alternaria dauci*) began to cause some leaf defoliation by week 22 and was more severe by week 24.

Plots were sampled on 3 occasions ; 20, 22 and 24 weeks after sowing. At each harvest, five by 0.5 m of row (0.5 m from each twin row) were harvested, except at the 20 and 40 plants/m^2 treatments where five 1 m lengths of row were sampled. Roots were washed, graded and weighed. In addition, at 22 weeks, the average root weight from the middle three inside rows and the two outer rows was determined separately for each plot.

The carrots were graded according to size: export (25 to 50 mm crown diameter, greater than 150 mm length), marketable shorts (25 to 50 mm crown diameter, 100-150 mm length), undersize (less than 100 mm length, less than 25 mm crown diameter), oversize (greater than 50 mm crown diameter) and other (forked, misshapen, split and green). The fresh weight of leaves from each plot was also recorded as was the length of 20 roots. Crop height was also measured in the crop at 20 weeks. The roots from each plot were then regraded at each harvest to determine the percentage of total yield affected by the diseases cavity spot and scab.

The effect of density and nitrogen and their interactions on yield were analysed by analysis of variance using GENSTAT software.

Results

Table 1 shows the target plant densities and the actual average density for the 3 harvest times.

Table 1. Target densities and measured plant densities averaged for the three harvest times

Target density (plants/m^2)	Actual plant density (plants/m^2) (± s.e.)
20	22 (± 0.3)
40	42 (± 1.2)
60	54 (± 1.4)
80	73 (± 1.2)
100	84 (± 3.9)
120	93 (± 1.0)
140	120 (± 1.2)

Yield and root length

Carrot yields were highly dependent on plant density. Plotting total yield (t/ha) against plant density shows that, at each harvest time, most of the variation in total yield could be accounted for by changes in plant density (Fig. 1). Mitscherlich functions described the relationship between plant density and total yield (Fig. 1). Total yield increased with increasing density at each harvest with the maximum recorded yield of 113 t/ha at 24 weeks.

Polynomial functions fitted to export yield versus density for each harvest accounted for 96 to 99 % of the variation in export yield (Fig. 2). For a given plant density, export yield increased with later harvest. Maximum export yield at the 20 week harvest was 64.0 t/ha at a density of 52 plants/m^2 while the maximum at 22 weeks was 76.9 t/ha at 61 plants/m^2 the maximum export yield at 24 weeks was 82.8 t/ha at 70 plants/ m^2.

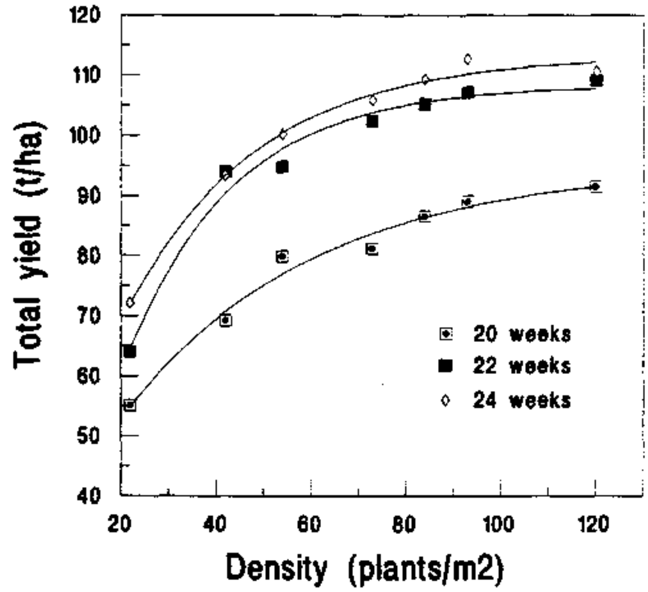


Fig. 1. The effect of plant density and time of harvest (20, 22 and 24 weeks after sowing) on the total yield of Top Pak carrots.

20 weeks, $y1 = 95.06 - 69.21e^{-0.025x}$, $R^2 = 0.97$.
22 weeks, $y2 = 108.32 - 117.0e^{-0.045x}$, $R^2 = 0.97$.
24 weeks, $y3 = 113.31 - 92.17e^{-0.036x}$, $R^2 = 0.99$.

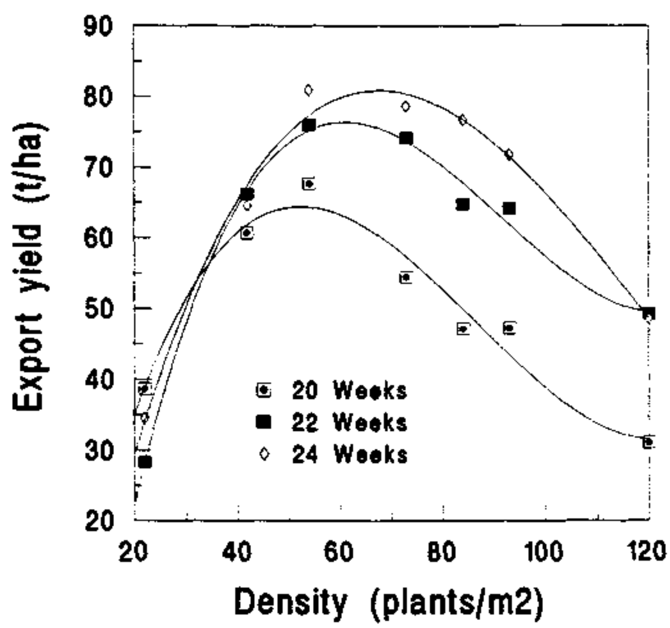


Fig. 2. The effect of plant density and time of harvest (20, 22 and 24 weeks after sowing) on the export yield of Top Pak carrots.

20 weeks, $y1 = -23.9 + 3.9x - 0.054x^2 + 0.0002x^3$, $R^2 = 0.96$.
22 weeks, $y2 = -60.8 + 5.4x - 0.066x^2 + 0.0002x^3$, $R^2 = 0.99$.
24 weeks, $y3 = -32.7 + 3.8x - 0.039x^2, + 0.0001x^3$, $R^2 = 0.99$.

Root length decreased significantly ($P<0.001$) with increasing plant density for each harvest date. Densities of greater than 80 plants/m^2 produced average root lengths of less than 15 cm while at 20 plants/m^2, the average root length was over 20 cm at each harvest date. Root length also increased with later harvest particularly from 20 to 22 weeks after sowing (Fig. 3).

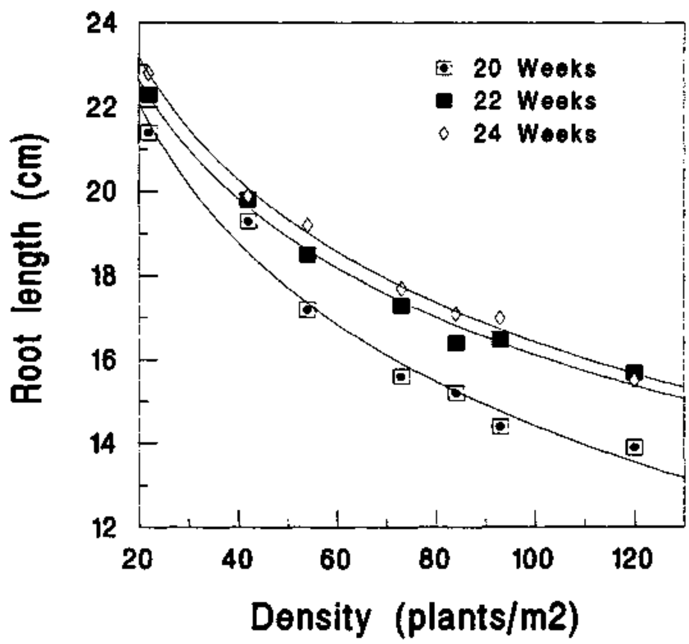


Fig. 3. The effect of plant density and time of harvest (20, 22 and 24 weeks after sowing) on the average root length of Top Pak carrots.

20 weeks, $y1 = 36.38 - 10.98 * \log(X)$, $R^2 = 0.98$.
22 weeks, $y2 = 34.76 - 9.32 * \log(X)$, $R^2 = 0.99$.
24 weeks, $y3 = 35.77 - 9.67 * \log(X)$, $R^2 = 0.99$.

Plant density affected the size distribution of roots. As expected lower densities produced a higher proportion of oversize carrots and higher densities produced more undersize carrots. An example of this effect of density on root size distribution is shown for the 22 week harvest in Fig. 4.

Rejects

The major reasons for rejects for the 3 harvest dates were green shoulders, forked, split and misshapen roots (Tables 6A-8A). The incidence of forked roots was low at this site averaging less than 2 % of total yield (Tables 6A-8A). The proportions of split or misshapen roots were also low and were not affected by plant density (Tables 6A-8A). The incidence of green shoulders was negligible at 20 weeks but increased with later harvest. The yield affected by green crown increased as density decreased for the 22 and 24 week harvests (Tables 6A-8A).

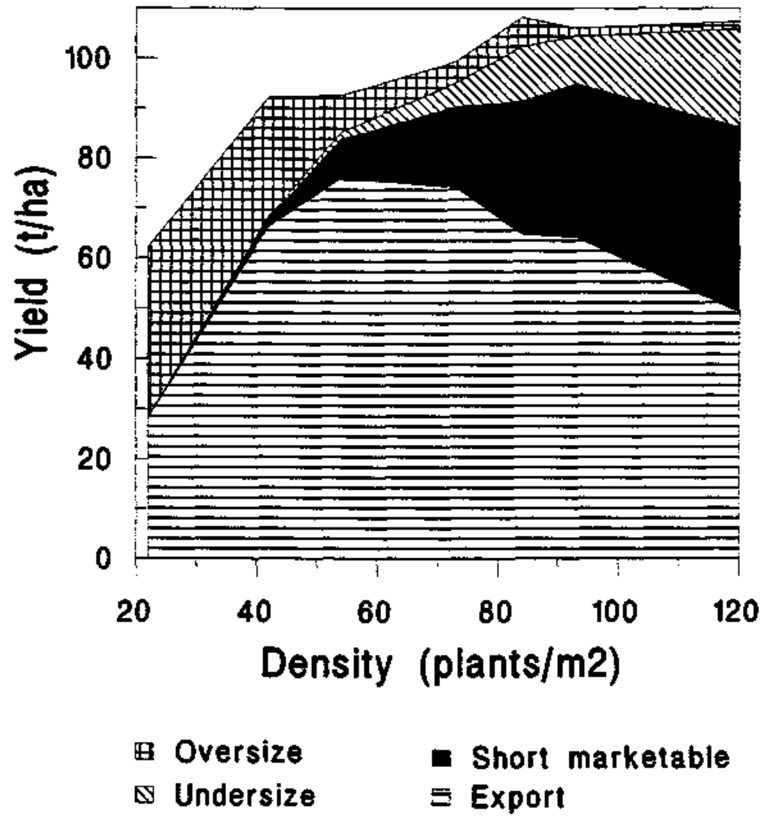


Fig. 4. The effect of plant density on the size distribution of Top Pak carrots harvested 22 weeks after sowing.

Effect of nitrogen on yield and length

There was no significant difference between high and low N treatments for total or export yield (Tables 5A-7A). The high nitrogen treatment did result in a small but significant reduction in the yield of marketable short roots at 20 and 24 weeks (Data not presented). Nitrogen also had a small though significant effect on average root length at the 20 and 24 week harvests, with the high N treatment producing longer roots (Table 8A).

The only significant interaction between density and nitrogen observed was for marketable short yield at the 20 week harvest. At low density there was little difference between high and low N however above 73 plant/m^2 the low N treatment had greater yields of short marketable roots.

Effect of plant density on leaf yield

Plant density had a significant ($P < 0.05$) effect on leaf yield at each of the three harvest dates (Table 2). The leaf yield was reduced over time because of the progression of leaf blight. The crop height at 20 weeks is shown in Table 2. The 20 and 40 plants/m^2 treatments produced the shortest tops.

Effect of nitrogen on leaf yield

There was a significant effect of nitrogen treatment on the leaf yield at 20 weeks where the high N treatment produced larger tops across all densities (Table 2). However there was no interaction between density and nitrogen for the three harvest dates. Nitrogen treatment affected crop height, but again there was no interaction between density and nitrogen for crop height (Table 2).

Table 2. The effect of plant density and nitrogen on leaf yield and crop height of Top Pak carrots harvested at three times

Average plant density (plants/m^2)	Leaf yield at 20 weeks (t/ha)		Leaf yield at 22 weeks (t/ha)		Leaf yield at 24 weeks (t/ha)s		Crop height (cm) at 20 weeks	
	high N	*low N*	*high N*	*low N*	*high N*	*low N*	*high N*	*low N*
22	6.7	6.5	6.4	6.0	4.7	4.5	22.8	21.5
42	9.9	9.4	5.1	5.1	2.9	3.6	31.5	28.8
54	13.1	11.2	11.6	10.4	7.5	7.7	35.5	34.8
73	14.9	13.3	14.2	12.3	7.7	8.4	35.3	34.8
84	15.3	14.1	13.2	12.9	7.9	8.9	38.3	34.8
93	16.2	13.9	14.7	14.0	8.9	8.7	36.5	36.5
120	19.7	17.3	14.4	15.5	9.5	8.4	33.5	34.3
Significance (density)	***		***		***		***	
l.s.d. (P=0.05)	1.7		1.4		1.3		3.5	
(N)	***		ns		ns		*	
l.s.d. (P=0.05)	0.71		-		-		0.9	
(density *N)	ns		ns		ns		ns	

Effect of plant density and nitrogen on disease incidence

Cavity spot was detected at each harvest, but at low levels (less than 10 % of total yield) and there was no significant effect of plant density on cavity spot (Table 3). However because of the low level of disease, this result will need confirmation on a site with higher disease levels. The high N treatment produced significantly ($P<0.01$) less cavity spot than the low N treatment at the 24 week harvest (Table 3).

Scab disease was detected at the 24 week harvest. The incidence of scab was not affected by plant density but was exacerbated by the high N treatment (Table 3).

Table 3. The effect of plant density and time of harvest on the incidence of cavity spot and scab disease for the variety Top Pak

Average plant density (plants/m^2)	Cavity spot (% of total yield) at 20 weeks	Cavity spot (% of total yield) at 22 weeks	Cavity spot (% of total yield) at 24 weeks		Scab disease (% of total yield) at 24 weeks	
			high N	low N	high N	low N
22	1.4	7.4	4.2	8.8	37.6	27.3
42	0.6	14.7	1.1	7.7	26.0	23.5
54	0.1	8.2	2.0	6.8	25.5	17.2
73	0.5	7.9	2.8	2.3	31.4	14.9
84	0.4	13.5	2.9	4.8	26.9	9.2
93	0.5	18.6	7.5	9.2	16.9	9.6
120	0.7	10.7	2.9	7.5	15.2	5.5
Significance						
(density)	ns	ns	ns		ns	
(N)	ns	ns	**		**	
l.s.d. (P=0.05)	-	-	2.1		10.9	
(density*N)	ns	ns	ns		ns	

Average root weight from outside and inside rows

Table 4 shows the effect of location in either outside and inside rows of the bed on average root weight for the 22 week harvest. The average root weight was greater in outside rows compared to inside rows and the ratio of inside/outside root weight decreased with increasing plant density (Table 4). Average root weight decreased with increasing plant densitiy.

Effect of density on $ return

Fig. 5 shows the gross income/ha at varying densities for the three harvest times. The lowest incomes occurred at the early harvest (20 weeks). Gross income increased over the three harvest dates and was not particularly sensitive to changes in plant density between 54 and 93 plants/m^2. The highest gross return was $22,236 at 73 plants m^2 (80 plants /m^2 sown) at the 24 week harvest. The lowest gross return was $11,184 at 22 plants/m^2 at 20 weeks (Table 10A).

Table 4. Average root weight of carrots in outside and inside rows for 22 week harvest

Average plant density (plants/m^2)	Average root weight in outside rows (g)	Average root weight in inside rows (g)	Inside weight/ outside weight
22	316	297	0.94
42	228	213	0.93
54	184	161	0.87
73	152	128	0.84
84	137	117	0.85
93	123	111	0.90
120	105	80	0.76
Significance density	***		
l.s.d. (P=0.05)	11.9		
(row position)	***		
l.s.d. (P=0.05)	10.7		
(density* row)	ns		

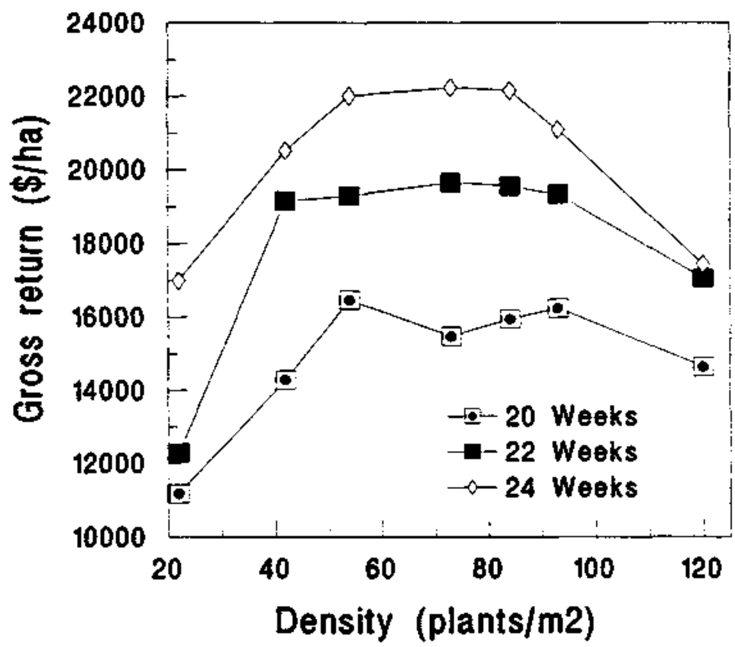


Fig. 5. Gross income ($) from carrots at varying densities and three times of harvest. Calculated with short marketables = $0.16 /kg, export = $0.22 /kg and large = $0.18 /kg.

Discussion

Total yields increased with increasing plant density and tended to plateau above 84 plants/m^2. This asymptotic response to carrot plant density was also found by Salter *et al.* (1979, 1980). McCollum *et al.* (1988) found that marketable and total carrot yields increased linearly with increased plant density over the limited range from 24 to 85 plants/m^2. Phillips (1988) found various responses to yield over 4 sowing dates, ranging from asymptotic to linear responses. Some of these differences can be explained by differences in the size range of marketable roots, in plant densities used and crop growing conditions.

In our study the relationship between density and export grade yield was well described by a polynomial function at each harvest. Later harvest generally produced higher export yields. Plant density for maximizing export yield increased from 52 plants/m^2 at 20 weeks to 61 at 22 weeks to 70 plants/m^2 at 24 weeks.

Time until harvest is an important consideration for maximizing yield and size of carrots (Bleadsdale 1973; Salter *et al.* 1979). Our results also show that the size of roots and yield increased with later harvest date. For instance, at 73 plants/m^2, harvesting at 20 weeks produced a export yield of 54.5 t/ha, and this increased by 25 % to 74.2 t/ha at 22 weeks. At 24 weeks, yield increased a further 6 % up to 78.7 t/ha. The smaller yield increase between the 22 and 24 week harvests was perhaps because leaf blight (*Alternaria dauci*) affected the yield potential of the crop.

Nantes carrot varieties produce shorter roots than some other carrot groups, such as Imperator varieties, and the roots are shortest from late winter and early spring harvests. Average root length was found to increase with later harvests and high N but plant density had the bigger effect on root length.

Lower densities and later harvests can lead to an increase in the proportion of carrots which reach export size grades. The balance must be found between high total yield and high proportion of roots in the desired size range. This is an important consideration if carrot producers are to maximise yield and returns. Earlier harvest may often be necessary if diseases such as blight or cavity spot are developing in the crop.

The nitrogen treatment affected only some yield parameters suggesting that the commercial N rate (the low N treatment) was near adequate. The high N treatment did increase leaf yield and crop height, and reduced the yield of marketable short carrots. N treatment also had a variable effect on the incidence of the the two root diseases present at the last harvest. The high N treatment exacerbated scab but reduced the incidence of cavity spot. The reasons for these effects are not known however in the case of scab, a link with leaf blight is possible. The greater mass of tops on the high N plots appeared to suffer more severely from blight which may have favoured scab development.

Results from the experiment showed that the outside row's contribution to total yield increased at higher plant densities. Salter *et al.* (1980) found the mean root weight was consistently greater from the outer rows when there were more than 3 rows per bed and this 'edge effect' became larger with later harvests. Benjamin and Sutherland (1992) found that this edge effect could be overcome by increasing the seeding rate in the outer rows while holding the overall plant density constant.

For high yielding autumn sown Nantes carrot crops grown for export markets,final plant densities should be in the range of 60 to 70 plants/m² to optimize total yield, proportion of export grade roots and income.

Appendix for 92PE32

Table 5A. Effect of plant density on yield at 20 week harvest.

Plant density (/m²)	Total yield (t/ha)	Export yield (t/ha)	Marketable short yield (t/ha)	Undersize (t/ha)	Oversize (t/ha)	Forked (t/ha)	Split (t/ha)	Misshapen (t/ha)
22	55.1	38.7	0.9	0.03	14.1	0.3	0.29	0.1
42	69.2	60.7	2.4	0.13	3.0	1.0	0.61	0.9
54	79.9	67.7	8.6	0.54	1.1	1.5	0	0.1
73	81.2	54.5	21.3	1.77	0.4	2.1	0.26	0.1
84	86.6	47.2	34.4	2.86	0.4	0.4	0.22	0.8
93	89.1	47.3	36.0	3.96	0.4	0.4	0.14	0.2
120	91.5	31.1	48.7	10.18	0	0.6	0.08	0.3
Significance (density)	***	***	***	***	***	**	ns	ns
l.s.d (P=0.05)	5.8	6.6	4.7	1.3	3.4	1.0	-	-
(N)	ns	ns	***	ns	ns	**	ns	ns
l.s.d (P=0.05)	-	-	1.6	-	-	0.4	-	-
(density *N)	ns	ns	***	ns	ns	ns	ns	ns
l.s.d (P=0.05)	-	-	5.5	-	-	-	-	-

* = P<0.05, ** = P<0.01, *** = P<0.001

Table 6A. Effect of plant density on yield at 22 week harvest

Plant density (plants/m²)	Total yield (t/ha)	Export yield (t/ha)	Marketable short yield (t/ha)	Undersize (t/ha)	Oversize (t/ha)	Green (t/ha)	Forked (t/ha)	Split (t/ha)	Misshapen (t/ha)
22	64.0	28.3	0.1	0.04	24.9	8.7	1.2	0.4	0.4
42	94.0	66.2	1.8	0.3	21.4	2.5	1.8	0	0
54	94.8	76.0	7.9	1.4	6.9	0.4	1.2	0.5	0.5
73	102.4	74.2	16.1	4.8	2.5	1.7	2.2	0.5	0.4
84	105.2	60.1	26.5	11.0	4.6	1.3	1.2	0.6	0
93	107.1	64.1	30.8	9.5	1.7	0	0.8	0.1	0
120	109.1	49.3	37.0	19.5	0.7	0.9	1.1	0.7	0
Significance (density)	***	***	***	***	***	***	ns	ns	ns
l.s.d.(P=0.05)	8.2	11.2	5.3	6.8	6.0	2.8	-	-	-
(N)	ns	ns	ns	ns	ns	ns	ns	ns	ns
(density*N)	ns	ns	ns	ns	ns	ns	ns	ns	ns

Table 7A. Effect of plant density on yield at 24 week harvest

Plant density ($/m^2$)	Total yield (t/ha)	Export yield (t/ha)	Marketable short yield (t/ha)	Undersize (t/ha)	Oversize (t/ha)	Green (t/ha)	Forked (t/ha)	Split (t/ha)	Misshapen (t/ha)
22	72.1	34.5	0.2	0.2	33.8	18.0	2.4	0.3	0.9
42	93.4	64.6	1.8	0.7	21.6	11.8	3.7	1.0	0
54	100.2	81.0	5.6	0.9	9.8	8.5	2.5	0.2	0.2
73	105.9	78.7	16.7	3.9	5.4	7.1	1.2	0	0
84	109.3	76.6	21.6	6.5	3.8	6.5	0.7	0.2	0
93	112.7	71.8	25.4	7.1	2.7	4.2	5.8	0	0
120	110.6	48.6	38.8	20.8	0.5	2.4	1.3	0.4	0.1
Significance (density)	***	***	***	***	***	**	ns	ns	ns
l.s.d (P=0.05)	5.6	10.5	4.3	2.4	8.4	6.4			
(N)	ns	ns	**	ns	ns	ns	ns	ns	ns
l.s.d (P=0.05)	-	-	2.7	-	-	-	-	-	-
(density*N)	ns	ns	ns	ns	ns	ns	ns	ns	ns

Table 8A. Effect of density and nitrogen on average root length

Plant density ($/m^2$)	Root length (cm) at 20 weeks		Root length (cm) at 22 weeks		Root length (cm) at 24weeks	
	high N	*low N*	*high N*	*low N*	*high N*	*low N*
22	21.7	21.1	22.3	22.4	22.7	23.0
42	19.4	19.1	19.9	19.7	20.2	19.8
54	17.5	16.9	18.6	18.5	19.4	19.0
73	15.5	15.7	17.3	17.3	18.0	17.4
84	15.4	15.0	16.6	16.2	17.6	16.6
93	14.3	14.5	16.5	16.4	17.2	16.8
120	14.2	13.6	16.0	15.3	15.6	15.4
mean	16.9	16.5	18.2	18.0	18.5	18.1
Significance (density)	***		***		***	
l.s.d. (P=0.05)	0.7		0.6		0.8	
(N)	*		ns		*	
l.s.d. (P=0.05)	0.3		-		0.3	
(density*N)	ns		ns		ns	

Table 9A. Gross returns ($) from Top Pak carrots at 20, 22 and 24 week harvests. Price for smalls $0.16/kg, mediums $0.22/kg and large $0.18/kg

Harvest	Density (plants/m^2)	Smalls (Marketable shorts) (t/ha)	Mediums (Export) (t/ha)	Large (Oversize) (t/ha)	Gross return ($)
20 weeks					
	22	0.94	38.7	14.0	11 184
	42	2.4	60.7	3.0	14 278
	54	8.6	67.7	1.1	16 468
	73	21.3	54.5	0.4	15 470
	84	34.3	47.2	0.4	15 944
	93	36.0	47.3	0.4	16 238
	120	48.7	31.1	0	14 634
22 weeks					
	22	0.13	28.3	33.6	12 295
	42	1.8	66.2	23.9	19 154
	54	7.9	76.0	7.3	19 298
	73	16.1	74.2	4.2	19 656
	84	26.5	64.8	5.9	19 558
	93	30.8	64.1	1.7	19 336
	120	37.0	49.3	1.6	17 045
24 weeks					
	22	0.5	34.5	51.8	16 994
	42	1.8	64.6	33.4	20 514
	54	5.6	81.0	18.3	22 010
	73	16.7	78.7	12.5	22 236
	84	21.6	76.6	10.2	22 144
	93	25.4	71.8	6.8	21 084
	120	38.8	48.6	2.9	17 422

2. Experiment 92PE70 - The effect of plant density and harvest time on the yield and quality of Nantes carrots sown in summer

Introduction

The objective of this experiment was to examine the relationships between plant density and yield and size distribution of Nantes carrots sown in summer. An additional aim of this experiment is to examine the effect of plant density on the incidence of cavity spot disease at harvest. Cavity spot incidence is higher in older carrots (Vivoda *et al.* 1991). At low plant densities carrots reach marketable size earlier (Robinson 1969). Hence we test the hypothesis that at low plant densities cavity spot can be avoided by permitting earlier harvest.

Materials and Methods

The experiment was conducted on a Karrakatta sand on a commercial property 100 km north of Perth. The site, within a centre-pivot, had a history of cavity spot disease of carrots. Six plant density treatments were replicated 4 times as the main plots in a split-plot design with harvest times as sub-plots. The target densities were 40, 60, 80, 100, 120 and 140 plants/m^2 however actual plant densities were lower (Table 1).

Pelleted seed of the Nantes variety Top Pak (South Pacific Seeds) were sown with an Agricola® precision air seeder on 22 December 1992. Four twin rows were sown on 1.92 m wide (wheel centre to wheel centre) beds and each plot was 10 m long. All densities were calculated using wheel centre to wheel centre bed widths.

Fertiliser was applied according to a commercial regime however irrigation was considered inadequate particularly immediately after sowing and again near mid-growth because of the differing commercial cropping program surrounding the experimental site within the centre -pivot. Good weed control was achieved with applications of registered herbicides.

Plots were harvested on 3 occasions: 16, 18 and 20 weeks after sowing. At each harvest, four by 0.5 m lengths of twin-row were sampled from each plot. Roots were washed, graded and weighed.

The carrots were graded according to size: export (25 to 50 mm crown diameter, greater than 150 mm length), marketable short (25 to 50 mm crown diameter, 100-150 mm length), undersize (less than 100 mm length, less than 25 mm crown diameter), oversize (greater than 50 mm crown diameter) and other (forked, misshapen, split and green). The fresh weight of leaves from each plot was also recorded. The carrots from each plot were then regraded at each harvest to determine the percentage of yield affected by the root disease cavity spot. Thus yield data presented do not take cavity spot into account.

The effects of density and harvest time on yield and other variables were tested by analysis of variance using GENSTAT software.

Results

Table 10 shows the target plant densities and average densities from the 3 harvest times.

Table 10. Target densities and average plant densities

Target density (plants/m^2)	Actual plant density (plants/m^2) (± s.e.)
40	37 (± 0.6)
60	48 (± 1.0)
80	64 (± 0.7)
100	71 (± 1.9)
120	89 (± 1.5)
140	108 (± 0.9)

Yield.

Plant density had large effects on root yield. Total yield (t/ha) increased (P<0.05) with increasing plant density up to about 50 plants/m^2 for the 16 and 18 week harvests and tended to plateau at higher densities (Fig. 6). Yield from the 20 week harvest followed the same trend but tended to decline slightly above 60 plants/m^2. Later harvest produced significantly (P<0.001) higher total yields. Maximum total yields were close to 40 t/ha for the 16 week harvest, 50 t/ha at 18 weeks and 70 t/ha at 20 weeks (Fig. 6).

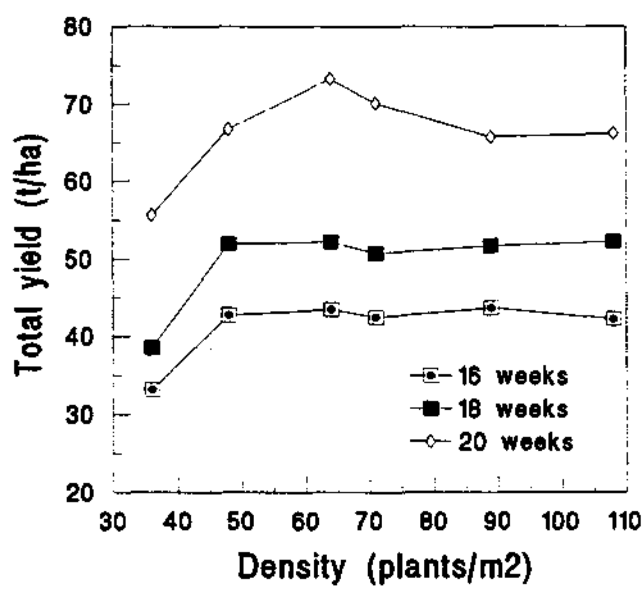


Fig. 6. The effect of plant density and time of harvest on the total yield of Top Pak carrots.

The main effects of density and harvest time, as well as their interaction, on export yield were significant (P<0.001). Polynomial functions were fitted to export yield versus density and accounted for at least 87 % of the variation in yield (Fig. 7). Export yield was maximized at the following : 16 week harvest at 14.2 t/ha with 44 plants/m², 18 weeks at 25.3 t/ha with 50 plants/m² and 20 weeks at 39.0 t/ha with 52 plants/m².

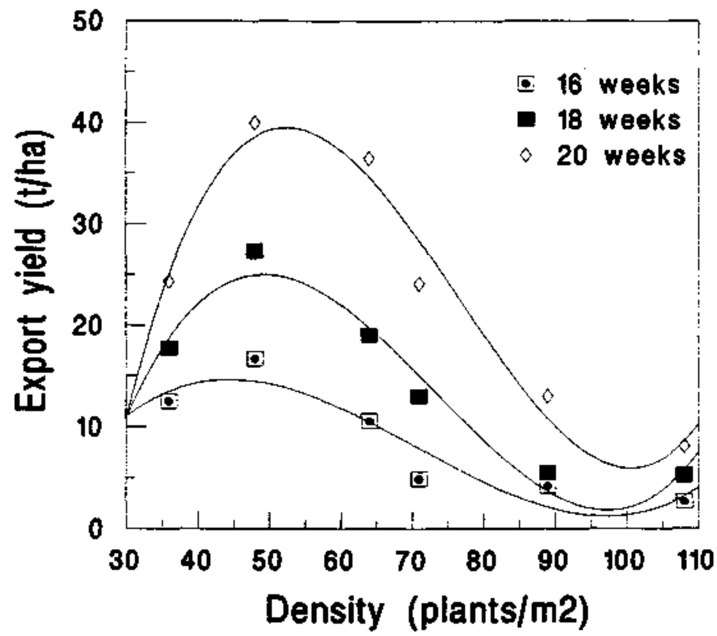


Fig. 7. The effect of plant density and time of harvest on the export yield of Top Pak carrots.

16 weeks, $y = -30.5 + 2.39x - 0.039x^2 + 0.00018x^3$, $R^2 = 0.87$

18 weeks, $y = -97.9 + 6.00x - 0.092x^2 + 0.00042x^3$, $R^2 = 0.96$

20 weeks, $y = -167.5 + 9.55x - 0.138x^2 + 0.0006x^3$, $R^2 = 0.96$.

Plant density affected size distribution of roots (Figs. 8a,b,c). Higher densities produced a greater proportion of undersize carrots. With later harvest, the proportion of yield as undersize roots was reduced while at lower densities for the 20 week harvest oversize root yield increased (Figs. 8a,b,c).

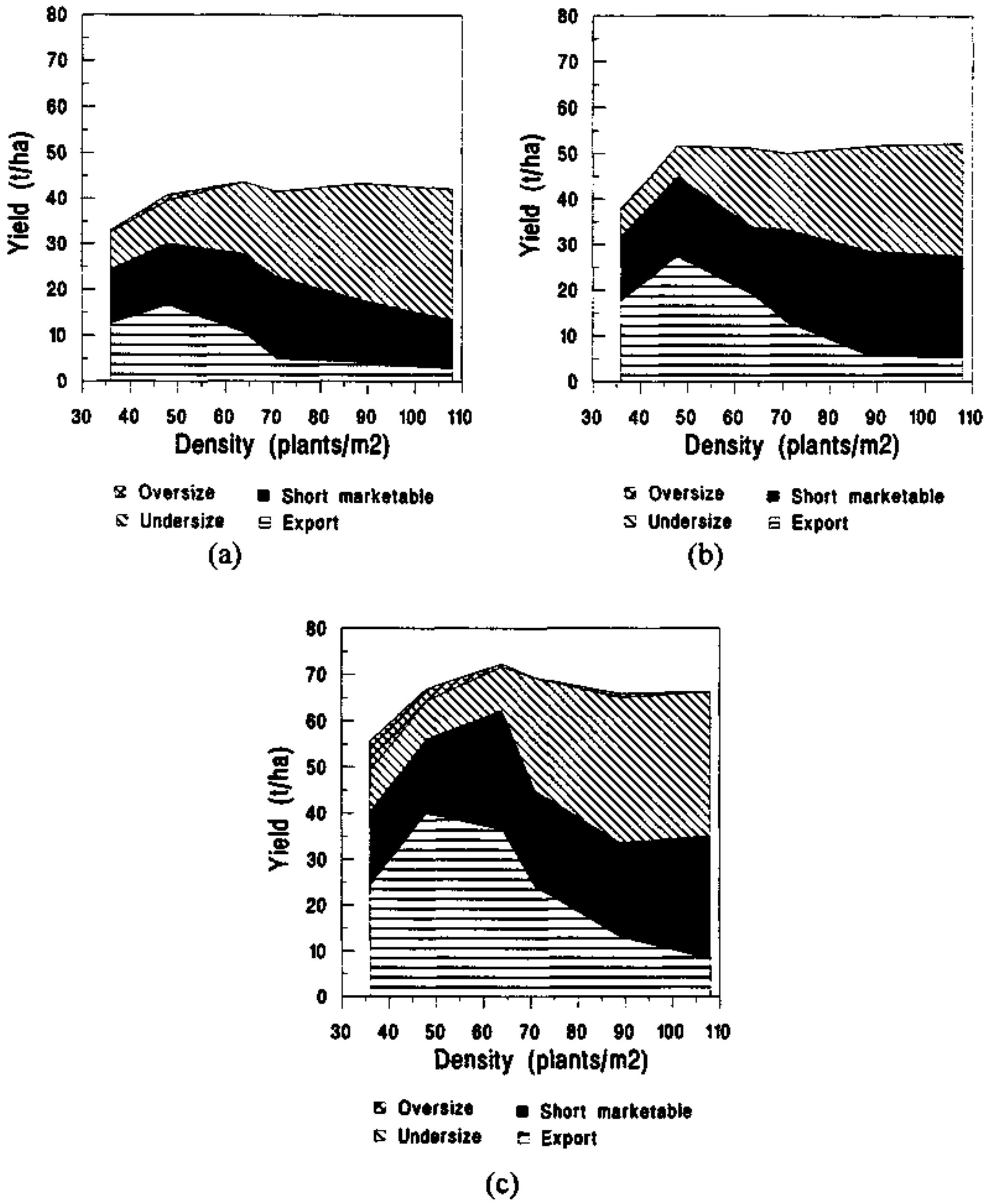


Fig. 8a-c. The effect of plant density on the yield of different root size categories for Top Pak carrots harvested at 16, 18 and 20 weeks respectively.

Similarly, density and harvest time also had effects on average root weight (Table 11).

Table 11. The effect of plant density and harvest time on the average root weight of Top Pak carrots

Plant density (/m^2)	16 weeks	18 weeks	20 weeks
		average root weight (g)	
37	93	110	147
48	89	107	148
64	70	80	115
71	57	77	108
89	48	59	75
108	40	47	62
harvest average	66	80	109
Significance			
Density		P<0.001	
l.s.d. (*P*=0.05)		18.5	
Harvest		P<0.001	
l.s.d. (*P*=0.05)		5.9	
Density x harvest		P<0.05	
l.s.d (*P*=0.05)		22.0	

Table 12 : The effect of plant density and harvest time on the leaf yield of Top Pak carrots

Plant density (/m^2)	16 weeks	18 weeks	20 weeks
		leaf yield (t/ha)	
37	6.0	6.8	9.0
48	6.5	8.3	9.8
64	7.2	8.8	11.1
71	7.4	8.7	11.2
89	8.1	9.3	12.1
108	8.1	10.0	12.6
harvest average	7.1	8.5	10.9
Significance			
Density		*P*<0.001	
l.s.d. (*P*=0.05)		1.2	
Harvest		*P*<0.001	
l.s.d. (*P*=0.05)		0.44	
Density x harvest		ns	

ns = no significant difference

Leaf yield

Leaf yield increased with increasing plant density at each harvest (Table 12). Leaf yield also increased ($P<0.001$) with later harvest, with average leaf yields for each harvest shown in Table 12.

Rejects

The major reasons for rejection (aside from cavity spot) were forked, split and misshapen roots. The level of these rejects was low and was not affected ($P>0.05$) by density or harvest time. (Tables 15A-17A).

Cavity spot

Cavity spot incidence decreased ($P<0.01$) with increasing plant density at each harvest and increased ($P<0.001$) with later harvest (Fig. 9). Cavity spot severity also increased with later harvest as the level of slight symptoms decreased and the proportion of yield showing severe symptoms increased markedly (Tables 16A and 18A).

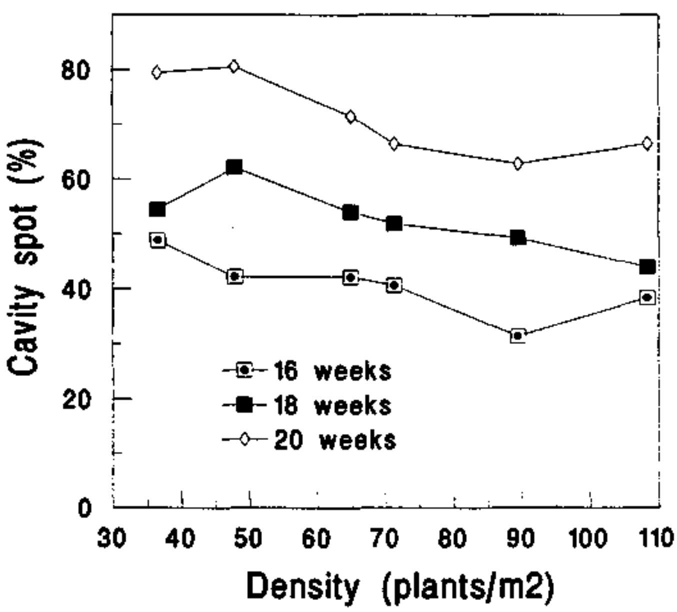


Fig. 9. The effect of plant density and time of harvest on the incidence of cavity spot (% of total yield) in Top Pak carrots.

Consideration of the relationship between average root weight for the three harvests and cavity spot incidence showed that average root weight accounted for about 65 per cent of the variation in cavity spot incidence. [$y = 23.1 + 0.38x$, $R^2 = 0.653$, where y = % total yield with cavity spot and x = average root weight (g)].

Gross income

The effect of plant density and harvest date on the gross income per hectare at an arbitrary price structure is shown in Fig. 10. These calculations are based on sixe and quality grades but do not account for the effect of cavity spot on marketability. Income peaked at about 50 plants/m^2 for the 16 and 18 week harvests and between 50 and 60 plants/m^2 for the 20 week harvest. Income declined substantially at higher plant densities because of the production of large yields of unsalable undersize roots mainly at the expense of export size roots.

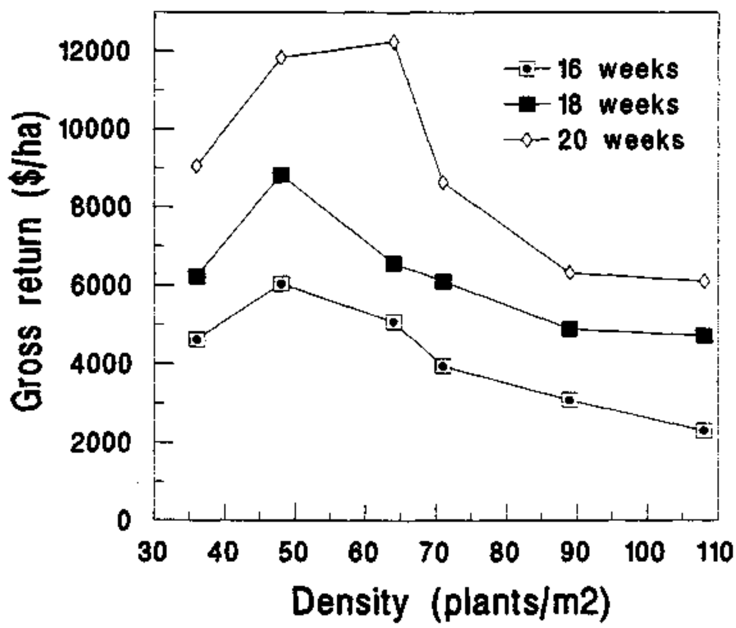


Fig. 10. The effects of plant density and harvest time on the gross income ($) from Top Pak carrots sown in summer. Calculated with short marketables = $0.16/kg, export = $0.22/kg and large = $0.18/kg.

Discussion

Maximum export yields were reached at 44, 50 and 52 plants/m^2 for the 16, 18 and 20 week harvests respectively. Export yields were low ranging from a maximum of 14.2 t/ha at 16 weeks to 39 t/ha at 20 weeks. Commercial carrot crops planted in December under similar circumstances would normally be harvested 16 to 17 weeks after sowing with average export yields close to 40 t/ha. In our experiment it took 20 weeks to reach these yield levels probably as a result of under-irrigation during the mid to late stages of the crop.

As in an earlier plant density experiment (92PE32), the relationships between plant density and export yields were also well described by polynomial functions at each harvest. It is interesting to note that across the 6 harvests from the 2 experiments combined, plant density for maximising export yield increased from 44 to 70 plants/m^2 as export yields increased from 14 to 83 t/ha.

At this site gross income increased with later harvest and was sensitive to plant density, with highest returns achieved near 50 plants/m^2 for the 16 and 18 week harvests and at about 60 plants/m^2 for the 20 week harvest. Maximum gross returns increased from $6,000 at 16 weeks to $8,800 at 18 weeks to $12,250 at 20 weeks. Optimum densities for maximizing returns depend on prevailing price structures for varying root size categories and the timing of harvest.

The difficulty in defining optimum plant densities is that they are dependent on the yield potential of the crop which is dependent on many factors. Where growing conditions are favourable Nantes carrots grown for export should be established at about 70 plants/m^2 while under less favourable lower yielding conditions or where there is a desire to harvest the crop early, a plant density of about 50 plants/m^2 would be appropriate. Even with high quality seed, growers need to sow at 10-15 % higher seeding rates to establish a given plant population in the field. Variation in inter-plant spacing also needs to be minimized in order to maximize root yields in desired size ranges.

Cavity spot increased with decreasing plant density and later harvest. Cavity spot incidence was correlated to average root weight for all density treatments across the 3 harvests suggesting that root surface area and/or physiological maturity related to size may affect cavity spot development.

The severity of cavity spot increased considerably with later harvest. However whether the increase in yield which occurs with later harvest can compensate for the decrease in marketable percentage because of disease will depend on a number of factors. In our experiment if we assume that yield affected by moderate and severe cavity spot was rejected then yields remaining were 36.3, 34.6 and 33.0 t/ha for the 16, 18, and 20 week harvests respectively. Total yields for the three harvests were 41.3, 49.6 and 66.3 t/ha respectively.

There appears to be little scope for avoiding cavity spot by sowing at lower density to permit earlier harvest and, while cavity spot could be reduced by harvesting earlier, yield and potential returns were severely compromised in doing so. Even with the high and rapidly developing levels of cavity spot encountered in this experiment early harvest would only be of marginal advantage. Growers should monitor the development of cavity spot along with root size within carrot crops to aid decisions on timing of harvest.

Appendix for 92PE70

Table 13A. Effect of plant density on the yield of carrots harvested at 16 weeks

Plant density (/m^2)	Total yield (t/ha)	Export yield (t/ha)	Marketable short yield (t/ha)	Undersize (t/ha)	Oversize (t/ha)	Rejects[A] (t/ha)
37	33.2	12.5	11.7	8.2	0	0.8
48	42.8	16.7	13.4	9.4	1.3	2.1
64	43.5	10.6	17.2	15.8	0	0
71	42.5	4.9	17.9	18.7	0	1.0
89	43.7	4.2	13.5	25.6	0	0.3
108	42.3	2.7	10.7	28.8	0	0.2

[A] Forked, split and misshapen roots

Table 14A. Effect of plant density on yield at 18 week harvest

Plant density (/m^2)	Total yield (t/ha)	Export yield (t/ha)	Marketable short yield (t/ha)	Undersize (t/ha)	Oversize (t/ha)	Rejects[A] (t/ha)
37	38.6	17.7	14.1	5.8	0.4	0.5
48	51.9	27.3	17.6	6.7	0	0.4
64	52.2	19.0	14.9	17.4	0	1.0
71	50.7	13.0	20.3	16.7	0	0.7
89	51.7	5.5	23.0	23.2	0	0
108	52.2	5.3	22.2	24.7	0	0

[A] Forked, split and misshapen roots

Table 15A. Effect of plant density on yield at 20 week harvest

Plant density (/m^2)	Total yield (t/ha)	Export yield (t/ha)	Marketable short yield (t/ha)	Undersize (t/ha)	Oversize (t/ha)	Rejects[A] (t/ha)
37	55.6	24.3	15.9	9.0	6.5	0
48	66.8	40.0	16.0	8.2	2.6	0
64	73.3	36.5	25.8	9.5	0.6	1.0
71	70.1	24.1	20.9	24.3	0	0.7
89	65.8	13.0	20.6	31.4	0.8	0
108	66.2	8.1	27.0	31.1	0	0

[A] Forked, split and misshapen roots

Table 16A. The effect of plant density and harvest time on the proportion of total root yield with slight cavity spot symptoms

Plant density (/m^2)	16 weeks	18 weeks	20 weeks
		slight cavity spot (%)	
37	31.2	19.1	16.0
48	20.8	22.7	22.2
64	32.6	28.1	26.8
71	29.0	24.2	19.8
89	24.2	26.3	22.3
108	32.9	19.6	22.0
Significance			
density		ns	
harvest		$P<0.001$	
density x harvest		ns	

Table 17A. The effect of plant density and harvest time on the proportion of total root yield with moderate cavity spot symptoms

Plant density (/m^2)	16 weeks	18 weeks	20 weeks
		moderate cavity spot (%)	
37	17.8	10.6	20.1
48	21.5	23.6	21.8
64	9.6	17.4	19.4
71	11.7	18.2	23.0
89	7.1	15.4	22.9
108	5.4	16.2	17.8
Significance			
density		$P<0.01$	
harvest		$P<0.001$	
density x harvest		ns	

Table 18A. The effect of plant density and harvest time on the proportion of total root yield with severe cavity spot symptoms

Plant density (/m^2)	16 weeks	18 weeks	20 weeks
		severe cavity spot (%)	
37	0	14.3	43.4
48	0	32.0	36.7
64	0	8.5	25.3
71	0	9.5	26.8
89	0	7.6	17.6
108	0	8.2	26.8
Significance[A]			
density		$P<0.01$	
harvest		$P<0.001$	
density x harvest		ns	

[A]Analysed for 18 and 20 week harvests only.

Acknowledgments

L. Biocich and C. Hoareau of the Sumich Group are thanked for their assistance with sowing these experiments. Thanks to K. Gajda for technical assistance and to the staff of Medina Research Centre for their assistance with harvesting. Margaret Graham is thanked for her helpful comments on an earlier draft of this report. The authors gratefully acknowledge the financial assistance of the Sumich Group Ltd. and the Horticulture Research and Development Corporation.

References

Benjamin, L. R. and Sutherland R. A. (1992). Control of mean root weight in carrots (*Daucus carota*) by varying within- and between-row spacing. *Journal of Agricultural Science, Cambridge* **119**, 59-70.

Bleasdale, J. K. A. (1973). Control of size and yield in relation to harvest date of carrot roots. *Acta Horticulturae* **27**, 173-82.

Bussell, W. T. (1973). Effect of plant density and time of harvest on yield of small finger carrots. *New Zealand Journal of Experimental Agriculture* **1**, 69-72.

Gray, D. and Benjamin, L. (1991). Reducing the 'grade-out' pile. *Grower*, July 11, 26-28.

Mack, H. J. (1980). Effect of row spacings on processing carrot root yields. *Horticulture Science* **15**(2), 144-5.

McCollum, T. G, Locascio, S. J. and White, J.M. (1986). Plant density and row arrangements effects on carrot yields. *Journal of the American Society of Horticultural Science* **111**(5), 648-51.

McKay, A. G. and Galati, A. (1992). Survey looks at cause of carrot yield decline. *Good Fruit and Vegetables* **3** (5), 24-5.

Northcote, K. H. (1979). 'A Factual Key to the Recognition of Australian Soils'. 4th Ed. (Rellim Technical Publications, South Australia)

Phillips, D. R. (1988). Investigations of cultural and management techniques for mechanically harvested export carrots. Australian Special Rural Research Fund project final report.

Phillips, D. R. (1990). Planting and harvesting carrots. Farmnote No. 93/90. Western Australian Department of Agriculture Agdex 267/20.

Robinson, F. E. (1969). Carrot population density and yield in an arid environment. *Agronomy Journal* **61**, 499-500.

Salter, P. J. Currah, I. E. and Fellows J. R. (1979). The effects of plant density, spatial arrangement and time of harvest on yield and root size in carrots. *Journal of Agricultural Science, Cambridge* **93**, 431-40.

Salter, P. J. Currah, I. E., and Fellows J. R. (1980). Further studies on the effects of plant density, spatial arrangement and time of harvest on yield and root size in carrots. *Journal of Agricultural Science, Cambridge* **94**, 465-78.

Vivoda, E., Davis, R. M., Nunez, J. J., and Guerard, J. P. (1991). Factors affecting the development of cavity spot of carrot. Plant Disease 75, 519-22.

Warne, L. G. G. (1951). Spacing experiments on vegetables. II. The effect of thinning distance on the yields of globe beet, long beet, carrots and parsnips grown at a standard inter-row distance in Cheshire, 1948. *Journal of Horticultural Science* **26**, 84-7.

Webster, A. B. (1969). Manuring and spacing experiments on vegetables. *New Zealand Journal of Agricultural Research* **12**, 381-416.

11. CARROT VARIETY EVALUATION

A. Galati and A. G. McKay

CARROT VARIETY EVALUATION

Summary

Seven variety evaluations were carried out during this project. The major objectives of these screenings were to identify suitable varieties with disease (cavity spot and blight) tolerance. The material tested changed over the course of the project because of the carrot industry and overseas importers were redefining their requirements. In 1990, the W.A. carrot industry was based on the open pollinated variety, Western Red. The industry was examining hybrid varieties-(Imperator and Nantes types) during 1991 and by late 1992, most of the export carrot industry was based on Nantes carrot varieties.

Major results

- Early evaluations were concerned with the yield potential of Western Red compared with Nantes and Imperator varieties. Early evaluations found Nantes lines to be comparable to Western Red for yield. Leaf yield of hybrids was lower, allowing for easier mechanical harvesting.
- Varieties were evaluated for scab tolerance in a March and August planting. Scab disease was found in some Western Red lines and some Western Red related hybrids, but rarely in Nantes varieties. There were differences in scab incidence between sites.
- Varieties were evaluated for cavity spot tolerance in February and December plantings. There were differences among Nantes varieties with respect to cavity spot severity.
- Blight tolerance, root length and maturity of varieties grown over winter were evaluated in varieties sown in March and April. There were significant differences in average root length and blight tolerance among varieties.

Recommendations

(a) Extension/adoption by industry

Varieties from trial 92PE30 that showed promised were displayed at the Carrot Industry seminar in November 1992. Sumich Group Ltd. further evaluated varieties on their properties and introduced some of these varieties into their commercial export program. Reports were sent to seed companies, Sumich Group and other interested parties. Disease tolerance of varieties was also discussed in newsletter articles.

(b) Directions for future research

Evaluation of carrot varieties for Western Australian conditions needs to be continued as varietal disease tolerance can be an important component for the integrated management cavity spot and leaf blight.

(c) Financial/commercial benefits

Improvement in yield and quality which can be made with the introduction of superior varieties contribute directly to industry efficiency and profitability. Varieties with tolerance to leaf blight would reduce the dependence on fungicides and would improve mechanical harvesting efficiency. A Nantes variety with cavity spot tolerance would result in higher marketable yields for the producer.

CARROT VARIETY EVALUATION

Introduction

For many years the carrot industry in Western Australia was based on the open-pollinated variety Western Red. However the industry is changing to hybrid lines, particularly 'Nantes' varieties, because of the demand for these carrots in South East Asia.

As part of the carrot yield decline project, new varieties were screened to compare yield and disease tolerance.

1. Experiment 90MD26 - Carrot variety observation-July planting

Aim

The aim of this observation was to compare the yield of some new carrot varieties to the industry standard, Western Red.

Materials and Methods

The site at the Medina Research Centre was treated prior to seeding with Nemacur® at a rate of 24 L/ha. Superphosphate (500 kg/ha), muriate of potash (120 kg/ha) and trace elements (150 kg/ha) were broadcast and rotary hoed across the site.

Eleven varieties were assessed (Table 1). Plots were 4 m long and 1.5 m wide. Five single rows were sown per bed with an Earthway® seeder on 18 July 1990. There were 2 replicates per treatment and these were arranged in a randomised block.

Table 1. Details of variety, carrot type and seed company

Variety	Carrot type[A]	Seed company
Western Red	Autumn King (OP)	Lefroy Valley Seeds
Lefroy Valley F1	Autumn King (H)	Lefroy Valley Seeds
Western Red (MK)	Autumn King (OP)	Magnus Kahl Seeds
Top Pak	Nantes (H)	South Pacific Seeds
Hybrid 451(Hi Pak)	Nantes (H)	South Pacific Seeds
Nandor	Nantes (H)	South Pacific Seeds
Red Sabre	Imperator (H)	Henderson Seeds
Red Count	Imperator (H)	Henderson Seeds
Red Ned	Imperator (H)	Henderson Seeds
Riverina Red	Imperator (OP)	Yates Seeds
Red Brigade	Imperator (H)	Yates Seeds

[A](OP) = open pollinated, (H) = F1 hybrid

Two days after seeding, Linuron® was applied at a rate of 1 kg/ha in 200 L water/ha. Six weeks after emergence, the plots were hand thinned to a target density of 80 plants/m^2.

Commencing at emergence, a total of 750 kg/ha of urea, 600 kg/ha of muriate of potash and 200 kg/ha of magnesium sulphate was applied to the crop on a fortnightly regime in 10 dressings.

At harvest (18 December 1990), 2.0 m of each 4 m plot were hand harvested from the middle 3 rows. Tops and roots were weighed and checked for disease. Roots were categorised into the following categories:

export: 25 to 50 mm crown diameter and greater than 150 mm length,
marketable, short: 25 to 50 mm crown diameter and 100-150 mm length,
undersize: less than 25 mm crown diameter and less than 100 mm length,
oversize: more than 50 mm crown diameter and,
other rejects such as forking, misshapen, nodal enlargement and bolting.

Results and Discussion

The total yield ranged from 57 t/ha for Red Ned to 101 t/ha for Red Sabre. The marketable yield ranged from 40 to 83 t/ha. Top Pak and Red Brigade had the highest marketable yields at 83 t/ha. Nandor had a marketable yield of 63 t/ha with another 8 t/ha classed as marketable, short (Table 2). The Nantes lines are often less than 150 mm length even though the roots have marketable diameter (ie between 25 and 50 mm).

The total and marketable yields of many of the hybrids were comparable to the industry standard, Western Red. The major difference is that these hybrids are shorter, for example 19 cm for Nandor compared to 24 cm for Western Red (Table 4). The advantage of short carrots is that packing time is reduced. The candle-like shape of the Nantes means that a tighter pack can be achieved without overpacking (Phillips 1988).

Table 2. Total and marketable yields, leaf yield, rejects and plant density for 11 carrot varieties planted at Medina Research Centre (data is mean of two replicates)

Variety	Density (plants/m^2)	Leaf yield (t/ha)	Total yield (t/ha)	Export yield (t/ha)	Marketable short yield (t/ha)	Total rejects (t/ha)
Top Pak	63	15.8	98.6	82.2	3.2	13.0
Riverina Red	74	18.4	90.7	71.6	1.7	17.4
Red Count	59	18.5	83.5	74.2	0.15	9.1
Red Sabre	75	19.7	101.3	76.8	0.21	24.3
W. Red (LV)	63	37.7	99.4	77.3	0.74	21.3
Red Brigade	71	27.5	94.0	82.8	0	11.2
Nandor	81	14.5	88.2	63.2	7.89	17.1
Hybrid 451	57	15.6	86.0	57.6	0.44	28.0
Red Ned	46	9.5	57.2	39.9	0	16.8
Lefroy Valley F1	69	14.4	77.1	64.3	1.07	11.7
W. Red (MK)	62	35.7	92.9	57.4	0.54	35.0

The plant density of the varieties for which data is presented was in the range of 51 to 81 plants/m^2. The target density was 80 plants/m^2.

Table 3. Categories of rejects shown as percentages of total yield for 11 carrot varieties planted at Medina Research Centre (data is mean of two replicates)

Variety	% of total yield							
	Total rejects	Under-size	Over-size	Miss-hapen	Forked	Nodal enlargement	Green	Other[A]
Top Pak	13.2	0.4	3.0	1.0	5.4	1.6	1.2	0.4
Riverina Red	19.2	1.0	0.9	4.7	12.1	0	0	0.3
Red Count	10.9	0.4	0	2.0	6.2	1.6	0	0.6
Red Sabre	24.0	2.1	4.4	8.1	8.9	0.7	0	0
W. Red (LV)	21.3	1.3	4.9	5.6	5.5	1.6	0	2.4
Red Brigade	11.9	2.7	0.9	3.6	2.6	1.2	0	0.8
Nandor	19.4	1.2	7.4	0.1	8.7	0	1.6	0.1
Hybrid 451	32.6	0.3	5.1	2.4	11.5	4.3	9.8	0
Red Ned	29.4	2.4	6.8	3.0	4.0	0.9	11.7	1.4
Lefroy Valley F1	15.2	3.6	4.3	1.8	2.3	0.5	1.6	1.1
W. Red (MK)	37.7	2.4	5.9	9.7	14.4	5.3	0	0

[A]includes splitting, bolting

Table 4. Root:top ratio, crop height and average length of marketable roots for 11 carrot varieties planted at Medina Research Centre (data is mean of two replicates)

Varieties	Root:top ratio	Crop height (cm)	Average root length (cm)
Top Pak	6.2	50	21.7
Riverina Red	4.9	39	20.8
Red Count	4.5	40	23.6
Red Sabre	5.1	45	22.9
W. Red (LV)	2.6	65	24.5
Red Brigade	3.4	57	24.5
Nandor	6.1	40	19.0
Hybrid 451	5.5	45	21.5
Red Ned	6.0	40	21.7
Lefroy Valley F1	5.3	40	22.2
W. Red (MK)	2.6	60	24.0

The leaf yield ranged from 9 to 38 t/ha. However both lines of Western Red had leaf yields greater than 35 t/ha. One of the advantages of the hybrid lines (eg Top Pak and Hybrid 451) is the smaller tops that can make mechanical harvesting easier. The root to top ratio for hybrid carrots is higher than that of Western Red (Table 4). Phillips (1988) also reported that hybrid carrot tops are more easily cut from the roots by the harvester.

The major categories of rejects are listed in Table 3. Greening of shoulders was a problem with some hybrid lines, but not with the Western Red lines. No diseases were recorded at this site. There was a high incidence of forking in some varieties (eg 14 % in the Magnus Kahl line of Western Red). The cause of forking on this site was not confirmed, but Pythium fungi were a possible cause.

Conclusion

The hybrid lines such as Top Pak were comparable to Western Red in their total and marketable yields. The smaller top produced by the hybrid varieties is also important as large tops often hinder mechanical harvesting. Hybrid varieties thus have the advantage of higher root/shoot ratios. The Nantes varieties are being adopted by industry because export markets are now demanding these sweeter flavoured varieties.

Top Pak and Nandor are becoming the industry standard varieties for export production. Further work on the multitude of hybrid varieties available is required, particularly screening for yield and disease resistance.

---

2. Experiment 90MO67 - Yield and disease tolerance of carrot varieties-August planting

Aim

This experiment was sown into an area on which the previous crop had been severely affected by scab. The symptoms of scab are thin black corky lesions that arise from the carrot secondary root nodes. The cause of scab is not known. The aims of this experiment were to assess the yield performance of a range of carrot varieties and to compare their susceptibility to scab.

Materials and Methods

The experiment was conducted on a commercial property, 100 km north of Perth. Raw seed (size 5/64) was dusted with Thiram® (5 g/kg) to control seed borne disease and seeded with an Agricola Italia® airseeder on 8 August 1990. Plots were 11 m long on beds 1.92 m wide. Five double rows were sown per bed. Plots were hand thinned at the 3 leaf stage to ensure uniform densities among varieties. Plots were arranged in a randomised block with 4 replicates. The crop was watered with a centre pivot irrigator and fertiliser, weed and pest management was as for the surrounding commercial crop. Soil was a deep grey sand with a pH of 6.1 (1:5 water), bicarbonate extractable phosphorus of 26 mg/kg, bicarbonate extractable potassium of 45 mg/kg and organic carbon content of 0.3%.

At each harvest, the carrots were washed, weighed and graded according to size and marketability. Carrots were assessed at two harvest dates:

Harvest 1 on 13 December 1990 (127 days after sowing{DAS})
Harvest 2 on 2 January 1990 (155 DAS).

Table 5. List of varieties assessed

Variety	Carrot type[A]	Seed company
LV 8901	Nantes (H)	Lefroy Valley Seeds
Hybrid 451	Nantes (H)	South Pacific Seeds
Majestic Red	Autumn King (H)	Yates Seeds
Top Pak	Nantes (H)	South Pacific Seeds
Cellobunch	Imperator (H)	New World Seeds
Western Red	Autumn King (OP)	Yates Seeds
Western Red	Autumn King (OP)	Lefroy Valley Seeds
Red Hot	Imperator (H)	Henderson Seeds
Hero	Imperator (H)	W.A. Produce
Western Red	Autumn King (OP)	Arbuckle Seeds
Nandor	Nantes (H)	South Pacific Seeds
Riverina Red	Imperator (H)	Yates Seeds
Lefroy Valley F1	Autumn King (H)	Lefroy Valley Seeds

[A](OP) = open pollinated, (H) = F1 hybrid

Leaf nutrient analysis was undertaken over the life of the crop commencing at 63 DAS for the varieties Top Pak, Nandor, F1, Majestic Red, Red Hot (see appendix). Crop height and % bolting was estimated at harvest 2. A total of 232 kg N/ha, 167 kg P/ha and 670 kg K/ha were applied to the crop.

Results and Discussion

Scab symptoms appeared on the roots about 4 weeks before harvest 1. The percentage of infected roots increased in the 3 weeks between harvest 1 and 2 (Tables 7 and 9). The Nantes varieties (Hybrid 451, Top Pak, Nandor, LV 8901) were generally less susceptible to scab than the other varieties. One exception to this trend was Arbuckle's Western Red which had low levels of scab. Hybrid 451 had the lowest percentage of scab infected roots followed by Arbuckle's Western Red and Top Pak.

Export yield includes roots with a crown diameter of between 25 and 50 mm and a length greater than 150 mm. Export yields are shown in Tables 2 and 4. Between harvest 1 and harvest 2 marketable yield averaged over all varieties increased from 50.7 t/ha to 57.3 t/ha an increase of 13%. In this period total yield increased by 19% on average (Table 8).

The Nantes varieties LV 8901, Hybrid 451 and Top Pak had amongst the highest marketable yields at harvest 2 even after discarding a large yield of short (<150 mm) roots (eg 30 t/ha for Top Pak). The average length of marketable roots is shown in Tables 6 and 8.

Table 6. Leaf yield, density, total and marketable yields for 13 carrot varieties harvested on 13 December 1990 (127 DAS)

Variety	Average root length (cm)	Leaf yield (t/ha)	Density (plants/m^2)	Total yield (t/ha)	Export yield (t/ha)	Marketable short yield (t/ha)
Hybrid 451	17.8	21.2	103	83.2	53.8	17.5
Top Pak	17.1	15.3	125	100.3	51.4	30.8
Nandor	17.3	14.7	110	89.3	48.6	23.7
WR (Yates)	20.4	35.1	111	86.0	56.5	6.5
Majestic Red	19.1	28.4	115	91.9	61.1	12.6
Riverina Red	17.6	18.9	114	80.8	37.9	20.3
WR (LVS)	20.0	32.8	108	84.7	54.0	8.6
Fl (LVS)	19.3	20.8	137	78.6	36.7	8.2
LV 8901	17.7	13.6	98	89.0	58.7	19.0
Cellobunch	21.0	20.1	106	85.5	63.2	2.4
Hero	20.9	20.9	120	75.7	40.8	2.3
Red Hot	17.6	18.8	97	75.6	50.9	4.4
WR (Arb)	21.1	37.7	98	72.9	45.4	7.4
Significance	***	***	***	***	***	***
l.s.d (P=0.05)	0.6	3.8	15.3	7.3	10.1	8.7

The Western Red lines had the largest leaf yield while the Nantes line LV 8901, Top Pak and Nandor had the lowest leaf yield (Tables 6 and 8). Weight of tops decreased from harvest 1 to harvest 2 apparently as a result of early senescence caused by disease. The overall average plant density was 112 plants/m^2. This was higher than targeted and a density of 80 plants/m^2 would have been ideal for this time of planting.

Table 7. Rejects for 13 varieties harvested on 13 December 1990 (127 DAS)

Variety	Under-size (t/ha)	Smalls (t/ha)	Over-size (t/ha)	Misshapen (t/ha)	Forked (t/ha)	Splits (t/ha)	Rots (t/ha)	Other (t/ha)	Scab (t/ha)
Hybrid 451	4.9	0	0	1.0	5.0	0.1	0.3	0	0.7
Top Pak	5.8	0.3	0	0.6	8.2	0.7	0.1	0.4	2.0
Nandor	5.3	0	0	2.1	4.9	0.4	0	0.2	4.1
WR (Yates)	3.1	1.7	0	3.9	6.8	0	0.7	1.2	5.6
Majestic Red	4.3	0.1	0.3	2.1	3.9	0	0.3	0	7.3
Riverina Red	9.0	0.1	0	0.8	8.8	0.2	0	0	3.8
WR (LVS)	3.3	0	0	4.9	8.1	0	1.1	0.2	4.5
Fl (LVS)	7.4	2.9	0	3.0	13.7	0	0.2	0	6.5
LV 8901	4.6	0	0.3	0.7	3.7	0.1	0	0.2	1.8
Cellobunch	2.1	2.9	0	3.6	7.7	0.1	0.2	0	3.3
Hero	2.2	11.4	0	2.8	6.6	0	0.2	0.2	9.2
Red Hot	1.7	4.0	0	2.3	4.9	0.1	0.3	0.2	6.8
WR (Arb)	1.8	4.3	0	4.6	6.9	0	0.2	0.2	2.1
Significance	***	***	ns	*	***	*	ns	ns	**
l.s.d (P=0.05)	3.3	10.3	-	2.8	5.0	0.3	-	-	3.9

Table 8. Leaf yield, total and marketable yields for 13 carrot varieties harvested on 2 January 1990 (155 DAS)

Variety	Average root length (cm)	Leaf yield (t/ha)	Density (plants/m^2)	Total yield (t/ha)	Export yield (t/ha)	Marketable short yield (t/ha)
Hybrid 451	18.3	13.8	107	111.5	70.5	20.2
Top Pak	17.7	11.2	130	123.0	62.2	29.8
Nandor	17.7	8.5	118	105.9	50.9	24.0
WR (Yates)	20.9	26.9	115	109.4	60.2	5.2
Majestic Red	19.8	19.4	119	114.7	64.9	10.9
Riverina Red	17.9	13.9	122	96.7	41.9	18.3
WR (LVS)	20.5	21.7	109	112.3	59.5	6.1
FI (LVS)	19.7	12.5	123	90.5	36.7	8.5
LV 8901	17.9	8.6	113	113.0	70.8	17.5
Cellobunch	21.2	12.0	105	95.0	60.7	4.3
Hero	21.1	14.0	124	96.9	54.5	2.7
Red Hot	21.0	13.4	106	92.0	59.4	5.1
WR (Arb)	21.8	27.1	100	88.1	53.7	2.1
Significance	***	***	ns	***	***	***
l.s.d (P=0.05)	0.6	3.2	-	10.8	11.8	4.4

Cavity spot which is caused by Pythium fungi is typically seen as brown sunken elliptical lesions on the roots and is quite different in appearance to scab. Symptoms of cavity spot were almost absent at harvest 1 but a low level had developed by harvest 2 (Tables 7 and 9).

Table 9. Rejects for 13 varieties harvested on 2 January 1990 (155 DAS)

Variety	Under-size (t/ha)	Smalls (t/ha)	Over-size (t/ha)	Misshapen (t/ha)	Forked (t/ha)	Rot (t/ha)	Cavity spot (t/ha)	Scab (t/ha)	Other (t/ha)
Hybrid 451	1.6	0.1	0.8	3.2	8.7	0.6	1.9	3.7	0.1
Top Pak	5.2	0.3	0	1.4	8.9	0.8	5.9	7.1	1.3
Nandor	3.8	0.1	1.0	4.0	4.8	0.3	5.7	9.8	1.3
WR (Yates)	1.7	1.9	1.3	5.5	10.8	0.8	1.6	16.7	3.7
Majestic Red	3.3	0.6	2.4	2.7	8.1	0.7	0.4	20.5	0.1
Riverina Red	4.8	0.4	1.8	3.1	12.0	0.4	6.8	8.1	0
WR (LVS)	1.8	0.8	3.6	6.0	8.6	2.3	2.0	20.6	0.9
FI (LVS)	4.1	1.1	0	5.3	21.0	1.8	0.3	11.5	0.2
LV 8901	2.4	0	0.9	2.6	3.9	0.7	3.0	10.6	0.6
Cellobunch	1.8	2.2	0	3.9	6.5	2.2	0	12.9	0.6
Hero	2.4	5.3	0	6.0	5.6	2.2	1.1	16.4	0.7
Red Hot	1.8	2.7	0.8	2.1	4.3	3.4	0.6	11.8	0
WR (Arb)	2.0	2.0	1.3	7.4	10.8	2.1	1.3	3.6	2.2
Significance	*	**	*	ns	***	ns	*	**	*
l.s.d (P=0.05)	2.3	2.3	2.1	-	5.0	-	4.2	9.0	1.8

The percentage of roots rejected because of cavity spot at harvest 2 is shown in Table 9. The Nantes varieties Riverina Red, Nandor and Top Pak had the highest levels of cavity spot. These differences need confirmation under higher disease pressure.

Table 10. Crop height (cm) and estimated % bolting (visual estimate) at 155 DAS

Variety	Crop height (cm)	% Bolted
Hybrid 451	35	0.1
Top Pak	35	0.1
Nandor	35	0.1
WR (Yates)	55	1
Majestic Red	53	0
Riverina Red	40	0
WR (LVS)	52	0.25
F1 (LVS)	42	0
LV 8901	36	0.1
Cellobunch	38	0.5
Hero	28	0
Red Hot	27	0
WR (Arb)	53	2.0

The incidence of bolting is shown in Table 10. The Western Red lines (WA Arb and WR Yates) had 2 and 1 % bolted tops, respectively, at 155 DAS. Crop height was greater than 50 cm for the following varieties: WR Yates, Majestic Red, WR LVS and WR Arb (Table 10).

Conclusion

The Nantes varieties such as Hybrid 451 and Top Pak had the lowest levels of scab when treated seed was planted on a scab infected site. Arbuckle's Western Red had low levels of scab. Other lines of Western Red and Majestic Red developed the highest levels of scab. Hybrid 451 and LV 8901 had high marketable yields, low scab and low cavity spot. These varieties are worthy of further evaluation.

Although the seed was treated with Thiram before planting, recent publications indicate that this would not have eradicated seed borne pathogens such as *Alternaria radicina* (Pryor *et al.* 1994). Differences amongst varieties may reflect differences in seed infection levels rather than varietal differences in susceptibility.

Appendix. Table 11A. Nutrient analysis over time for 5 carrot varieties

	62 DAS	75 DAS	90 DAS	104 DAS	117 DAS	127 DAS	147 DAS
N (%)							
F1(LVS)	4.34	2.99	2.33	2.41	2.75	2.03	2.02
Majestic Red	4.25	2.48	2.08	2.18	2.45	2.01	1.89
Nandor	4.19	3.02	2.37	2.61	2.90	2.22	2.35
Red Hot	4.25	2.96	2.40	2.42	2.66	2.04	2.21
WR (LVS)	4.06	2.48	2.11	2.22	2.43	2.24	2.29
variety				**			
l.s.d ($P = 0.05$)				1.29			
time				***			
l.s.d ($P = 0.05$)				0.12			
var*time				*			
l.s.d ($P = 0.05$)				0.28			
P (%)							
F1(LVS)	0.50	0.36	0.35	0.27	0.28	0.23	0.25
Majestic Red	0.41	0.37	0.31	0.25	0.25	0.21	0.21
Nandor	0.46	0.35	0.27	0.23	0.24	0.18	0.24
Red Hot	0.46	0.37	0.32	0.26	0.31	0.25	0.28
WR (LVS)	0.46	0.40	0.33	0.24	0.30	0.26	0.30
variety				**			
l.s.d ($P = 0.05$)				0.02			
time				***			
l.s.d ($P = 0.05$)				0.015			
var*time				***			
l.s.d ($P = 0.05$)				0.04			
K (%)							
F1(LVS)	3.46	2.26	2.48	2.08	1.88	1.50	1.17
Majestic Red	3.82	2.54	2.36	2.09	1.84	1.74	1.43
Nandor	3.46	2.77	12.43	1.81	1.68	1.41	0.98
Red Hot	3.11	2.42	2.08	1.96	2.25	1.42	1.20
WR (LVS)	3.49	2.57	2.41	1.93	2.40	2.12	2.22
variety				**			
l.s.d ($P = 0.05$)				0.185			
time				***			
l.s.d ($P = 0.05$)				0.22			
var*time				**			
l.s.d ($P = 0.05$)				0.03			
Mg (%)							
F1(LVS)	0.34	0.30	0.29	0.32	0.36	0.42	0.43
Majestic Red	0.34	0.28	0.25	0.28	0.34	0.38	0.45
Nandor	0.36	0.34	0.32	0.39	0.42	0.48	0.57
Red Hot	0.35	0.35	0.35	0.37	0.40	0.48	0.46
WR (LVS)	0.32	0.27	0.24	0.28	0.31	0.31	0.38
variety				***			
l.s.d ($P = 0.05$)				0.02			
time				***			
l.s.d ($P = 0.05$)				0.02			
var*time				***			
l.s.d ($P = 0.05$)				0.04			

Ca (%)							
F1(LVS)	2.02	2.11	1.71	1.46	2.31	2.45	2.56
Majestic Red	1.61	1.60	1.03	1.01	1.60	1.63	1.93
Nandor	1.57	1.64	1.30	1.42	2.23	2.20	2.40
Red Hot	2.04	2.13	1.92	1.55	1.93	2.37	2.32
WR (LVS)	1.84	1.64	1.02	1.16	1.16	1.34	1.45
variety				***			
l.s.d ($P = 0.05$)				0.09			
time				***			
l.s.d ($P = 0.05$)				0.13			
var*time				***			
l.s.d ($P = 0.05$)				0.23			
Na (%)							
F1	1.30	2.06	2.40	2.25	2.00	2.12	2.03
M Red	1.94	2.60	2.63	2.61	2.41	2.84	2.49
Nandor	1.53	2.59	2.71	2.81	2.48	2.62	2.15
Red Hot	1.51	2.21	2.59	2.24	1.73	2.20	1.80
WR	1.43	2.16	2.46	2.69	2.11	2.56	2.43
variety				***			
l.s.d ($P = 0.05$)				0.12			
time				***			
l.s.d ($P = 0.05$)				0.11			
var*time				***			
l.s.d ($P = 0.05$)				0.26			
Cl (%)							
F1(LVS)	2.96	3.59	4.12	3.88	4.68	5.14	3.30
Majestic Red	3.82	3.47	4.70	4.57	4.95	5.60	3.39
Nandor	3.56	3.97	5.33	5.49	5.88	6.73	4.33
Red Hot	3.29	3.62	4.64	4.40	4.07	5.33	3.02
WR (LVS)	3.51	3.49	4.53	4.92	4.22	5.60	3.61
variety				***			
l.s.d ($P = 0.05$)				0.19			
time				***			
l.s.d ($P = 0.05$)				0.21			
var*time				***			
l.s.d ($P = 0.05$)				0.47			
Mn (mg/kg)							
F1(LVS)	92.4	128.6	230.6	294.3	369.3	339.5	318.1
Majestic Red	70.0	94.6	127.0	167.6	252.8	235.3	277.8
Nandor	107.2	169.1	213.5	335.3	411.9	364.9	324.6
Red Hot	87.9	139.0	187.4	240.9	250.8	272.5	227.7
WR (LVS)	63.9	67.3	94.5	157.3	146.6	154.0	158.3
variety				***			
l.s.d ($P = 0.05$)				49.5			
time				***			
l.s.d ($P = 0.05$)				27.5			
var*time				***			
l.s.d ($P = 0.05$)				75.4			

Zn (mg/kg)							
Fl(LVS)	73.1	67.9	65.4	77.3	91.0	78.8	71.3
Majestic Red	49.3	47.6	40.8	48.1	58.1	52.7	60.7
Nandor	73.1	64.9	60.0	87.7	99.0	109.3	101.7
Red Hot	65.3	59.8	61.0	69.4	84.9	76.3	75.7
WR (LVS)	60.3	48.8	42.6	52.3	59.4	54.6	59.5
variety				**			
l.s.d ($P = 0.05$)				16.0			
time				***			
l.s.d ($P = 0.05$)				5.52			
var*time				***			
l.s.d ($P = 0.05$)				19.6			
Cu (mg/kg)							
Fl(LVS)	7.68	15.75	7.08	9.43	8.18	7.75	6.20
Majestic Red	6.53	11.15	6.25	7.63	7.30	7.08	7.45
Nandor	7.60	14.10	6.25	9.45	7.30	7.20	6.98
Red Hot	7.58	10.38	6.35	8.18	7.93	8.10	7.45
WR (LVS)	7.35	9.30	6.70	7.40	8.15	7.73	8.08
variety				**			
l.s.d ($P = 0.05$)				0.66			
time				***			
l.s.d ($P = 0.05$)				0.89			
var*time				***			
l.s.d ($P = 0.05$)				1.97			
Fe (mg/kg)							
Fl(LVS)	183.3	239.3	296.0	266.8	233.7	173.4	160.5
Majestic Red	151.0	192.6	207.3	170.6	199.3	160.5	170.4
Nandor	207.2	263.8	317.6	341.4	298.9	200.1	177.3
Red Hot	192.9	293.3	315.7	266.5	229.8	195.1	168.7
WR (LVS)	167.5	146.2	143.5	179.5	144.2	104.3	112.4
variety				***			
l.s.d ($P = 0.05$)				25.0			
time				***			
l.s.d ($P = 0.05$)				23.6			
var*time				**			
l.s.d ($P = 0.05$)				54.9			
B (mg/kg)							
Fl(LVS)	46.9	48.9	62.7	48.0	48.6	51.9	62.3
Majestic Red	43.9	48.2	59.3	47.0	48.2	51.4	60.7
Nandor	43.4	44.3	52.5	41.7	43.6	46.7	54.6
Red Hot	51.3	53.7	66.5	51.3	52.6	59.0	69.1
WR (LVS)	41.3	50.0	59.7	47.2	49.1	52.1	56.8
variety				***			
l.s.d ($P = 0.05$)				1.53			
time				***			
l.s.d ($P = 0.05$)				1.64			
var*time				*			
l.s.d ($P = 0.05$)				3.72			

3. Experiment 91MO17 - Disease tolerance of carrot varieties- March planting

Aim

Diseases such as cavity spot and scab of carrots were detected in 48 and 23% respectively, of all crops in a commercial carrot survey in 1990/91 (90PE8).

The objective of this experiment was to determine whether certain varieties of carrots possess tolerance to root disease.

Materials and Methods

Twelve varieties (Table 12) were dusted with Thiram® (5 g/kg seed) and sown with an Earthway® seeder on 26 March 1991. The site was north of Perth on a deep grey sand, where the three previous crops were carrots. The site had a history of scab and cavity spot. Five single rows were sown on beds 1.92 m wide. Plots were 4 m long. Each variety was replicated 4 times in a randomised block design. The crop was managed as per the surrounding commercial carrot crop. Carrots were harvested (1.5 m x 3 middle rows), washed, weighed and examined for disease on 1 October 1991. Leaves were also harvested and weighed.

Table 12. List of varieties and seed companies

Variety	Carrot type[A]	Seed company
Hi Pak	Nantes (H)	South Pacific Seeds
LV 88 2009	Imperator (H)	Lefroy Valley Seeds
LV 89 2032	Imperator (H)	Lefroy Valley Seeds
LV 8901	Nantes (H)	Lefroy Valley Seeds
Majestic Red	Autumn King (H)	Yates Seeds
Red Hot	Imperator (H)	Henderson Seeds
Red Sabre	Imperator (H)	Henderson Seeds
Superman	Nantes (H)	Henderson Seeds
Tango	Nantes (H)	Lefroy Valley Seeds
Top Pak	Nantes (H)	South Pacific Seeds
Western Red	Autumn King (OP)	Lefroy Valley Seeds
Western Red	Autumn King (OP)	Arbuckle Seeds

[A] (OP) = open pollinated, (H) = F1 hybrid

Results and Discussion

All varieties had a total yield of more than 60 t/ha and there were significant differences among varieties ($P<0.001$). Majestic Red had the highest total yield with 106 t/ha (Table 13). The carrots were left in the ground past the normal harvest date to encourage disease development. This may have favoured the Majestic Red over the Nantes lines which have had the highest yields in other plantings.

Table 13. Yield of 12 carrot varieties harvested on 1 October 1991

Variety	Density (plants/m^2)	Leaf yield (t/ha)	Total yield (t/ha)	Export yield (t/ha)	Marketable short yield (t/ha)
Hi Pak	74	9.3	94.7	53.8	10.2
LV 88 2009	137	7.9	71.3	26.2	12.4
LV 89 2032	78	6.8	75.9	43.5	7.0
LV 8901	99	4.9	81.3	38.7	10.9
Majestic Red	63	15.8	105.7	59.1	5.0
Red Hot	76	11.8	97.1	49.9	5.5
Red Sabre	78	9.5	86.4	49.5	3.3
Superman	92	6.0	79.8	41.8	4.4
Tango	57	5.1	69.3	42.2	2.8
Top Pak	90	9.0	93.1	52.9	11.9
Western Red (Arb)	79	41.0	65.3	29.7	7.0
Western Red (LV)	54	29.7	93.7	30.0	2.2
Significance	***	***	***	***	***
l.s.d. (P=0.05)	17.2	2.4	2.0	10.6	5.2

The varieties Top Pak, Hi Pak and Majestic Red had the highest marketable yields. These varieties had marketable yields over 50 t/ha. Both Western Red lines had a marketable yield of 30 t/ha (Table 13).

The Nantes varieties, Hi Pak, Top Pak, LV 88 2009 and LV 8901 had over 10 t/ha of carrots classed as marketable short (100-150 mm length, 25- 50 mm diameter) (Table 13, P<0.001).

The leaf yield for all varieties were reduced by leaf blight. Western Red (Arbuckle) had the highest leaf yield (P<0.001) because of the presence of bolted carrots (Table 13).

Table 14 shows the major categories of rejects expressed as % of the total yield. Differences among varieties in the incidence of scab were observed (P<0.05) however the level of scab was low (mean of 4.6% infection across all varieties) and was also variable across the site. Only Tango and LV 88 2009 had no scab (Table 14). The varieties LV 89 2032 and LV 8901 had about 13% of the total yield infected with scab.

Cavity spot was recorded in all varieties, with a site mean incidence across all varieties of 9.9%. Among the Nantes lines, Hi Pak had shown some tolerance to cavity spot from a January harvest (90MO67), however in this planting there were no significant varietal differences in cavity spot incidence (Table 14).

The results of varietal susceptibility to disease at this site are not consistent with the results from a previous variety planting (90MO67). Results for scab susceptibility need to be viewed with some caution because of the possibility of seed transmission of this disease. While all seed in the experiment was treated with Thiram® fungicide, recent results have shown that seed borne pathogens are not entirely eradicated from seed (Pryor *et al.* 1994).

Table 14. Categories of rejects shown as percentages of total yield for 12 carrot varieties

Variety	% of total yield							
	Scab	Cavity spot	Under-size	Mis-shapen	Forked	Split	Over-size	Other[A]
Hi Pak	2.8	14.8	1.8	3.6	2.6	5.3	1.0	1.2
LV 88 2009	0	5.7	9.5	5.0	20.2	5.4	0	0.2
LV 89 2032	13.0	4.2	1.5	2.6	5.7	4.4	0	1.6
LV 8901	13.5	7.3	8.2	1.2	7.0	1.1	0	0.9
Majestic Red	3.2	7.4	1.6	3.1	1.9	3.1	9.6	0.6
Red Hot	2.3	15.1	1.8	3.6	3.3	7.1	7.7	1.4
Red Sabre	4.2	13.3	0.9	7.3	5.3	5.4	1.7	0.4
Superman	2.2	12.2	3.3	6.4	10.3	4.9	0	3.1
Tango	0	10.6	0.9	5.4	4.3	6.7	0	7.6
Top Pak	9.4	7.5	1.9	3.2	3.2	4.1	1.1	0.6
Western Red (Arb)	3.7	7.2	3.5	14.0	3.1	5.2	3.6	3.3
Western Red (LV)	1.3	13.6	1.3	6.9	2.7	13.1	20.9	4.5
Significance	*	ns	***	**	***	*	***	*
l.s.d (P=0.05)	8.2	-	2.28	5.29	3.05	5.21	8.08	3.94

[A]green shoulders and rots

Appendix-Carrot Variety Observation

Eighteen varieties were sown in this observation (Table 15A). A single 4 m by 1.92 m wide plot was sown with an Earthway® seeder. Five single rows were sown per plot. The varieties were sown at Guilderton on 26 March 1991 and harvested on 1 October 1991.

Table 15A Details of varieties and seed company

Variety	Seed company
Nandor	South Pacific Seeds
Lefroy Valley F1	Lefroy Valley Seeds
84 178	Royal Sluis Seeds supplied by Lefroy Valley Seeds
Red Count	Henderson Seeds
87 2419	Royal Sluis Seeds supplied by Lefroy Valley Seeds
Liberno F1	Royal Sluis Seeds supplied by Lefroy Valley Seeds
Flamaro F1	Royal Sluis Seeds supplied by Lefroy Valley Seeds
Red Star	Henderson Seeds
Red Ned	Henderson Seeds
Hotspur	Henderson Seeds
Carrot 103	Fairbanks Seeds supplied by Arbuckle Seeds
Carrot 105	Fairbanks Seeds supplied by Arbuckle Seeds
Carrot 106	Fairbanks Seeds supplied by Arbuckle Seeds
Carrot 107	Fairbanks Seeds supplied by Arbuckle Seeds
Carrot 108	Fairbanks Seeds supplied by Arbuckle Seeds
Carrot 109	Fairbanks Seeds supplied by Arbuckle Seeds
Riverina Red	Henderson Seeds
Glamaro F1	Royal Sluis Seeds supplied by Lefroy Valley Seeds

Notes on varieties

- Nandor: Small topped variety, good shape, cavity spot (18% total yield), Nantes type.
- F1: Low density in this trial (53 plants/m^2), no cavity spot, major reject was splitting (12%), tapered carrot, similar to Western Red.
- 84 178: 44% rejected due to oversize, caused by low density, Chatennay type.
- Red Count: 85% class as marketable, 7% of total yield reduced by soft rots, Imperator.
- 87 2419: About 75% marketable, Imperator type, very long carrot.
- Liberno: Even sized sample, but many marketable carrots just over 15 cm in length. About 16% of the yield rejected due to cavity spot, Chatennay type.
- Flamaro: Highest total yield, but 34% of the total yield oversized, Nantes type.
- Red Star: Imperator type, very long carrot.
- Red Ned: Good even sized sample, long Imperator type, splitting (17%).
- Hotspur: Low density in this trial, 32% of the total yield had cavity spot, Nantes type.
- Carrot 103: Even sized Nantes type.
- Carrot 105: Good sample, major cause of rejection was rotting (28%), Nantes type.
- Carrot 106: Low density in this trial, 16% of yield reduced by splitting, Nantes type.
- Carrot 107: Marketable yield reduced by cavity spot (22%), Nantes type.
- Carrot 108: Low density in this trial, no cavity spot, Nantes type.
- Carrot 109: About 23% yield reduction due to cavity spot, Nantes type.
- Riverina Red: Marketable yield reduced by forking, Imperator type.
- Glamaro: About 20% of yield affected by cavity spot, Nantes type.

Tables 16A and 17A show the density, yield of tops, total and marketable yields and total rejects for the 18 varieties.

Table 16A. Total yield and marketable percentage, leaf yield, percentage of rejects and plant density for 18 carrot varieties

Variety	Density (plants/m^2)	Leaf yield (t/ha)	Total yield (t/ha)	Rank	Marketable (%)	Marketable short yield (%)	Total rejects (%)
Nandor	78	4.3	89.2	11	50.1	6.9	43.0
F1	53	7.4	90.3	9	63.5	23.0	13.5
84 178	53	8.7	104.3	3	52.3	3.3	44.4
Red Count	53	6.8	95.6	6	85.2	0	14.8
87 2419	96	7.8	91.0	8	44.4	30.1	25.4
Liberno	65	5.6	83.8	14	53.1	18.7	28.2
Flamaro	76	11.1	110.1	1	64.2	2.8	33.1
Red Star	68	6.2	85.5	13	63.3	7.6	29.1
Red Ned	63	5.7	74.9	15	58.9	6.9	34.2
Hotspur	50	6.0	65.7	17	52.6	1.9	45.5
Carrot 103	73	4.7	93.8	7	55.6	4.7	39.7
Carrot 105	60	4.1	60.0	16	50.8	14.0	35.1
Carrot 106	44	3.5	51.7	18	20.0	0	80.0
Carrot 107	91	3.6	103.3	4	37.5	16.6	45.9
Carrot 108	34	5.2	89.8	10	69.8	0	30.2
Carrot 109	50	5.4	45.0	17	41.2	3.8	55.0
Riverina Red	130	9.8	86.2	12	46.4	11.3	42.3
Glamaro	78	8.8	95.7	5	58.8	10.0	31.1

Table 17A. Categories of rejects shown as percentages of total yield for the 18 carrot varieties sown at Guilderton

Variety	Cavity spot	Under-size	Oversize	% of total yield Misshapen	Forked	Split	Scab	Rot
Nandor	18.6	1.9	0	20.8	0	2.0	0.2	0
F1	0	4.7	0	0	5.3	3.4	0	0
84 178	0	0	44.4	0	0	0	0	0
Red Count	0	2.7	0	0	5.2	0	0	6.9
87 2419	6.6	2.7	9.4	1.2	5.5	0	0	0
Liberno	15.6	6.2	0	0	4.1	0	0	2.3
Flamaro	0	3.7	33.8	0	2.5	0	0	0
Red Star	6.7	1.6	0	18.4	2.4	0	0	0
Red Ned	3.71	0.9	0	2.8	0	17.2	9.6	0
Hotspur	31.8	0	0	0	1.9	11.9	0	0
Carrot 103	16.2	1.4	0	2.5	2.9	0	0	0
Carrot 105	0	0	0	0	6.9	0	0	28.3
Carrot 106	0	0.7	0	55.3	7.6	16.5	0	0
Carrot 107	21.8	10.9	0	6.3	0	2.4	4 6	0
Carrot 108	0	0	22.4	0	0	7.7	0	0
Carrot 109	23.1	0.6	31.3	0	0	0	0	0
Riverina Red	7.3	7.1	0	0	25.1	2.3	0	0
Glamaro	19.4	5.1	0	5.0	1.6	0	0	0

4. Experiment 91PE65 - Nantes carrot variety evaluation- January planting

Aim

The aim of this experiment was to compare agronomic characteristics and disease tolerance of some new Nantes carrot varieties to the industry standard, Top Pak.

Materials and Methods

Eighteen Nantes varieties (Table 18) were sown with an Earthway® seeder on 24 January 1992. Five single rows were sown on beds 1.92 m wide and plots were 3 m long. Each variety was replicated four times in a randomised block design.

Table 18. List of varieties and seed companies

Variety	Seed company
Bolero	Vilmorin Seeds
Coral	Fito Semillas, Espana
Flame	Lefroy Valley seeds
Futuro	Royal Sluis
GF03	Sumich coded line
GF04	Sumich coded line
Merida	Nunhems Seeds
Liberno	Royal Sluis
RS 88 2311	Royal Sluis
RS 88 2451	Royal Sluis
RS 89 2394	Royal Sluis
SPS 545	South Pacific Seeds
SPS 567	South Pacific Seeds
SPS 573	South Pacific Seeds
Swazi	WA produce
S 365 G	Henderson Seeds
S 395 F	Henderson Seeds
Top Pak	South Pacific Seeds

Plots were hand thinned at the 3-true leaf stage with a target density of 60 plants/m^2 on 10 March 1992.

The experimental site was situated on a deep grey sand, 100 km north of Perth with soil pH (1:5 water) 7.4, bicarbonate extractable phosphorus of 41 mg/kg and bicarbonate extractable potassium of 38 mg/kg.

The crop was watered, fertilised and sprayed as per the surrounding commercial carrot crop. A total of 180 kg/ha of nitrogen was applied as Agran, NPK type fertilisers and Basamon®. Superphosphate (48 kg/ha P) was applied preplanting. Potassium was applied at a rate of 320 kg/ha as muriate of potash, sulphate of potash and potassium nitrate. Magnesium (16 kg/ha) and boron (4 kg/ha) was also supplied to the crop.

Herbicides including fluaziflop (Fusilade®), trifluralin (Trifluralin®) and metoxuron (Carrotex®) were applied when necessary. Chlorothalonil (Bravo®) and vinclozolin

(Ronilan®) were used for the control of Alternaria leaf blight and sclerotinia crown rot.

Each variety was scored visually for leaf blight on 4 May 1992. Carrots were harvested (1.5 m x 3 middle rows), washed and weighed and examined from disease on 21 May 1992. Roots were graded into:

- export marketable (25 to 50 mm crown diameter and greater than 150 mm length),
- marketable short (25 to 50 mm crown diameter and 100-150 mm length),
- undersized (less than 25 mm crown diameter and less than 100 mm length),
- oversized (more than 50 mm crown diameter),
- forked, misshapen and other (split, albinos and nodal enlargement).

Leaves were harvested and weighed. The root length and percentage of core of 20 carrots were measured from each plot. Core measurements were taken 2.5 cm below the root crown.

Results and Discussion

Plant densities varied among varieties ($P<0.001$) in the range of 40-61 plants/m^2. Some care should be taken so as to only directly compare varieties with similar densities. The total yield of all varieties was more than 70 t/ha and there were significant differences among varieties. Top Pak had the highest total yield at 95 t/ha. However the following varieties had similar yields to Top Pak: GF03, GF04, Liberno, Merida, RS 88 2311, RS 88 2451, RS 89 2394, SPS 545, SPS 567 and Swazi (Table 19).

Top Pak and S 395 F had the highest export yield at 71 t/ha. The following varieties had similar export yields: GF03, GF04, Merida, RS 88 2311, RS 88 2451, SPS 567, SPS 573, S 395 F and Top Pak (Table 19).

Top Pak, Swazi, Coral and SPS 573 had over 10 t/ha classed as marketable short (Table 19). RS 88 2311 had the smallest proportion of its yield classed as marketable short. Although the time of year and low plant density was suitable for producing long roots, Top Pak had a large proportion of yield classed as marketable short (100 to 150 mm length).

Leaf yield ranged from 16 to 32 t/ha (Table 19). The variety RS 89 2394 had the largest yield of tops. Bolero, Futuro, RS 89 2394 and SPS 567 all had significantly larger yield of tops compared to other varieties. GF03, S 395 F and S 365 G all had the smallest sized tops. The varieties GF03, GF04, SPS 545, S 365 G and Top Pak appeared to be more susceptible to leaf blights than the other varieties (Table 20).

Table 19. Total and marketable yield, leaf yield and plant density for 18 carrot varieties

Variety	Density (plants/m^2)	Leaf yield (t/ha)	Total yield (t/ha)	Export yield (t/ha)	Marketable short yield (t/ha)
Bolero	48	29.4	71.7	51.8	4.39
Coral	60	24.9	73.4	48.7	13.5
Flame	51	21.6	75.6	54.3	5.73
Futuro	54	28.8	79.4	58.8	5.56
GF03	43	15.8	87.6	61.3	3.13
GF04	44	20.8	83.8	60.0	6.00
Liberno	45	22.2	91.0	45.4	4.49
Merida	40	21.3	85.3	66.4	0.39
RS 88 2311	41	25.5	91.8	59.2	0.23
RS 88 2451	46	23.7	83.2	67.7	6.70
RS 89 2394	45	32.1	86.8	55.6	2.52
SPS 545	40	23.9	90.7	42.8	6.90
SPS 567	46	29.9	83.9	67.9	1.09
SPS 573	51	20.8	80.6	67.5	8.92
Swazi	60	25.7	85.8	59.1	16.6
S 365 G	55	15.9	71.6	56.1	5.94
S 395 F	54	19.7	77.5	71.3	2.49
Top Pak	61	26.4	94.9	71.4	14.0
Significance	***	***	***	***	***
l.s.d (P=0.05)	10.6	5.1	12.8	12.2	6.62

The average root length was greater than 15 cm for all varieties (Table 20). S 395 F, RS 89 2394 and Merida were longer than other varieties with an average root length greater than 22 cm. The % core across varieties is shown in Table 20. RS 89 2394 had over 55 % of the root diameter as core.

Table 20. Blight rating, average root length and average percentage of core for 18 varieties

Variety	Blight rating[A]	Average root length (cm)	Core (%)[B]
Bolero	1	19.3	46.5
Coral	2	18.0	44.0
Flame	2.5	21.0	44.9
Futuro	1	20.6	41.1
GF03	3.5	18.8	46.9
GF04	2.5	19.6	55.4
Merida	1	23.6	41.9
Liberno	1	20.3	52.5
RS 88 2311	2	21.0	46.7
RS 88 2451	2	19.8	46.2
RS 89 2394	2	21.9	62.7
SPS 545	3	18.4	52.7
SPS 567	1	20.2	49.7
SPS 573	1	19.5	55.6
Swazi	1	17.8	56.7
S 365 G	3	19.5	40.4
S 395 F	2	22.2	44.5
Top Pak	2.5	19.0	47.2
Significance		2.3	6.0
l.s.d (P=0.05)		***	***

[A]visual estimate on 1 replicate, 1 = no blight, 2 = slight blight, 3 =moderate blight, 4 = severe blight, plants defoliated. [B]Core % = core diameter/root diameter x 100

Table 21 shows the major reject categories for all varieties. For example RS 88 2311 had a high incidence of forking (14 %) compared to other varieties. Coral and Swazi both had about 7% of the total yield classed as undersize. Over 30 % of Liberno and SPS 545 were classed as oversize. S 365 F, SPS 573, Top Pak and RS 88 2451 had less than 11 % of rejects. There were no root diseases observed in this experiment.

Table 21. Categories of rejects shown as percentage of total yield for 18 carrot varieties

Variety	Total rejects	% of total yield Oversize	Undersize	Forked	Misshapen	Other[A]
Bolero	21.6	5.9	1.04	1.55	0.67	12.4
Coral	15.5	2.5	7.40	4.38	0	1.3
Flame	20.7	7.2	2.81	4.43	2.26	4.0
Futuro	17.5	5.6	2.43	3.94	2.82	2.7
GF03	21.9	7.3	0	1.15	1.15	12.3
GF04	21.4	17.0	0.46	3.63	0.33	0
Liberno	43.5	30.5	3.20	2.91	0.59	6.3
Merida	20.8	4.5	0.51	4.29	0	11.5
RS 88 2311	35.4	17.8	0.24	13.60	3.12	0.6
RS 88 2451	10.6	4.5	0.13	2.61	1.50	1.9
RS 89 2394	32.0	11.5	1.01	6.08	1.62	11.8
SPS 545	45.3	35.2	0.50	3.13	0	6.5
SPS 567	17.8	3.0	1.25	3.10	0.90	9.5
SPS 573	5.4	2.6	0.86	0.48	1.44	0
Swazi	12.0	3.1	6.45	2.23	0	0.2
S 365 G	13.6	3.1	1.22	2.46	3.74	3.1
S 395 F	4.5	0	0.53	1.62	1.32	1.0
Top Pak	10.1	4.5	1.33	1.57	0.74	2.0
Significance	***	***	**	***	ns	**
l.s.d (P=0.05)	12.5	10.82	3.53	3.31	-	7.74

[A]split, albino, and nodal enlargement

Conclusion

There were several Nantes varieties in this experiment that appear to match the performance of Top Pak. These varieties need further evaluation under high disease pressure to ascertain their cavity spot tolerance and confirm their blight tolerance.

Varieties that should be further evaluated include:

- S 395 F
- RS 88 2311
- SPS 567
- RS 89 2394
- Merida - for July, August harvest
- RS 88 2451
- GF03 and GF04 - some susceptibility to blight.

Appendix- Carrot variety observation

The following table includes some Nantes varieties which were screened for yield and disease tolerance.

Seven varieties were sown unreplicated on January 24 and harvested on May 21 1992. Five single rows were sown with an Earthway® seeder in 2 m long plots with five single rows per 1.92 m wide bed.

Table 22A. Leaf yield, density, total yield, export and marketable short yield, length and % core of seven varieties

Variety	Seed company	Leaf yield (t/ha)	Density (plants/m^2)	Total yield (t/ha)	Export yield (%)	Marketable short yield (%)	Length (cm)	Core (%)
Superman	Henderson	13.5	60	78.9	78.8	5.5	20.9	51.7
Glamaro	Royal Sluis	21.5	63	74.3	67.1	22.7	16.2	56.4
Flamaro	Royal Sluis	27.2	44	84.1	68.7	3.3	19.7	50.5
Hotspur	Henderson	20.9	41	68.3	90.7	-	25.4	48.2
Red Count	Henderson	25.2	42	77.0	77.7	-	23.4	42.7
Nandor	South Pacific	15.1	58	71.4	63.1	14.3	17.8	43.9
Hi Pak	South Pacific	31.3	43	86.2	71.4	6.1	19.4	49.9

Notes on varieties:

- Length was greater than 18 cm for all varieties except Glamaro and Nandor.
- Glamaro and Nandor had the highest % of short marketable.
- Hipak had the highest total yield and Hotspur had 91 % of the yield classed as export marketable.

5. Experiment 92PE30 - Nantes carrot variety evaluation-April planting

Aim

Until recently, the Western Australian export carrot industry was based on the open pollinated variety Western Red. South-east Asian markets now favour the sweeter, higher yielding, blunt ended Nantes varieties. High yielding winter varieties that are tolerant to leaf blight and cavity spot are required.

The aim of this experiment was to compare agronomic characteristics and disease tolerance of a range of Nantes carrot varieties to the existing industry Nantes standard, Top Pak.

Materials and Methods

The trial site was situated 100 km, north of Perth on a deep grey sand, with a pH (1:5 water) of 6.2, bicarbonate extractable phosphorus of 60 mg/kg and bicarbonate extractable potassium of 16 mg/kg.

Twenty three Nantes varieties (Table 23) were sown with an Earthway® seeder on 22 April 1992. Five single rows were sown on beds 1.92 m wide and plots were 4 m long. Each variety was replicated four times in a randomised block design.

The varieties were thinned on 23 June 1992. The final density was lower than anticipated at around 50 plants/m^2. The crop was harvested on 1 October 1992, 162 days after sowing.

Table 23 List of varieties and seed companies

Variety	Seed company
Bolero	Vilmorin Seeds
Calade	Graines Gaultier
Coral	Fito Semillas, Spain
Flame	Lefroy Valley seeds
Futuro	Royal Sluis
GF03	Sumich coded line
GF04	Sumich coded line
Liberno	Royal Sluis
Merida	Nunhems Seeds
RS 88 2311	Royal Sluis
RS 88 2451	Royal Sluis
RS 89 2394	Royal Sluis
SPS 543	South Pacific Seeds
SPS 597	South Pacific Seeds
SPS 609	South Pacific Seeds
SPS 545	South Pacific Seeds
SPS 567	South Pacific Seeds
SPS 573	South Pacific Seeds
S 365 G	Henderson Seeds
S 366 G	Henderson Seeds
S 367 G	Henderson Seeds
S 395 F	Henderson Seeds
Top Pak	South Pacific Seeds

The crop was managed as per the surrounding commercial carrot crop. Lime (1.8 t/ha), superphosphate (300 kg/ha), gypsum (500 kg/ha) and muriate of potash (300 kg/ha) were applied preplanting. A total of 324 kg/ha of nitrogen, 285 kg/ha of potassium, 32 kg/ha magnesium and boron (6.4 kg/ha) was applied during the growth of the crop.

Herbicides including fluaziflop (Fusilade®) and linuron (Linuron®) were applied when necessary. Chlorothalonil (Bravo®) and vinclozolin (Ronilan®) were used for the control of alternaria leaf blight and sclerotinia crown rot. Each variety was scored visually for leaf blight at harvest. Carrots were harvested (1.5 m x 3 middle rows), washed and weighed and examined from disease on 1 October 1992. Roots were graded into:

export (25 to 50 mm crown diameter and greater than 150 mm length),
marketable short (25 to 50 mm crown diameter and 100-150 mm length),

undersized (less than 25 mm crown diameter and less than 100 mm length),
oversized (more than 50 mm crown diameter),
forked, misshapen and other (split, crown rot, misshapen).

Leaves were harvested and weighed. The root length of 20 carrots selected at random from marketable carrots from each plot was recorded.

Results and Discussion

Yield

The mean total yield for the site was 82 t/ha. There were significant differences among varieties (Table 24).

Table 24. Total, export and marketable short yield for 23 carrot varieties

Variety	Total yield (t/ha)	Export yield (t/ha)	Marketable short yield (t/ha)
Bolero	87.2	61.9	3.4
Calade	71.3	34.0	24.7
Coral	76.5	47.5	19.2
Flame	67.3	44.9	6.5
Futuro	79.0	57.2	3.3
GF03	72.4	60.6	2.1
GF04	84.9	64.1	5.1
Liberno	81.9	48.4	6.4
Merida	85.5	74.8	1.5
RS 88 2311	81.6	61.5	5.7
RS 88 2451	88.0	63.0	8.7
RS 89 2394	91.6	47.7	3.9
SPS 543	91.1	69.0	9.8
SPS 597	105.2	69.5	8.1
SPS 609	96.2	74.2	1.4
SPS 545	85.6	57.8	13.5
SPS 567	98.6	70.2	1.5
SPS 573	83.2	61.6	14.1
S 365 G	59.5	38.9	10.4
S 366 G	79.5	58.6	0.7
S 367 G	74.2	54.6	5.4
S 395 F	84.4	72.1	2.1
Top Pak	81.3	48.1	16.4
Significance	***	***	***
l.s.d (P=0.05)	13.3	15.9	6.08

The varieties SPS 597, SPS 609 and SPS 567 produced the highest total yields (P<0.05) (Table 24). Only S 365 G and Flame had total yields significantly less than Top Pak (Table 24).

Seven varieties had export yields significantly higher than Top Pak (48 t/ha). These were: GF04, Merida, SPS 543, SPS 597, SPS 609 SPS 567 and S 395 F (Table 24). Calade had the lowest export yield at 34 t/ha. Calade and Coral also had a high proportion of the total yield classed as marketable short. The following varieties had more than 10 t/ha of their yield classed as marketable short: Calade, Coral, SPS 573, S 365 G, SPS 545 and Top Pak.

Table 25. Categories of rejects shown as a percentage of total yield for 23 carrot varieties

Variety	Undersize	Oversize (% of total yield)	Forked	Other[A]
Bolero	0.2	12.7	4.5	7.0
Calade	1.5	1.1	8.7	6.2
Coral	4.1	0	4.3	4.6
Flame	3.0	6.7	12.3	1.7
Futuro	0.7	8.9	8.3	4.3
GF03	0.5	7.1	2.2	2.7
GF04	0.7	7.8	8.2	1.6
Liberno	2.8	24.6	3.2	2.4
Merida	0.8	5.4	2.4	2.3
RS 88 2311	1.4	6.7	5.5	4.2
RS 88 2451	2.0	5.6	3.8	7.2
RS 89 2394	2.5	30.1	5.0	5.6
SPS 543	0.8	6.9	3.9	1.9
SPS 597	0.4	17.2	3.1	5.7
SPS 609	0.2	20.9	0.3	0
SPS 545	1.3	3.3	11.7	0.3
SPS 567	0.6	18.6	3.1	5.4
SPS 573	1.3	1.0	6.0	0.8
S 365 G	2.9	0	6.4	7.8
S 366 G	1.2	10.1	11.7	2.8
S 367 G	0.7	2.9	10.8	4.7
S 395 F	0.7	2.6	3.8	4.6
Top Pak	3.2	12.3	2.3	3.1
Significance	ns	***	ns	ns
l.s.d (P=0.05)	-	10.90	-	-

[A]split, misshapen, crown rot

Many of the varieties failed to 'blunt up' fully from this planting even though the crop was planted at low density and had grown under favourable conditions for 23 weeks. From a May harvest (91PE65), most of these varieties did reach true Nantes shape. The acceptability of 'semi blunt' roots on export markets needs assessment.

Table 25 shows the reject categories for all varieties. There were no significant differences among varieties with respect to levels of forking (average 5.7 % of the total yield), undersized (on average 1.5 % of the total yield) or other rejects (average 3.8 % of the total yield). There were significant varietal differences in the proportion of oversized carrots. For example Liberno, RS 88 2394 and SPS 609 had a large proportion of the total yield classed as oversized. Higher plant densities would have been more appropriate for these varieties.

Table 26. Visual blight rating, leaf yield, root length and plant density for 23 carrot varieties

Variety	Visual blight score[A]	Root length (cm)	Leaf yield (t/ha)	Density (plants/m^2)
Bolero	1.6	20.5	15.0	51
Calade	4.8	17.6	7.1	66
Coral	3.6	18.7	11.6	65
Flame	3.6	19.6	10.0	46
Futuro	2.9	19.6	14.7	49
GF03	3.3	20.2	8.1	42
GF04	2.3	19.5	11.1	47
Liberno	4.0	19.1	9.5	48
Merida	2.5	21.3	8.3	51
RS 88 2311	1.9	20.0	12.8	51
RS 88 2451	2.9	19.7	14.5	55
RS 89 2394	1.6	22.2	16.8	42
SPS 543	2.5	19.0	13.3	55
SPS 597	1.9	21.0	13.9	56
SPS 609	1.8	20.4	16.1	45
SPS 545	3.4	18.5	9.7	55
SPS 567	2.0	19.9	17.3	50
SPS 573	2.5	19.2	11.0	59
S 365 G	3.1	18.6	5.1	59
S 366 G	2.9	21.8	8.4	41
S 367 G	3.5	19.8	9.6	57
S 395 F	3.8	20.1	9.1	53
Top Pak	4.6	18.6	8.8	59
Significance	***	***	***	***
l.s.d (P=0.05)	0.61	1.5	2.2	10.9

[A] 1 = no blight, 2 = slight blight, 3 = moderate blight, 4 = severe blight, 5 = very severe, plants defoliated.

Yield of tops

Top size is important in relation to mechanical harvesting. Differences in top size in this experiment are a reflection of genetic differences in top size and the susceptibility of the variety to leaf blight. The leaf yield ranged from 5 to 17 t/ha (Table 26). Bolero, Futuro, RS 89 2394, SPS 609 and SPS 567 all had significantly higher leaf yields than other varieties. Bolero, Coral, Futuro, GF04, the three RS lines and all SPS lines except SPS 545 had significantly higher top yields than Top Pak (Table 26).

Root length

The average marketable root length was greater than 17 cm for all varieties (Table 26). In this experiment, plant densities at around 50 plants/m^2 were lower than optimal and this would have resulted in longer roots. Bolero, Merida, RS 89 2394, SPS 597, SPS 609 and S 366 G all produced significantly longer marketable roots than Top Pak (Table 26).

Diseases

Cavity spot was not present at this site. Leaf blight was severe in several varieties and visual blight ratings showed that Top Pak, Calade and Liberno had the highest levels of blight infection (Table 26). Bolero, RS 88 2311, RS 89 2394, SPS 597 and SPS 609 had significantly less blight than Top Pak (Table 26).

Conclusion

Many of these varieties tested in this planting produced higher yields, longer roots and had better blight tolerance than Top Pak. However many of these varieties failed to mature or 'blunt up' to true Nantes shape after growing slowly through winter and may require longer than 23 weeks to reach maturity at this time of year. The variety Merida did blunt up and is worthy of further testing for winter and early spring harvest only. It has previously been found unsuitable (too long with enlarged eyes) for harvest during warmer conditions.

Varieties that should be further evaluated include:

For July- September harvest:

- Merida
- SPS 597

Other times of the year:

- Bolero
- S 395 F
- SPS 567
- SPS 597
- SPS 609
- RS 88 2311
- RS 89 2394

6. Experiment 92PE73 - Varietal tolerance of Nantes carrot varieties to cavity spot - December planting

Aim

Cavity spot caused by soil borne Pythium fungi is a major disease of Western Australian fresh market carrots. The aim of this experiment was to compare the tolerance of Nantes carrot varieties to cavity spot.

Materials and Methods

The experiment was conducted on an irrigated site on a yellow Karrakatta sand, 100 km north of Perth. Previous carrot crops on this site had been affected by cavity spot.

Twenty varieties (Table 27) were sown on 29 December 1992 in a randomised block design with three replicates. Four double rows were sown on beds 1.92 m wide and plots were 6 m long. The crop was harvested on 25 May 1993.

Table 27. List of varieties and seed companies

Variety	Seed company
Bolero	Vilmorin Seeds
Flame	NK Seeds [A]
Futuro	Lefroy Valley Seeds [A]
Hinan	Henderson Seeds
Nandor	South Pacific Seeds
RS 87 2092	Lefroy Valley Seeds [A]
RS 87 2365	Lefroy Valley Seeds
RS 87 2417	Lefroy Valley Seeds
SPS 543	South Pacific Seeds
SPS 567	South Pacific Seeds [A]
SPS 597	South Pacific Seeds
SPS 609	South Pacific Seeds
S 395 F	Henderson Seeds [A]
Top Pak	South Pacific Seeds
Y 53	Yates Seeds
Y 61	Yates Seeds
Y 62 (Merida)	Yates Seeds
Y 63	Yates Seeds
Y 67	Yates Seeds
Y 68	Yates Seeds

[A]raw seed

For most varieties pelleted seed was available and was sown with a precision air seeder. Five lines were sown as raw seed with an Earthway® seeder (see Table 27).

The site was prepared and maintained as per a commercial carrot crop, although lack of sufficient irrigation, particularly during germination and early growth had detrimental effects on crop density.

Yield was not determined in this experiment because of less than optimum crop density and growing conditions. At harvest maturity, 50 carrots were randomly sampled from each plot. Each carrot was graded according to disease severity: nil, slight (1 lesion per root), moderate (2-3 lesion per root), and severe (more than 4 lesions per root). In addition, a cavity spot index that weights the incidence of each disease category (% by number of roots) according to increasing severity was calculated using the following formula:

$$\text{Cavity spot index} = \frac{(\%\ \text{slight} \times 1) + (\%\ \text{moderate} \times 2) + (\%\ \text{severe} \times 3)}{3}$$

The data was analysed by analysis of variance using GENSTAT software.

Results and Discussion

The experiment showed highly significant differences among varieties for field tolerance to cavity spot (Table 28).

In Table 28, varieties are ranked according to the weighed index. The varieties SPS 567, RS 87 2417, Bolero, Y 67 and SPS 609 had low cavity spot indices and thus were the most tolerant varieties tested. Top Pak and Y63 had high cavity spot indices. Many of these varieties have been examined for yield potential in previous experiments (92PE30 and 91PE65).

Bolero was found to have an acceptable yield in previous experiments and was also found to be tolerant to leaf blight. This variety should be tested on a limited commercial scale. In the United Kingdom, NIAB trials in 1993 Bolero was rated as tolerant to cavity spot (Anon 1993). The yield and cavity spot tolerance of Bolero, SPS 567, RS 87 2417, Y 67 and SPS 609 and other varieties will be compared in another experiment (93PE9).

Table 28. Cavity spot index and the incidence of cavity spot disease in 20 carrot varieties. Data are percentage of carrots by number in each category.

Variety	Nil (%)	Slight (%)	Moderate (%)	Severe (%)	Total cavity spot (%)	Cavity spot index[A]
Bolero	46.1	20.8	15.3	17.8	53.9	34.9
Flame	23.4	15.7	18.9	42.0	76.6	59.8
Futuro	38.7	22.3	15.2	23.8	61.3	41.4
Hinan	22.4	23.7	19.7	34.2	77.6	55.2
Nandor	23.2	20.6	26.6	29.6	76.8	54.2
RS 87 2092	32.0	21.0	20.2	26.7	67.9	47.2
RS 87 2365	18.0	13.3	21.3	47.3	81.9	65.9
RS 87 2417	50.6	25.3	13.7	10.4	49.4	28.0
SPS 543	23.8	15.9	21.2	39.1	76.2	58.5
SPS 567	50.7	25.0	15.1	9.2	49.3	27.6
SPS 597	19.3	22.0	23.3	35.3	80.6	58.2
SPS 609	33.6	30.9	16.5	19.0	66.4	40.3
S 395 F	36.5	16.4	18.7	28.3	63.4	46.2
Top Pak	6.1	14.1	19.4	60.4	93.9	78.0
Y 53	26.7	24.7	14.0	34.7	73.4	52.3
Y 61	20.1	23.3	17.9	38.7	79.9	58.4
Y 62 (Merida)	32.3	10.6	22.5	34.5	67.6	53.0
Y 63	8.5	21.2	24.3	46.0	91.5	69.3
Y 67	38.5	22.4	21.9	17.1	61.4	39.2
Y 68	24.7	17.3	18.7	39.3	75.3	57.5
Significance	***	*	ns	***	***	***
l.s.d (P=0.05)	15.6	10.1	-	17.7	15.6	15.1

[A] A lower cavity spot index indicates greater tolerance, * = $P<0.05$, *** = $P<0.001$

7. Experiment 93PE9 - Yield and disease tolerance of Nantes carrot varieties- February planting

Aim

The export carrot industry is in need of a Nantes variety with high yield potential and greater disease tolerance. In this experiment, we compare a range of Nantes varieties for yield and tolerance to cavity spot disease.

Materials and Methods

The experiment was conducted on a Karrakatta sand, 100 km north of Perth, at an irrigated site where previous carrot crops had been affected by cavity spot disease. Twenty seven varieties were arranged in a randomised block design with 3 replicates per treatment (Table 29).

All pelleted varieties were sown with an Agricola Italia® precision air seeder. Seed of some varieties was only available in small quantities. These varieties were sown as raw seed with an Earthway® seeder, and later hand thinned where necessary. Four double rows were sown on beds 1.92 m wide and 6 m long. The varieties were sown on 10 February 1992 and harvested on 2 June 1993 (112 days after sowing). The varieties were managed as per the surrounding commercial carrot crop.

Table 29. List of varieties and seed companies

Variety	Seed company
Bolero	Vilmorin Seeds
Cesaro	Lefroy Valley Seeds
Flame	NK Seeds ^{A}
Futuro	Lefroy Valley Seeds ^{A}
Hinan	Henderson Seeds
Nandor	South Pacific Seeds
Narbonne	Bejo Zaden ^{A}
Narman	Bejo Zaden ^{A}
Navarre	Bejo Zaden ^{A}
Nerac	Bejo Zaden ^{A}
Newton	Bejo Zaden ^{A}
RS 87 2092	Lefroy Valley Seeds ^{A}
RS 87 2365	Lefroy Valley Seeds
RS 87 2417	Lefroy Valley Seeds
SPS 543	South Pacific Seeds
SPS 567	South Pacific Seeds ^{A}
SPS 597	South Pacific Seeds
SPS 609	South Pacific Seeds
S 390 G	Henderson Seeds ^{A}
S 395 F	Henderson Seeds ^{A}
Top Pak	South Pacific Seeds
Y 53	Yates Seeds
Y 61	Yates Seeds
Y 62 (Merida)	Yates Seeds
Y 63	Yates Seeds
Y 67	Yates Seeds
Y 68	Yates Seeds

^{A}raw seed sown

At harvest maturity, four 0.5 m lengths from the middle rows of each plot were sampled, washed, weighed and graded for yield. Root length of 10 carrots per plot was measured to determine average root length. The carrots were then regraded for cavity spot incidence. Each carrot was graded according to disease severity: nil, slight (1 lesion per root), moderate (2-3 lesions per root) and severe (more than 4 lesions per root).

In addition, a cavity spot index that weights the incidence of each disease category (% by number of roots) according to increasing severity was calculated using the following formula:

$$\text{Cavity spot index} = \frac{(\%\ \text{slight} \times 1) + (\%\ \text{moderate} \times 2) + (\%\ \text{severe} \times 3)}{3}$$

The data was analysed by analysis of variance using GENSTAT software.

Results and Discussion

Yield

The site mean total yield was lower than anticipated at 61 t/ha. There were differences in total yield among varieties (Table 30). The varieties Bolero, Hinan, Narbonne, RS 87 2365, SPS 543, SPS 597, SPS 609, S 390G, S 395F, Top Pak, Y53, Y61, Y62 and Y63 produced the highest total yields. No variety produced a total yield greater than Top Pak.

Flame, Futuro, Cesaro, Narman, Navarre and RS 87 2092 produced the lowest export yields. The export yields reported are based on size grades and do not take account of cavity spot. Many varieties had a large proportion of the roots classed as marketable short (Table 30). The carrots were harvested at less than optimal maturity (112 DAS) because the commercial crop surrounding to the trial was harvested. This has led to a higher proportion of marketable short carrots and many varieties failed to 'blunt up'. Only the following varieties had less than 10t/ha classed as marketable short: SPS 543, SPS 567, S 395 F, Y 61, Y 62 and Y 63.

Table 31 shows the reject categories for all varieties. There was no significant difference among varieties for the level of forking which averaged only 1.3 % of the total yield. There were varietal differences for the proportion of oversized and undersized carrots. These differences probably related to differences in plant density (Table 31). The variety SPS 567 was sown as raw seed and the density was low at 30 plants/m^2, and consequently 20 % of the total yield was classed as oversized (Table 31).

Leaf yield

The leaf yield ranged from 12 to 22 t/ha. Bolero, Hinan, Narbonne, Narman, RS 87 2417, SPS 597, SPS 609, S 390 G and Y 63 produced higher leaf yields than the other varieties (Table 30).

Root length

The average root length was about 18 cm, and was greater than 16 cm for all varieties (Table 30). The following varieties had significantly longer roots than Top Pak: SPS 567, S 395 F and Y 62.

Table 30 Leaf yield, root length, total, export and marketable short yield for 27 carrot varieties[A]

Variety	Leaf yield (t/ha)	Root length (cm)	Total yield (t/ha)	Export yield (t/ha)	Marketable short yield (t/ha)
Bolero	21.5	19.6	62.1	48.1	11.0
Cesaro	12.7	16.4	48.7	16.5	24.3
Flame	13.7	17.3	50.4	22.2	21.3
Futuro	14.8	17.9	53.6	22.8	20.7
Hinan	20.2	18.4	62.9	47.6	11.3
Nandor	14.9	17.9	56.1	33.0	15.8
Narbonne	20.0	19.4	66.1	39.6	16.0
Narman	21.5	17.8	56.9	25.5	18.6
Navarre	14.0	16.6	55.7	22.6	25.8
Nerac	15.0	17.8	54.7	32.3	16.2
Newton	17.7	17.0	55.2	25.9	17.5
RS 87 2092	13.5	16.6	54.1	26.9	21.2
RS 87 2365	16.3	17.8	67.4	41.4	16.0
RS 87 2417	18.9	19.6	52.6	35.6	6.4
SPS 543	21.3	17.3	71.3	52.5	15.0
SPS 567	15.8	21.4	57.1	40.8	1.5
SPS 597	21.0	19.3	68.8	43.6	16.6
SPS 609	22.8	19.1	64.0	46.8	13.3
S 390 G	19.7	18.5	73.2	50.2	17.3
S 395 F	15.8	21.6	68.9	53.7	3.6
Top Pak	17.7	17.6	73.2	45.9	22.2
Y 53	21.2	18.9	63.0	37.6	20.9
Y 61	13.5	19.6	64.1	53.0	5.6
Y 62 (Merida)	17.4	20.0	64.7	45.6	8.5
Y 63	20.6	19.6	66.2	51.2	9.3
Y 67	14.4	18.0	56.1	36.6	14.4
Y 68	16.7	18.0	59.7	40.2	12.6
Significance	***	***	***	***	***
l.s.d (P=0.05)	5.0	2.1	13.6	16.7	14.8

[A]The export and marketable short yields are reported without accounting for cavity spot. Actual marketable yields from the site would be lower due to cavity spot. *** = P<0.001

Diseases

Leaf blight was not present on this site probably because of the unusually dry conditions this season. Cavity spot was severe in several varieties and disease ratings show that there were significant differences among varieties (Table 32). The following varieties had the lowest cavity spot indices: SPS 609, SPS 567, Y 61, Narbonne, Bolero, Navarre, Y 62, Nerac and Newton. Bolero, SPS 567 and SPS 609 have previously shown good field tolerance to cavity spot (92PE73). Top Pak was found to be highly susceptible to cavity spot confirming results of the early field screening.

Table 31. Categories of rejects as sown as a percentage (%) of total yield for 27 carrot varieties[A]

Variety	Undersize (% of total yield)	Oversize (% of total yield)	Forked (% of total yield)	Density (plants/m^2)
Bolero	1.3	4.2	0.1	43
Cesaro	15.0	0.0	2.2	63
Flame	14.0	0.0	0.2	58
Futuro	16.3	2.6	0.0	77
Hinan	5.6	0.0	0.4	58
Nandor	8.7	2.3	1.6	52
Narbonne	8.5	6.2	1.2	67
Narman	17.2	1.8	2.4	59
Navarre	12.3	0.0	0.8	66
Nerac	11.8	0.0	0.0	61
Newton	10.9	8.8	2.5	53
RS 87 2092	8.4	0.0	5.0	62
RS 87 2365	5.3	9.7	0.5	52
RS 87 2417	6.3	9.0	3.7	36
SPS 543	3.5	0.9	1.0	63
SPS 567	1.3	20.3	4.7	30
SPS 597	6.7	4.2	1.7	57
SPS 609	3.5	2.9	0.0	49
S 390 G	6.7	0.0	1.5	63
S 395 F	5.8	3.9	7.4	49
Top Pak	3.5	0.0	0.7	60
Y 53	6.3	0.0	1.0	66
Y 61	1.2	5.5	1.6	44
Y 62 (Merida)	8.8	6.3	0.9	54
Y 63	4.5	3.0	1.4	50
Y 67	8.8	1.4	0.9	51
Y 68	9.9	0.0	1.5	54
Significance	*	*	ns	***
l.s.d (P=0.05)	8.9	9.4	-	11.1

[A]Does not take into account the incidence of cavity spot. * = $P<0.05$, *** = $P<0.001$

Table 32. Cavity spot index and the incidence of cavity spot in 27 carrot varieties harvested 2 June 1993. Data are percentage of carrots by number in each category

Variety	Nil (%)	Slight (%)	Moderate (%)	Severe (%)	Total cavity spot (%)	Cavity spot index[A]
Bolero	73.7	15.2	6.6	4.5	26.3	14.0
Cesaro	24.8	18.1	21.2	35.9	75.2	56.1
Flame	18.0	21.6	18.1	42.3	82.0	61.6
Futuro	34.8	16.3	20.4	28.6	65.2	47.6
Hinan	40.1	28.6	12.0	19.3	59.9	36.8
Nandor	45.5	32.1	11.1	11.3	54.5	29.4
Narbonne	72.9	19.4	2.9	4.7	27.1	13.1
Narman	58.2	19.5	11.4	10.9	41.8	25.0
Navarre	66.6	23.7	7.5	2.1	33.4	15.0
Nerac	65.5	22.6	8.2	3.6	34.5	16.6
Newton	65.5	16.5	9.5	8.6	34.5	20.4
RS 87 2092	31.5	27.9	8.0	32.7	68.5	47.3
RS 87 2365	34.8	20.0	17.5	27.6	65.2	45.9
RS 87 2417	49.1	23.7	10.4	16.8	50.9	31.6
SPS 543	27.4	20.6	18.0	34.0	72.6	52.9
SPS 567	81.0	17.9	0.0	1.1	19.0	7.1
SPS 597	54.4	26.8	8.9	9.9	45.6	24.8
SPS 609	83.6	12.8	2.8	0.7	16.4	6.8
S 390 G	57.4	21.4	13.4	7.9	42.6	24.0
S 395 F	53.7	21.4	6.2	18.6	46.3	29.9
Top Pak	24.6	27.6	17.9	29.9	75.4	51.0
Y 53	37.3	23.7	15.9	23.2	62.7	41.7
Y 61	77.6	15.4	2.9	4.1	22.4	11.2
Y 62 (Merida)	69.9	18.1	8.4	3.6	30.1	15.2
Y 63	34.1	23.7	18.1	24.1	65.9	44.1
Y 67	51.5	26.5	8.8	13.3	48.5	28.0
Y 68	32.0	20.8	17.5	29.7	68.0	48.3
Significance	***	ns	***	***	***	***
l.s.d (P=0.05)	16.2	-	9.2	15.7	16.2	15.8

[A] A lower cavity spot index indicates greater tolerance, *** = P<0.001

Table 32 shows the cavity spot index for each variety in ascending order. Cavity spot is a major disease of export carrots and is likely to become more widespread as carrot cropping intensifies. Varietal tolerance can form part of an integrated disease management program along with crop rotation and other treatments. Varieties that have shown promise in this trial for cavity spot tolerance and with yield similar to the industry standard, Top Pak, need to be evaluated on commercial properties on a small scale for late summer-autumn harvest. Varieties should be evaluated against current commercial varieties and additional information on the variety (mechanical harvesting, breakage, leaf blight tolerance) should be obtained.

The following varieties should be considered for further evaluation in relation to cavity spot tolerance: SPS 609, SPS 567 and Bolero. Navarre, Narbonne and Nerac should also be further tested on the basis of cavity spot tolerance and good root quality.

Notes on varieties

- Bolero- corrugated, slightly rough, heavy carrot, moderately tapered Nantes.
- Flame- very smooth Nantes, very slightly tapered but small.
- Futuro- short, corrugated, not worth pursuing.
- Hinan- long, very slightly tapered, smooth, small eyes.
- Nandor- short Nantes, slightly tapered, appeared immature.
- Narbonne- smooth, very tapered, not blunt, good length, immature.
- Narman- very tapered Nantes, short, corrugated, immature.
- Navarre- slightly tapered but true to Nantes shape, good potential, needs further evaluation.
- Nerac- corrugated, tapered Nantes, reasonable appearance.
- Newton- short carrot, but smooth, attractive, possible Japanese market variety?
- RS 87 2092- reasonably smooth, very tapered, like miniature Western Red.
- RS 87 2365- slightly corrugated, chunky, reasonable appearance but slightly short and tapered, true Nantes carrot.
- RS 87 2417- extremely tapered, corrugated, not true Nantes type.
- SPS 543- smooth Nantes, good quality, short to medium length, similar to Top Pak.
- SPS 567- Nantes but tapered, large 'eyes'.
- SPS 597- corrugated, large eyes.
- SPS 609- slightly rough appearance, slightly tapered Nantes.
- S 390 G- tapered, pointy, slightly rough, Imperator cross?
- S 395 F- longer than most other varieties, semi-Nantes, reasonably smooth, skinny.
- Top Pak- corrugated, very slightly tapered.
- Y 53- small, short, reasonable appearance, slightly tapered.
- Y 61- rough, long Nantes, slightly tapered, possible winter variety?
- Y62 (Merida)- long tapered Nantes, reasonably skinny, appearance OK.
- Y 63- tapered Nantes, reasonable, but large eyes, good length.
- Y 67- variable shape and size, semi Nantes, quite tapered, rough, large eyes.
- Y 68- corrugated, blunt ended tending to be tapered.

Acknowledgments

K. Gajda is thanked for technical assistance. The authors thank all seed companies involved for donating seed. L. Biocich and staff at Guilderton Farms, particularly C. Hoareau and R. Woonings are kindly thanked for managing the trials. Financial assistance from the Sumich Group Ltd. and the Horticulture Research and Development Corporation is gratefully acknowledged.

References

Anon (1993). Descriptive list of varieties of early and maincrop carrots grown in NIAB trials. NIAB Vegetable growers leaflet No.5.

Phillips, D. R. (1988). Investigation of cultural and management techniques for mechanically harvested export carrots. Australian Special Rural Research Fund Final Report.

Pryor, B. M., Davis, R. M., and Gilbertson, R. L. (1994). Detection and eradication of *Alternaria radicina* on carrot seed. *Plant Disease* **78**, 454-56.

12. SEED PRIMING FOR CARROTS

A.G. McKay, A. Galati and K. Gajda

SEED PRIMING FOR CARROTS

Summary

Seeds may vary in uniformity of germination, which along with interplant competition leads to variation in plant size within a crop . Seed priming is a technique which can reportedly increase the speed and uniformity of seedling emergence and hence improve crop establishment and uniformity.

Primed and natural carrot seed were purchased from the UK. The objective of these experiments was to determine whether 'drum' primed carrot seed had any advantages over natural seed for carrot cropping. The primed seed emerged 1 to 2 days earlier when sown in the field under late winter to early spring conditions near Perth, Western Australia. No differences in crop yields between primed and unprimed seed were measured. However consideration of the potential yield benefit based on time of harvest data for carrots does indicate there may be an economic gain from even 1 or 2 days earlier crop emergence.

Major results

- Primed carrot seed germinated quicker than natural seed, however, the difference was only 1 to 2 days.
- There was no measurable difference in yield between primed and natural seed in two field experiments.
- The primed seed had a lower germination percentage than the natural seed and produced lower plant densities which probably accounted for minor differences in root size distribution at harvest.

Recommendations

(a) Extension/adoption by industry

- Recommended for commercial trials only.
- Article outlining results to growers in CARD newsletter.

(b) Directions for future research

- With seed company collaboration, field comparisons of primed and unprimed seed with multiple times of harvest would help quantify the possible benefit of primed seed.

(c) Financial/commercial benefit

- An autumn sown density by time of harvest experiment (92PE32) showed that as carrots approached maturity total yield increased by 1.5 tonnes/ha/day while export yield increased by 1.4 tonnes/ha/day. In this case the increase in yield translated to an increased return of $300 per day (based on an average carrot price of $0.20/kg). Primed carrot seed germinated 2 days earlier than natural seed so that the potential benefit would be $600 per hectare. The cost of seed priming now available in Australia is about $100 per hectare (based on treating 1 kg of raw seed). Thus even at the low carrot price of $0.20/kg there is potential benefit to growers in adopting seed priming.

SEED PRIMING FOR CARROTS

Introduction

Slow and staggered emergence of seed can increase the time until crop maturity and can influence final yield in many crops (Brocklehurst and Dearman 1983b). Seed priming or osmoconditioning (Heydecker and Gibbins 1978) is a technique which allows seed to imbibe water to commence germination, but then water is limited, usually by osmotic means, to halt germination before radicle emergence. Priming aims to bring all seed to the same stage of development and leads to a faster and more even germination and emergence of seed (Brocklehurst and Dearman 1983a, Darby and Salter 1976; Wiebe and Tiessen 1979; Szafirowska *et al.* 1981). Thus scope exists to reduce variability among plants within a crop and shorten the time needed to reach maturity. It has also been suggested that growers could also control weeds at a lower cost through the use of lower herbicide rates applied earlier when weeds are smaller (Rowse and McKee 1991).

Until recently seed priming has involved placing seed in an osmotic solution (often polyethylene glycol) and allowing the seed to hydrate. After the moisture equilibrium is achieved, further uptake of water does not occur. The Horticulture Research Institute (UK) has developed an effective priming method, known as 'drum priming', which uses only water (Rowse and Stirling 1991). Drum priming is a non-osmotic means of priming seed with the supply of water to the seeds controlled by physical rather than osmotic means. The process has been commercialised and drum primed carrot seed is available from Sharpes International in the United Kingdom.

The aim of this series of experiments was to compare the emergence rates of drum primed and unprimed (natural) carrot seed and to compare crop yields from the primed and unprimed seed.

1. Experiment 92MD28 - The effect of priming on germination rate and crop yield

Aim

To compare the emergence rates of primed and natural (unprimed) carrot seed and to compare the root yields of carrots grown from primed and natural seed.

Materials and Methods

Drum primed and natural seed of the Nantes carrot variety Primo F1 (Vilmorin Seeds, France) was purchased in the 'raw' form from Sharpes International (UK). Both primed and natural seed came from the same seed batch.

There were two seed treatments (natural and primed seed) replicated 7 times in a randomised block. Raw seed was sown with an Agricola Italia® seeder at the Medina Research Centre on 2 September 1992. Five single rows per 1.5 m wide bed were sown with an intrarow spacing of 4.5 cm. Plots were 10 m long.

Germination rate was assessed on a 2 m section of row within a buffer area in each plot. Emerged seedlings were counted and removed daily until no further germination occurred. Soil (5 cm depth) and air temperature were recorded using Wesdata® loggers for one week during germination (Fig. 2). At crop maturity (14 January 1993), 6 x 0.5 m lengths of row were harvested from the middle 3 rows of each plot then weighed and graded.

Logistic functions were used to model the germination of primed and natural seed over time. Data was standardised prior to curve fitting such that the germination at each time was expressed as a percentage of the final germination for that treatment. The generalised logistic function was of the form :

$$y = c/[1 + \exp(-B(t - m)]$$

where c = estimated maximum % germination,
B = maximum germination rate (slope parameter),
m = time at which maximum germination rate occurs,
t = days after sowing.

Differences between seed treatments for time at which maximum germination rate occurred, duration of 95 % germination (from the start of germination) and maximum germination rate were determined by analysis of variance using GENSTAT software. Yield data were also analysed by analysis of variance using GENSTAT software.

Results and Discussion

Effect of priming on germination rate

The primed seed reached maximum germination rate 10.9 days after sowing while the natural seed achieved maximum rate 11.8 days after sowing (Table 1 and Fig. 1). There were also significant differences in maximum germination rates and estimates of duration of 95 % germination for natural and primed seed with the primed seed having the higher maximum germination rate and the shorter 95 % duration (Table 1). Laboratory tests in England showed drum primed carrot seed achieved 85 % emergence in 3 days compared with 5 days required for natural seed (Rowse and Stirling 1991).

Table 1. Time until maximum germination, 95 % duration and maximum germination rate for primed and natural carrot seed (* = $P < 0.05$, ** = $P < 0.01$, *** = $P < 0.001$)

Treatment	Time at which max. germination rate occurs (days)	95 % duration (days)	Max. germination rate (%/day)
Natural	11.8	4.8	3.4
Primed	10.9	3.7	3.7
Significance	***	**	*
l.s.d (P=0.05)	0.188	0.73	0.19

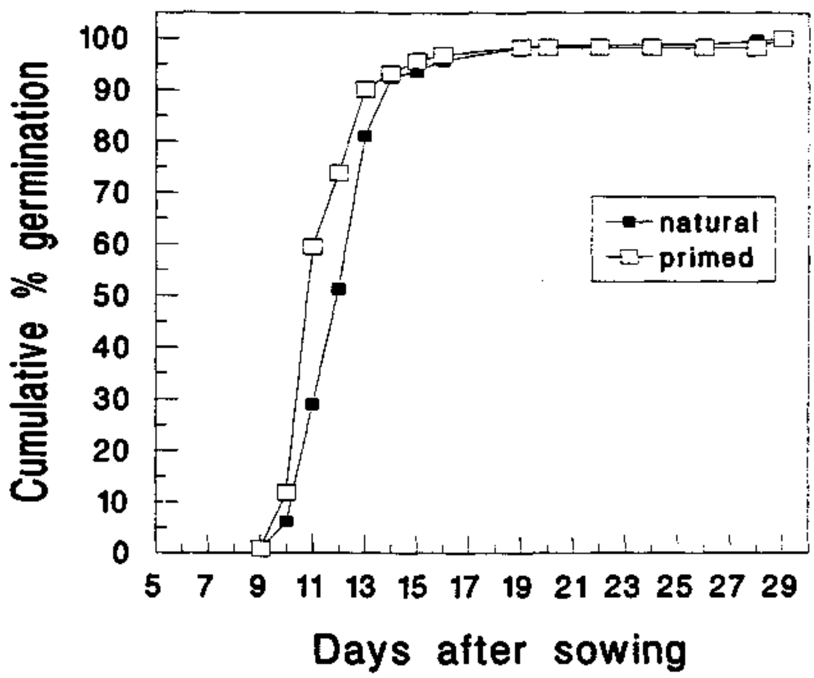


Fig. 1. Cumulative percentage germination of natural and primed seed over time

Effect of priming on yield

Seed treatment did not significantly (P>0.05) affect total yield, marketable yield or reject yield (Table 2). Natural seed produced a significantly higher plant density than the primed seed (Table 2). There was a trend for higher total yield from the primed seed which was contrary to the effect expected given the higher plant density produced from the natural seed. The higher marketable short yield produced by the natural seed (Table 2) probably resulted from the higher plant density in this treatment.

Table 2. The effect of natural and primed seed on yield, rejects and plant density of the carrot variety Primo at harvest

Treatment	Total yield (t/ha)	Density (plants/m^2)	Export yield (t/ha)	Marketable short yield[B] (t/ha)	Reject yield (t/ha)
Natural	100.9	65	62.1	6.0	32.7
Primed	105.9	55	65.0	2.6	38.4
Significance	ns[A]	*	ns	**	ns
l.s.d (P=0.05)	-	6.5	-	2.0	-

[A] P= *0.061*, [B] Marketable short roots = 25 - 50 mm diameter and 100 - 150 mm length

Aside from some differences in size distribution which can be accounted for by differences in germination and hence density, priming carrot seed had no measurable effect on yield. Primed seed did achieve maximum germination rate earlier than natural seed though the difference was only 1 day. As well as germinating earlier, the primed seed had a shorter spread of germination with the 95 % duration period 1.1 days less than that of the natural seed. The differences between primed and unprimed seed were small given that the carrots were sown during cool conditions, when minimum temperatures were less than 10°C (Fig. 2), conditions which were expected to magnify the effect of seed priming.

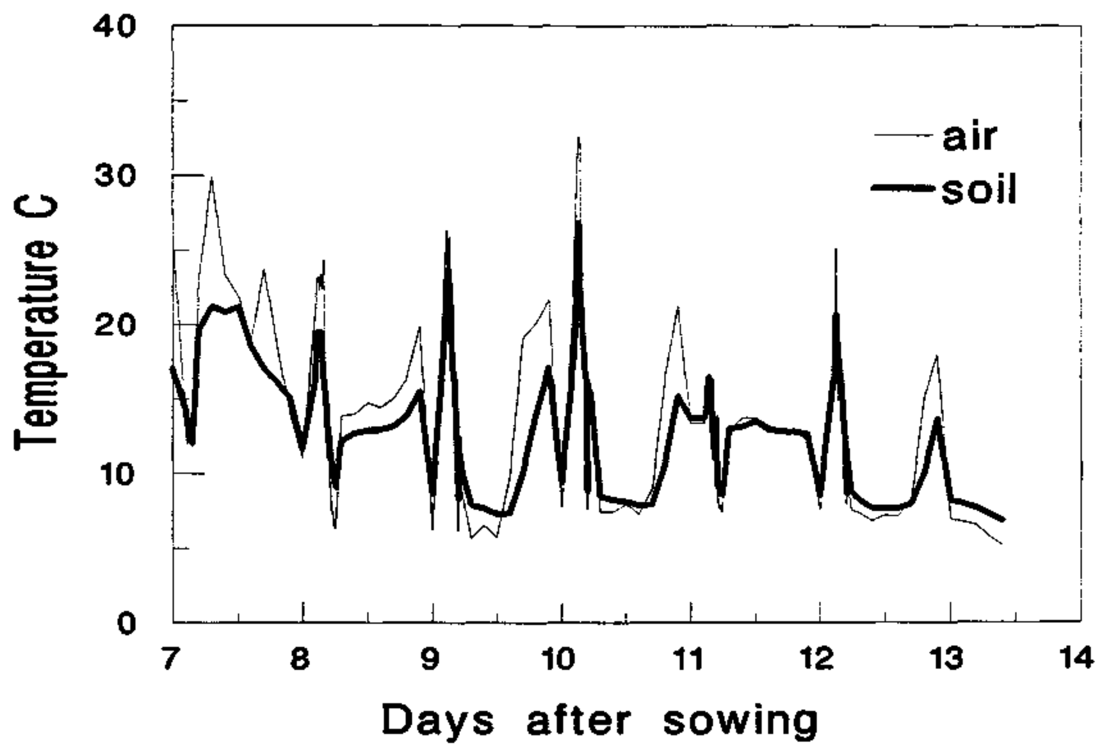


Fig. 2. Soil (5 cm depth) and air temperatures from 7 to 14 days after sowing.

---

2. Experiment 92PE54 - The effect of seed priming on yield

Aim

The aim of this experiment was to compare the final yield of crop grown from primed and natural (unprimed) carrot seed under commercial crop management.

Materials and Methods

Primed and natural pelleted seed of the variety Primo F1 (Vilmorin Seeds), was sown with an Agricola Italia® air seeder on 7 September 1992. The experiment was located on a commercial property, 100 km north of Perth. The crop was irrigated using centre-pivot irrigation . There were two treatments and 10 replicates with plots arranged in a randomised block design. Plots were 1.92 m wide and 10 m long. The plots were managed the same as the surrounding commercial carrot crop.

At harvest (11 January 1993), 1.5 m from the three middle rows were harvested from each plot, the roots were weighed and graded and the total, marketable and reject yields were calculated.

Results and Discussion

Priming had no effect (P>0.05) on the total yield of carrot roots (Table 3). There was a significant difference (P<0.001) in plant density at harvest with 88 plants/m^2 in the natural seed treatment compared to 74 plants/m^2 in the primed seed treatment (Table 3). Plant density work as part of this project showed that in this range while total yield differences may be small, the proportion of export grade roots falls quickly as plant densities rise above about 70 plants/m^2. The difference in density observed at this site would affect root size distribution at harvest maturity. Primed carrots with a lower density had a higher export yield than natural seed. The higher density in the natural seed treatment produced a higher yield of carrots classed as marketable short than the primed seed treatment. There was no significant difference in the yield of or type of rejects.

Thus, aside from some differences in root size distribution, probably resulting from differences in germination, and hence plant density, priming seed had no detectable effect on carrot yield.

Table 3. Yield, density, and rejects for natural and primed seed of the variety Primo at harvest maturity

Treatment	Total yield (t/ha)	Density (plants/m^2)	Marketable yield (t/ha)^A	Export yield (t/ha)	Marketable short yield (t/ha)	Undersize (t/ha)	Rejects (t/ha)
Natural	98.8	88	93.3	80.4	12.9	2.0	3.5
Primed	96.3	74	92.7	87.7	5.0	1.2	2.4
Significance	ns	***	ns	**	ns	**	ns
l.s.d (P=0.05)	-	4.4	-	5.1	-	0.76	-

^{A}export yield + marketable short

3. Experiment 92PE58 - The effect of priming and pelleting on the rate of carrot emergence in the field

Aim

In Western Australia, there may be some advantage in using primed carrot seed during cooler conditions when crops are slow to germinate. In July and August, it can take 14 to 20 days from sowing for carrot seed to emerge from the soil.

The aim of this experiment was to compare the germination of natural (unprimed) and drum primed carrot seed, with and without pelleting, sown in the field during winter.

Materials and Methods

Drum primed and natural seed from the same batch, were purchased in the 'raw' form from Sharpes International (UK). The variety was Primo F1 (Vilmorin Seeds). Upon arrival, a sample of both the primed and natural seed was pelleted by South Pacific Seeds Ltd, Australia.

The experiment was conducted on a grey-phase Karrakatta sand in Como near Perth, Western Australia. There were four seed treatments (natural raw seed, natural pelleted seed, primed raw seed and primed pelleted seed) which were replicated 4 times with 100 seeds sown per replicate. Seed was sown by hand on 20 August 1992. Emerged seedlings were counted and removed from plots daily until no further germination was observed.

As in previous expriments a logistic function was used to model the germination of primed and natural seed. Data was standardised prior to curve fitting such that the germination at each time was expressed as a percentage of the final germination for that treatment. The generalised logistic function was of the form :

$$y = c/[1 + \exp(- B(t - m)]$$

where c = estimated maximum % germination,
B = maximum germination rate (slope parameter),
m = time at which maximum germination rate occurs,
t = days after sowing.

The maximum germination rate was calculate as C x B/4 and the duration as 6/B, which includes 95 % of germination. Differences between seed treatments for maximum final % germination, time at which maximum germination rate occurs, time until 95 % germination and maximum germination rate (% per day) were determined by analysis of variance using GENSTAT software.

Results and Discussion

There was no significant (P>0.05) difference between treatments for the actual final % germination, time until 95 % germination (duration) and maximum germination rate. There was a significant difference (P<0.001) for the time taken to achieve maximum germination rate. For raw seed, the primed seed reached maximum germination rate 1.6 days quicker than the unprimed seed (14.1 days for natural seed and 12.5 days for primed seed) (Table 4).

Table 4. Time until maximum germination, 95 % duration, maximum germination rate and final % germination for primed and raw seed (± pelleting)

Treatment	Time at which max. germination rate occurs (days)	95 % duration (days)	Maximum germination rate (%/day)	Final germination (%)
Natural + raw	14.1	3.6	6.5	76.7
Primed + raw	12.5	4.2	6.0	72.2
Natural + pelleted	14.3	3.8	6.2	71.7
Primed + pelleted	13.0	4.5	5.8	72.5
Significance	***	ns	ns	ns
l.s.d (P=0.05)	0.07	-	-	-

Raw seed took less time to achieve maximum germination rate than pelleted seed. Fig. 3 shows the cumulative % germination over time for primed and natural seed with and without pellet. However, the maximum germination rate was the same for pelleted, raw, natural or primed seed. There was no difference in the final percentage germination among the treatments (73 % on average).

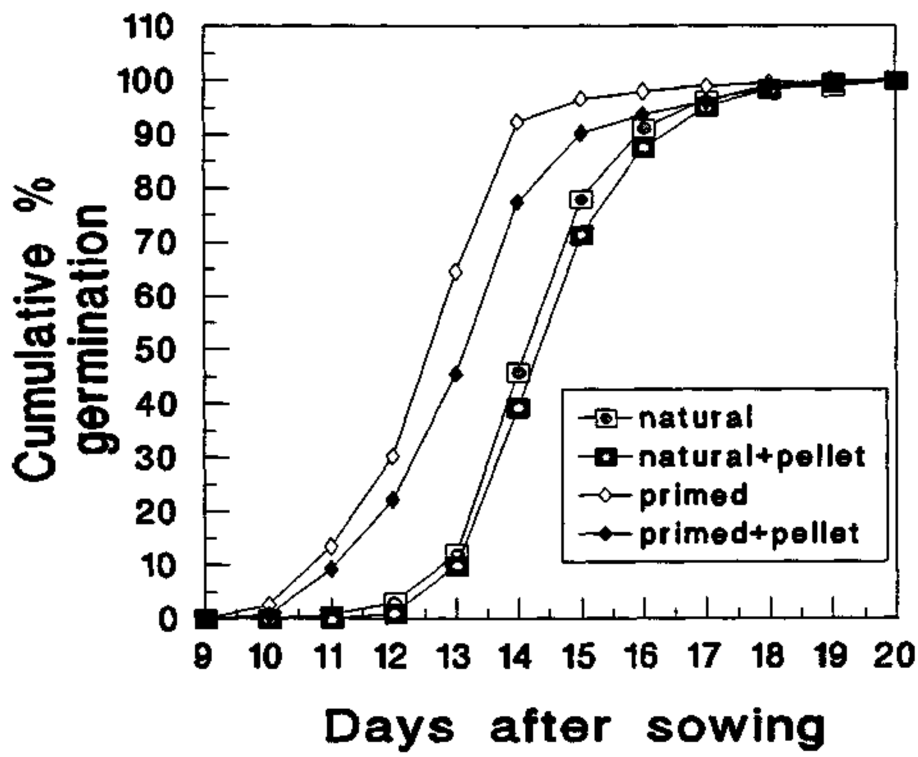


Fig. 3. Cumulative % germination of natural and primed seed over time.

Raw primed seed germinated about 2 days earlier than raw unprimed seed sown in August when soil temperatures in Western Australia are near their annual minima. This is the time when gains from seed priming might be expected to be greatest.

Pelleting the seed delayed the germination of the primed seed but had little effect on the unprimed seed. The potential benefit from only 2 days earlier germination as a result of priming would be easier to speculate about than it would be to measure.

An autumn sown density by time of harvest experiment showed that as carrots approached maturity total yield increase by 1.5 tonnes/ha/day while export yield increased by 1.4 tonnes/ha/day. In this case the increase in yield translated to an increased return of $300 per day (based on an average carrot price of $0.20/kg). Primed carrot seed germinated 1-2 days earlier than natural seed so that the potential benefit would be between $300 and $600 per hectare. The cost of seed priming now available in Australia is about $100 per hectare (based on treating 1 kg of raw seed). Thus even at the low carrot price of $0.20/kg there is potential benefit to growers in adopting seed priming.

The drum primed seed used in our work was dried back after the priming process for convenient transport, storage and handling. Freshly primed seed can be surface dried and sown immediately in which case the seed is reported to germinate faster. Seed can now be primed by 'secret' processes in Australia. The possible advantages of sowing primed seed should be further tested in co-operation with seed companies offering seed primed in Australia.

Acknowledgments

The staff of Guilderton Farms are thanked for their management of 92PE54 and the staff of Medina Research Centre, in particular J. Berston and E. Ikonen are also thanked for assistance with field work. Thanks to M. Eales for his assistance with the temperature loggers and to T. Guildera, South Pacific Seeds, for organising the seed pelleting. J. Dhaliwal is thanked for providing statistical analysis. Financial support from the Sumich Group Ltd. and the Horticulture Research and Development Corporation is gratefully acknowledged.

References

Brocklehurst, P. A., and Dearman, J. (1983a). Interactions between seed priming treatments and nine lots of carrot, celery and onion. I. Laboratory germination. *Annals of Applied Biology* **102,** 577-84.

Brocklehurst, P. A., and Dearman, J. (1983b). Interactions between seed priming treatments and nine seed lots of carrot, celery and onion. II. Seedling emergence and plant growth. *Annals of Applied Biology* **102,** 585-93.

Darby, R. J., and Salter, P. J. (1976). A technique for osmotically pre-treating and germinating quantities of small seeds. *Annals of Applied Biology* **83,** 313-15.

Heydecker, W., and Gibbins, B. M. (1978). The 'priming' of seeds. *Acta Horticulturae* **83,** 213-23.

Rowse, H., and McKee, M. (1991). Rapid commercialisation of 'green' seed priming technique. *Horticulture Research International UK. Annual Report (1990-91)* pp 52-53.

Rowse, H., and Stirling, H. G. (1991). Drum priming of seeds. British Technology Group, Technology Transfer, Data sheet CR No. 130546. 3 pp.

Szafirowska, A., Khan, A. A., and Peck, N. H. (1981). Osmoconditioning of carrot seeds to improve seedling establishment and yield in cold soil. *Agronomy Journal* **73**, 845-48.

Wiebe, H. J., and Tiessen, H. (1979). Effects of different seed treatments on embryo growth and emergence of carrot seeds. *Gartenbauwissenchaft* **44**, 280-84.