VG313
Intensive vegetable production and vesicular arbuscular mycorrhizas

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VG313

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Final Report

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Intensive Vegetable Production and Vesicular Arbuscular Mycorrhizas

Project No. VG313

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1 INTRODUCTION

1.1 Background

Soil fumigation with metam sodium (Vapam®, Metham®) is a popular management tool in intensive vegetable production. Metam sodium converts to the general biocide methyl isothiocyanate (MIT). It is used to control germinating weed seeds, nematodes, symphylids (centipedes) and soil borne diseases such as rhizoctonia, pythium and phytophthora. As a general biocide, MIT does not discriminate between pathogens and beneficial organisms such as vesicular arbuscular mycorrhizae (VAM).

Some vegetable growers in the Fassifern and Lockyer Valleys in S.E. Queensland have incorporated fumigation with metam sodium into their management practices. Metam sodium has been attributed to reduced incidence of cavity spot and pythium root rot in carrots. Some producers have also used metam sodium in an attempt to control *Sclerotium cepivorum*, causing white rot, in onions. Increased uniformity in the crop was perceived by growers to be associated with this presumed reduction in disease incidence.

The most efficient means of delivery of metam sodium in the field situation is by soil injection. The method of application differs to comply with normal management operations (Lembright 1990). Broad-acre production of vegetables such as onions demands that the metam sodium is applied to fumigate the entire area of potential production. Chisels or tynes, adapted to deliver the solution, are off-set to overlap the area of application, and presumably, provide uniform coverage. By comparison, the carrot growers of the Fassifern and Lockyer Valleys, who are using metam sodium, grow their carrots in raised beds. They have adapted the available technology to fumigate strips down the centre of each. This technique is believed to only fumigate the portion of the soil bed to be used in carrot production (Lembright 1990).

Anecdotal evidence of poor germination, stunted and uneven growth in carrot crops following fumigation with metam sodium on some farms in the Lockyer and Fassifern Valleys was received as the result of a commercial enquiry in 1992. Subsequent investigation confirmed a significant problem existed with some plants displaying symptoms of stunting, and purple stems and leaves. This suggested that the crops were suffering from phosphorus deficiency (Weir and Cresswell 1993), in soils that were known to have high to very high levels of phosphorus.

The extent of these symptoms in the carrot crops observed at one property in the Lockyer Valley and two properties in the Fassifern Valley suggested that the reasons for, and the effect of, this mid-crop decline required investigation.

The recommended rate of application of metam sodium by soil injection ranges from 245 – 485 litres accompanied by 400 – 700 litres of water per hectare (Vapam®, Agchem, 423 g.a.i./L). The producers we worked with were applying Vapam at 90 litres per acre (222.4 L metam sodium per hectare). However, strip fumigation actually only fumigates approximately 1/3 of the field. The effective rate of application to these strips is calculated 667 litres metam sodium per hectare. This rate (though acceptable on a whole field basis) is much higher than the recommended range of 245 – 485 L/ha.

After consideration of the facts at hand, a likely explanation for these crop establishment problems was that the high "effective" soil dose levels of metam sodium were somehow imparing plant function. A likely hypothesis was that the mycorrhizal fungi essential to plant growth and nutrition (particularly important in sensitive crops such as carots and onions) were being harmed by the fumigation process. To test this hypothesis and to find solutions to these problems, a research program was developed and taken on board by Ph.D. candidate Jocelyn Eskdale.

1.2 Literature Review

Mycorrhizae

About a century ago, several biologists noticed that some plant roots that were extensively invaded by fungi, were not diseased. The name mycorrhiza (fungus root) was thus coined in 1885 (Kendrick 1992). Mycorrhizas are the association between plant roots and the hyphae of various naturally occurring, soil inhabiting fungi which operate together in a symbiotic partnership. The nature of this partnership is such that the plant provides the fungal component with nutrients (sugars, amino acids, vitamins etc.), while the fungal component assists the plant with the uptake of nutrients such as phosphorus (P) and zinc (Zn) as well as water (Brown 1992) which are often limiting for plant growth. It is thought that over 90% of all higher plants species are normally mycorrhizal (Kendrick 1992) making the mycorrhizal situation the "normal situation".

There are two major categories of mycorrhizae; ectomycorrhizae and endomycorrhizae. Ectomycorrhizae are fungi which can be grown in artificial culture (like mushroom spawn) and occur largely on woody plants in families such as *Pinaceae, Fagaceae* and *Butulaceae* (pines, oaks and birches; Linderman, 1981) and *Eucalyptus* (Kendrick 1992).

The group of mycorrhizae most relevant to horticultural crops are the endomycorrhizae. These fungi produce loose networks of hyphal strands which are often associated with the plant's feeder roots making their presence undetectable without the use of a microscope. Often known as **Vesicular Arbuscular Mycorrhizae** (VA mycorrhizae or VAM) these fungi produce a range of microscopic structures within and outside of the plant root (Figure 1). The **arbuscule** is a branched feeding organ which penetrates the root's epidermal and cortical cells and allows the two-way exchange of nutrients between the fungus and the plant. The **vesicle** (which does not occur in all instances leading some experts to use the equivalent acronym AM) contains oil droplets and is thought to be a storage organ. VA mycorrhizal fungi are obligate symbionts, they can only exist in the presence of living plants, and as such, they cannot be grown in artificial culture. In general, VA mycorrhizal fungi are capable of colonising a wide range of plants (St John & Evans 1990), thus a single isolate may be used to colonise a wide range of plant species.

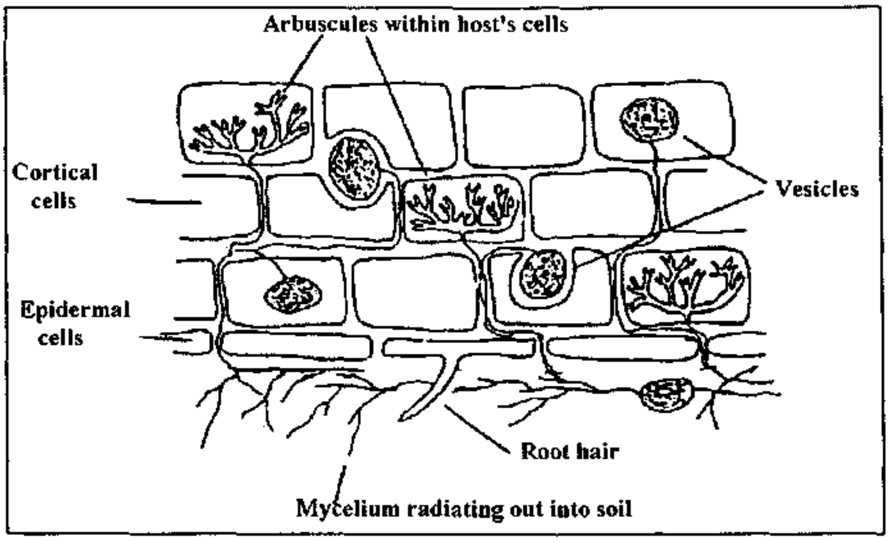


Figure 1. Diagram of a root section showing the features of VA mycorrhizas (Brown 1992).

Plant growth and mycorrhizae

Countless experimental trials have shown that plants colonised by mycorrhizal fungi are generally larger and have higher concentrations of phosphorous in their tissues (Krikun 1991). The improvement in plant nutrition is due to the production an extensive network of hyphae into the soil around the plant. Normally, the plant root removes phosphorous rapidly from the region immediately surrounding the root. The hyphal network grows beyond this depletion zone and supplies phosphorous that is not normally available to the plant's roots alone (Brown 1992; St. John and Evans 1990). This effect can often be reduced by the addition of high levels of P as mycorrhizae are most active in P deficient situations.

As mycorrhizas normally exist in most soils, their benefits are not normally seen until they are somehow removed from a field. Mycorrhizal populations may be reduced by rotations with non-host crops (such as brassicas) or through fallow. Mycorrhizas have also been shown to be sensitive to certain chemicals, particularly some fungicides (benomyl) and the soil fumigants methyl bromide and metam sodium (Trappe *et al.* 1984). The importance of mycorrhizae to the nutrition and growth of a wide range of vegetable crops has been clearly established in soils with moderate phosphorus fertility (Plenchette *et al.* 1983).

Baylis (1975) suggested that seedlings had a far greater dependence on mycorrhizae for nutrient and water uptake than mature perennials, because they have less storage tissue and a less extensive root system relative to the living biomass. In addition, ancestral crop plants were selected for high productivity and reproductive output under conditions of high nutrient availability which provided little advantage for efficient nutrient use (Chapin 1980). There are many examples showing that crop plants rarely show absolute dependence on mycorrhizae, instead they show more dependence on soil type, pH and the selection of fungal symbiont (St John and Coleman 1983).

Both carrots (*Daucus carota* L.) and onions (*Allium cepa* L.) are cultivated as annual crops. They form associations with arbuscular mycorrhizae, and are known to be highly dependant upon this relationship for their normal growth functions.

Fumigation

The term fumigant is believed to be derived from the Latin *fumigare* meaning "to heat with smoke" (Sinha *et al.* 1988). The function of soil fumigants are generally as a "soil sterilant (to eliminate microflora), for selective elimination of pathogen(s), to reduce the inoculum potential of pathogens and/or to provide conditions that stimulate antagonistic soil microoganisms" (Sinha *et al.* 1988). Complete sterilisation of the soil could cause the development of a "biological vacuum". Geypens (1974) and, later, Lembright (1990), recommended that fumigants should only be used to reduce the population of harmful microoganisms below a threshold level, so that the population is unable to rebuild to levels which would adversely affect production and crop quality within that season.

An alternative method is strip or bed fumigation which is considered to be more cost effective because only the soil to be used for production is treated (Lembright 1990). Therefore, the soil between the beds retains its original population of microoganisms, and, potentially, provides a refuge for both harmful and beneficial organisms.

Metam sodium and methyl isothiocyanate

Metam sodium (sodium N-methyldithiocarbamate dihydrate - C_2H_4NNa) is produced by the reaction of methylamine with carbon disulfide in the presence of sodium hydroxide (Cremlyn 1991). The common name, metam sodium, has been in use since 1990. It was previously known as metham sodium (Tomlin 1994). Metam sodium is used as a pre-plant control of soil fungi, nematodes, weed seeds and soil insects. It is highly phytotoxic (Tomlin 1994).

Metam sodium is usually sold as a water soluble liquid (31-33%) which can be applied by soil injection, sprinkler injection, drench or metered irrigation (Sinha *et al.* 1988). The effectiveness of the application usually depends on soil preparation, reduced volatilisation and maintenance of soil moisture levels for several days after application (Sinha *et al.* 1988).

Target action of metam sodium and MIT in vegetable crops

Most fumigants or fungicides are applied with a "target" organism in mind. The stimulation of plant growth following fumigation is usually explained by presumed reduction in parasitic activity (Martin 1963).

Metam sodium has been used as a fumigant to control a wide range of organisms. Some examples of pathogens affecting vegetables that are controlled by metam sodium are included in Table 1.

Both the rates, and method of application, of metam sodium used to control nematodes, pathogens and weeds varies accordingly.

Table 1 Some target vegetable pathogens, pests and weeds controlled by metam sodium

Target Organism	**Common Name**	**Host**	**Reference**
Pathogen/Pest			
Spongospora subterranea var *subterranea* (Wallr) Lagerh	powdery scab	potato	Nachimas & Krikun (1988)
Sclerotinia minor	lettuce drop	lettuce	Adams *et al.* (1983)
Rhizoctonia solani		various	Sumner & Phatak (1988)
Pythium sp., *P. ultimum, Fusarium* sp.		carrot	Roberts *et al.* (1988)
Meloidogyne spp.	root-knot nematodes	tomato	Adams & Johnston (1983)
Sclerotium cepivorum	allium white rot	onions	
Weeds			
Digitaria sanguinalis (L.) Scop.			Teasdale & Taylorson (1986)
Molluga verticillata L.			Teasdale *et al.* (1983)
Chenopodium album L.	fat hen		
Capsella bursa-pastoris (L.) Medic.	shepherd's purse		
Galinsoga parviflora Cav.	potato weed		Pieczarka & Warren (1960)
Amaranthus retroflexus			

2 EXPERIMENTAL PROGRAM

2.1 Vapam Dose Rate Effect on Field Grown Carrots and Onions

Objective

The objective of these field trials was to determine the relationship between fumigant dose (metam sodium) and crop performance for carrots and onions. Earlier observations had shown that the levels of metam sodium used in the commercial production of carrots was, in some instances, leading to crop damage. These trials were designed to more closely examine the effect metam sodium was having on these crops and to determine a dose rate which would maximise crop productivity while minimising damage to the beneficial VAM.

Materials and methods

1992 Field Experiment

A field trial was conducted at a commercial carrot farm at Kalbar, 85 km south east of Brisbane (Queensland). The soil was a deep-mulching seasonally cracking clay classified as a Kulgun (Black Earth). It was described by Powell (1987) as a "deep dark to grey self-mulching clay loam/clay with grey alkaline calcareous subsoil".

The trial design consisted of a randomised block design with eight levels of fumigation (metam sodium) replicated three times. Each treatment plot consisted of paired raised beds (width 75cm, length 35m) with a 10m buffer zone between replicates. The fumigant doses selected spanned recommended rates, grower rates and beyond (Table 2).

Table 2 Application rates of Vapam® (423 g metam sodium/L) applied at Kalbar in 1992 and 1993.

Treatment #	metam sodium g. ai. m^{-2}	Effective soil dose of Vapam® to plot centres (L ha^{-1})	Application rate of Vapam® to whole field (L ha^{-1})
1	0	0	0
2	5.6	111	37
3	11.0	222 *	74
4	15.2	333 *	111
5	21.0	445 *	148
6	31.1	556	185
7	35.0	667	222
8	46.3	889	296

* range of commercially recommended rates of application

Fumigation

Fumigation was performed using the farmer's own equipment. The apparatus consisted of a rear mounted power harrow which was preceded by a pair of tines carrying sub-soil injectors to deliver the fumigant solution to the bed centre at a depth of 23 cm. After incorporation by the power harrow tines, the bed was re-shaped by a trailing bed former. Upon completion of the fumigation process, the trial site was irrigated to seal the soil surface. This process effectively treated the bed centres only (approximately 1/3 of the total field area).

Sowing
The trial was sown to carrots (*Daucus carota* L. hybrid variety Condor) and onions (*Allium cepa* L. cv. Gladalan White) at the rates of 110 and 35-40 seeds per metre respectively using an Agricola Italiana precision air seeder on 14/8/1992. Each crop was sown in a single row into one of the paired treatment beds within the fumigation treatment sets. The trial site was managed according to normal production practices with the assistance of the farmer co-operator.

Trial Assessment - Carrots
The carrot sub-trial was assessed by subsampling treatment plots on five occasions (54, 68, 82, 97 & 111 days after sowing). Each sample consisted of ten plants removed from a 0.5 m length of row which was randomly assigned from within each treatment plot. Characteristics such as root, shoot and whole plant fresh weight were determined before oven drying (80°C) and determination of dry matter.

Trial Assessment - Onions
The onion sub-trial was assessed by subsampling treatment plots on six occasions (41, 54, 68, 82, 97 & 111 days after sowing). Each sample consisted of ten plants removed from a 0.5 m length of row which was randomly assigned from within each treatment plot. Characteristics such as root, shoot and whole plant fresh weight were determined. Only the shoots were oven dried (80°C) for dry weight determination. The roots were stored in 70% ethanol prior to staining for estimation of mycorrhizal colonisation.

1993 Field Experiment
A second field trial was conducted on the same farm at Kalbar (Queensland). This trial site had a similar soil composition to the first. The trial design, fumigation levels and procedures for fumigation, planting and assessment were not changed. The trial was sown on 11/5/1993. Plot lengths were reduced to 25 m and the onion cultivar was changed to Golden Brown. The carrot and onion sub-trials were assessed by sub-sampling at 64, 76, 97 & 118 days after sowing.

Results

1992 Field Trial
The mean carrot (whole plant) fresh weight from the control 0 and 111 L Vapam/ha plots were heavier than those measured from plots fumigated with higher rates of Vapam (Figure 2). Plant size generally declined with increasing rate of fumigation. ANOVA of each growth characteristic indicated that there were significant differences in plant weight associated with the rate of fumigation treatment. This observation was consistent for all mean fresh weight measurements 54, 68 and 82 days after sowing, and for mean total and root fresh weight measurements 97 and 111 days after sowing. The market harvest data for carrots (Figure 3) clearly indicated a reduction in grade size shift from large to medium and medium to small as Vapam rates increased.

Onion fresh weights were generally greater at the lowest rates of fumigant (0 & 111 L/ha Vapam) with this trend being most obvious 82 & 97 days after sowing (Figure 4). Plant weights were significantly lower at the highest rate of fumigation (889 L/ha Vapam) at the last three harvests indicating noticeable crop damage. The final harvest and grading of the trial

Figure 2

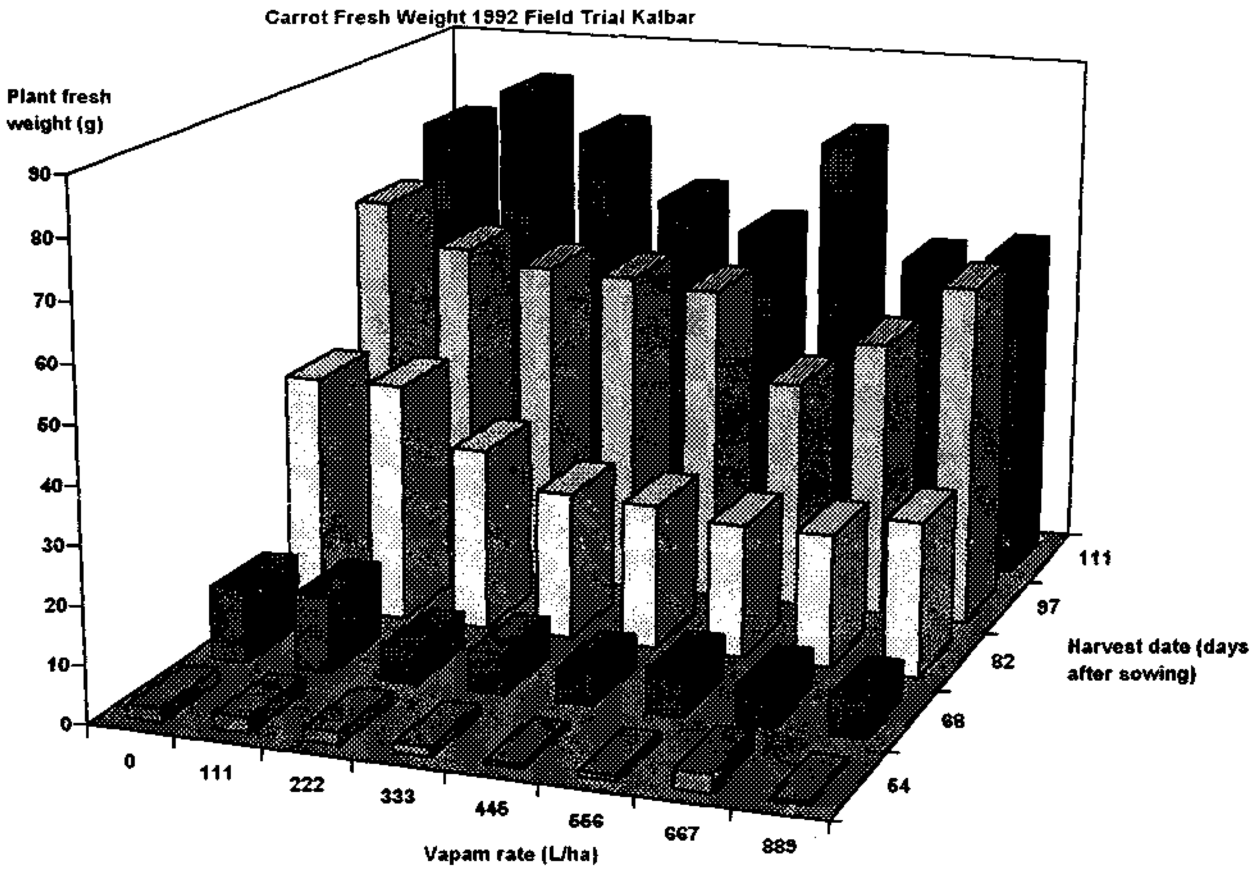


Figure 3

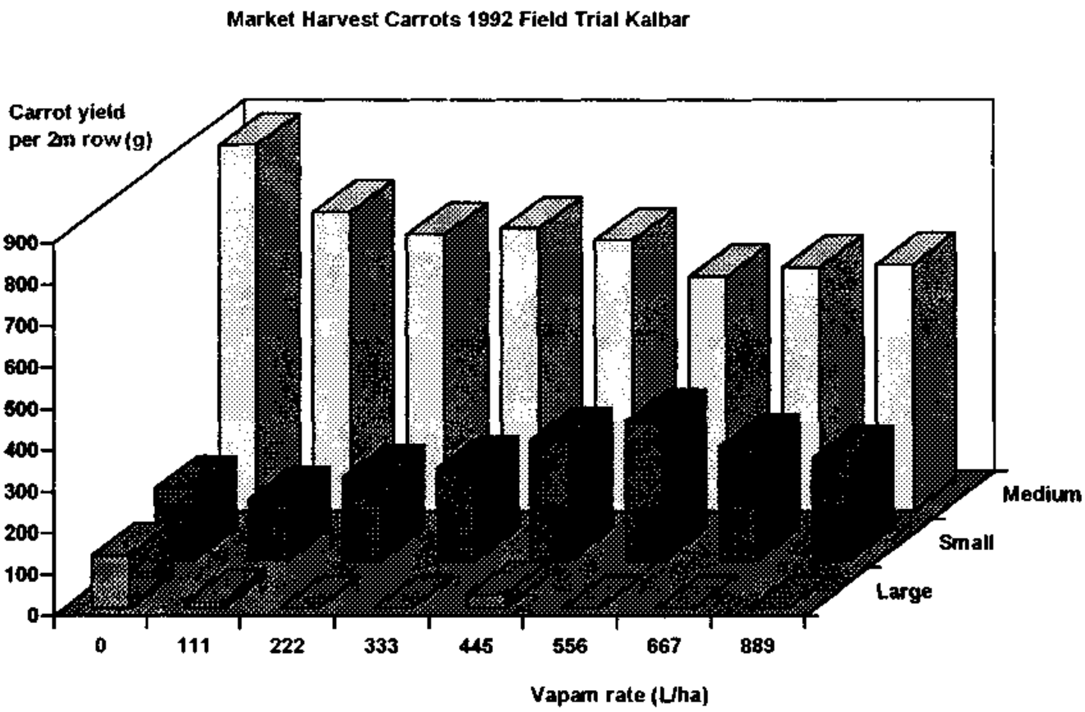


Figure 4

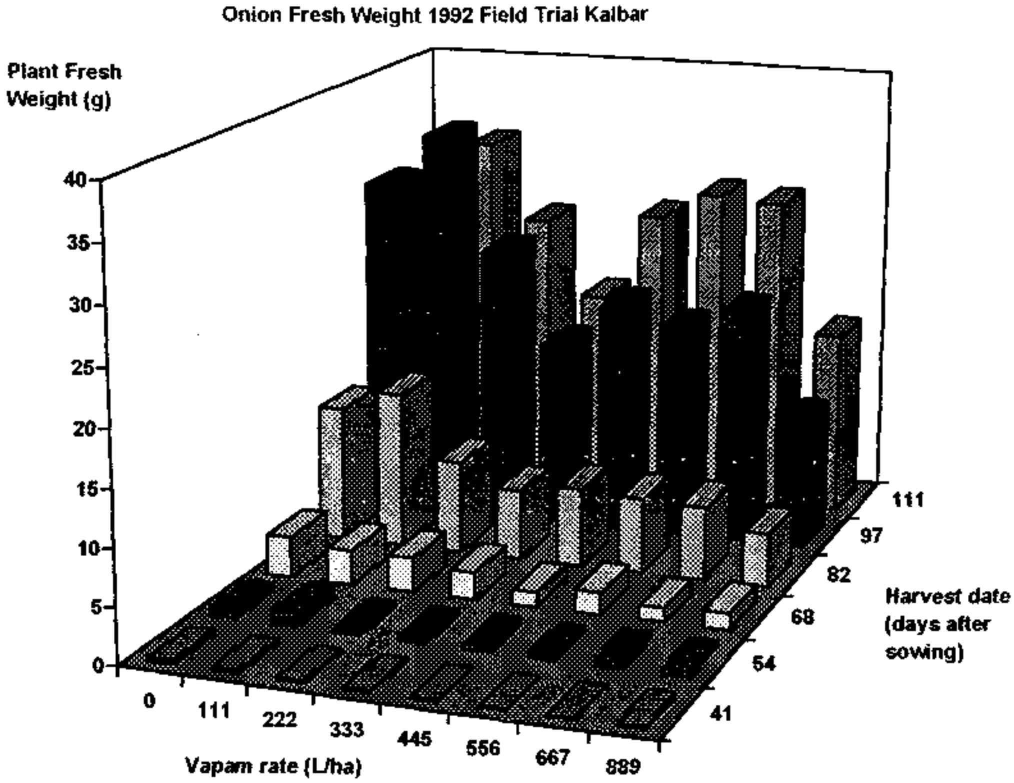
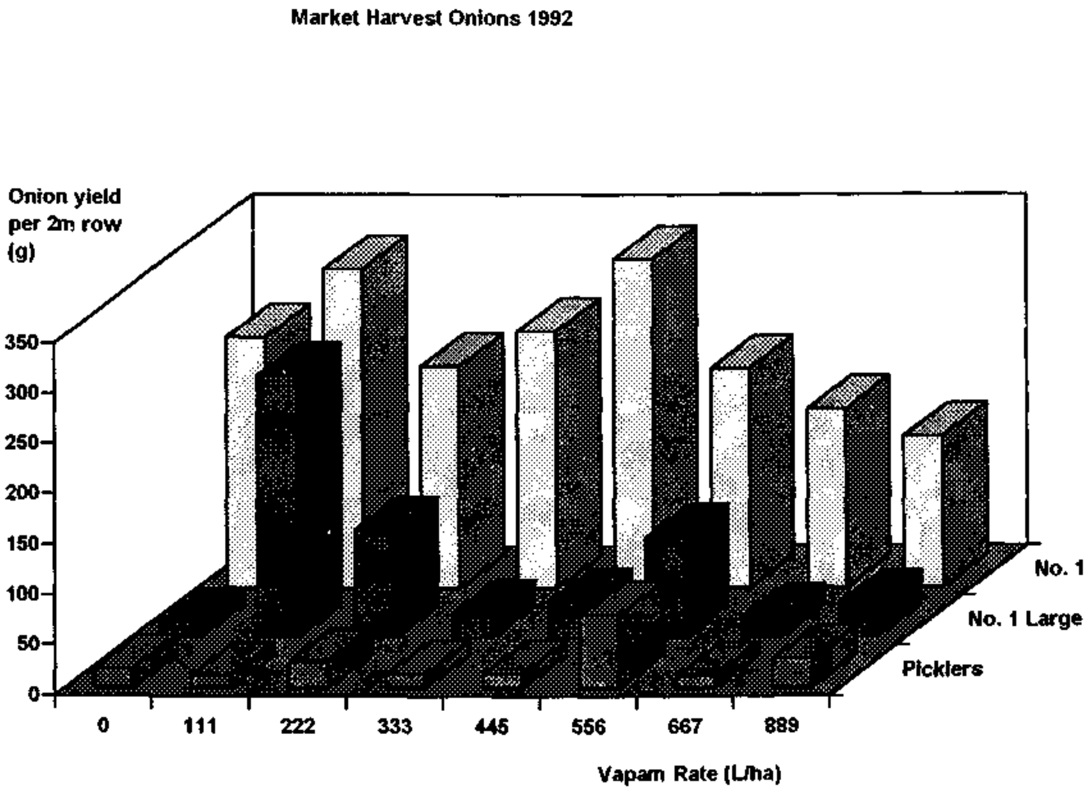


Figure 5



(Figure 5) indicated that onion quality was affected by fumigation levels with the proportion of No. 1 and No.1 large onions reduced at fumigation levels greater than 333 and 222 L Vapam/ha respectively.

The colonisation of onion roots by VAM was significantly greatest at the lowest rates of fumigation with a general reduction as the Vapam dose rate increased (Figure 6). This trend was generally maintained, though became less clear as the crop developed with time.

1993 Field Trial
Carrot whole plant fresh weights were essentially uniform across the fumigation treatments at the first two harvests (64 & 76 days after sowing) with variation between treatments becoming more obvious and random at subsequent harvests (Figure 7). The market harvests for carrots (Figure 8) indicated a general trend towards reduction of carrot size with the proportion of large grade carrots decreasing as Vapam rates rose. This resulted in greater proportions of medium and small grade carrots. Onion plant growth followed a similar pattern to that of carrots, however plant fresh weights showed a greater degree of uniformity (and thus no relationship to fumigation level) across the fumigation treatments (Figure 9).
The market harvest for onions (Figure 10) indicated that the final production and distribution of grades was not affected by the Vapam treatments. VAM colonisation results for the onion roots (Figure 11) indicated that colonisation of plants occurred independently of fumigation levels with a general trend towards increased colonisation levels with time.

Discussion

1992 Trial
Fumigation with metam sodium at levels within the recommended range 245-485 L/ha (Vapam) was found to significantly reduce plant growth for both carrots and onions. These results confirmed earlier field observations and reports from growers. Setbacks in plant growth appeared to be maintained as both crops developed to be reflected in the final plant fresh weight figures at 111 days after harvest. This trend was reflected in the marketable plant yields for onions with a clear depression in No.1 grade onions at the higher fumigant doses. Carrot production was also significantly affected with reductions in size grade caused by Vapam levels below that normally recommended and well below the dose used in the field (667L/ha). The indications are that the reductions in plant size as a function of increasing levels of fumigant did translate into slight yield reductions, but more importantly caused a shift in produce grades which were reduced as Vapam rates increased. This confirmed an observation made by the farmer - cooperator that Vapam fumigation increased grade uniformity at harvest. The VAM colonisation results clearly indicated that VAM activity was reduced by Vapam and that activity was generally restored with time for all fumigation treatments. Although VAM activity was reduced at the higher rates of fumigation, it was clear that metam sodium was not capable of eliminating this beneficial group from field soil and that recovery is possible at even the highest doses. As VAM activity was demonstrated to be sensitive to Vapam (even the lowest rates) it would be prudent to suggest that rates of application should be maintained at the lower end of the spectrum (111 - 333 L/ha) to minimise crop damage. However under conditions of high disease or weed pressure, higher rates of application would be suggested.

1993 Trial
The results from the second trial failed to demonstrate as clearly the relationship between rate of fumigation with metam sodium and a reduction in plant growth for both carrots and onions. This second trial was conducted on a different site to the first, although the soil type was essentially similar. It is possible that the cooler soil conditions experienced when preparing the

Figure 6

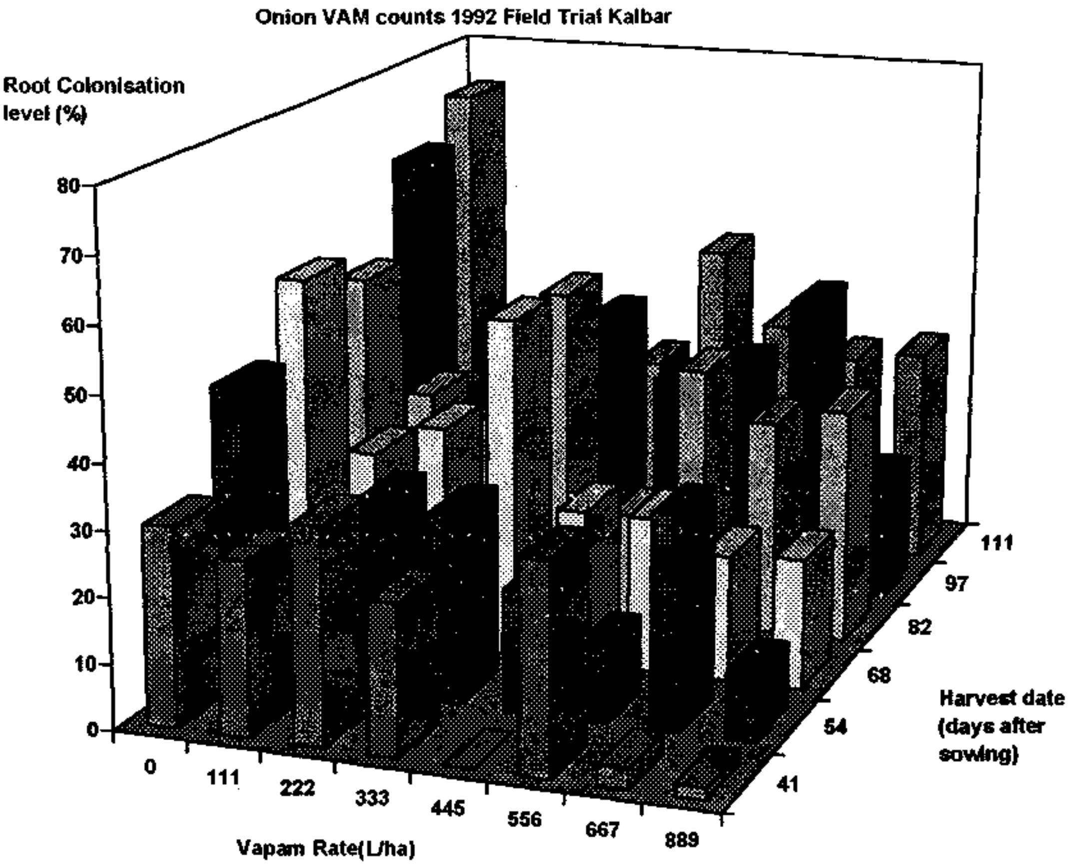


Figure 7

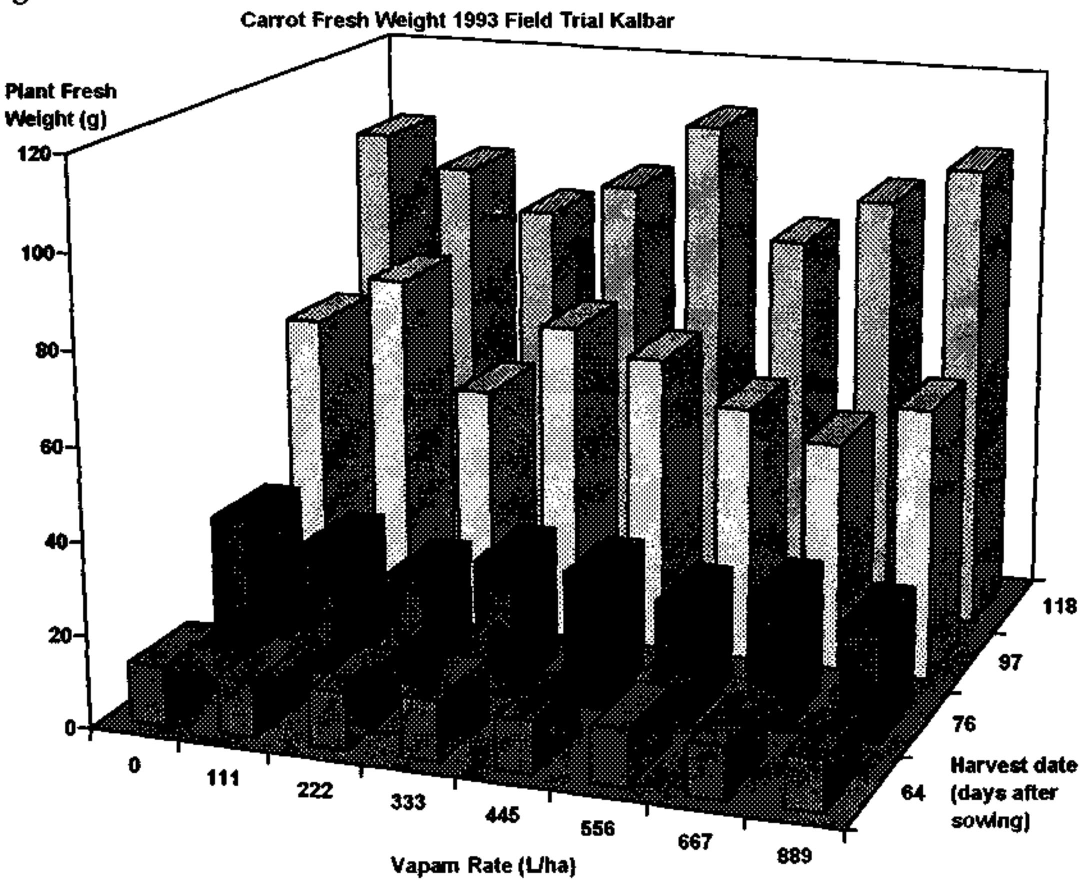


Figure 8

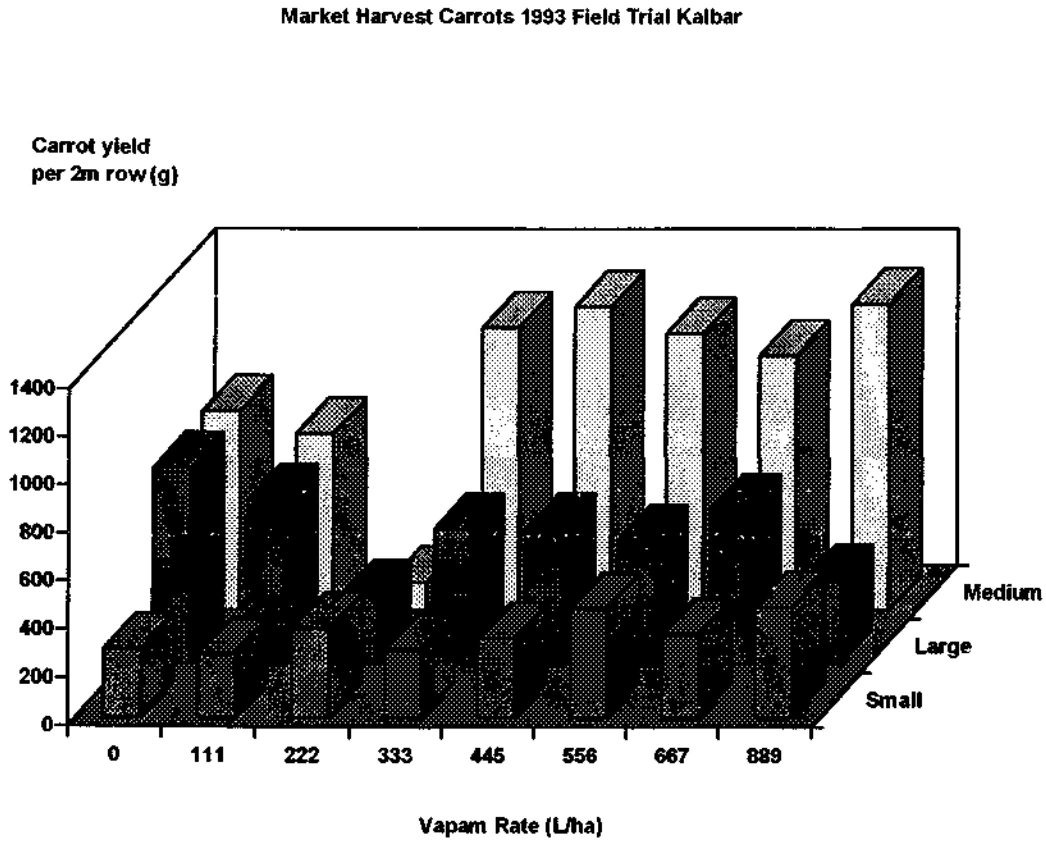


Figure 9

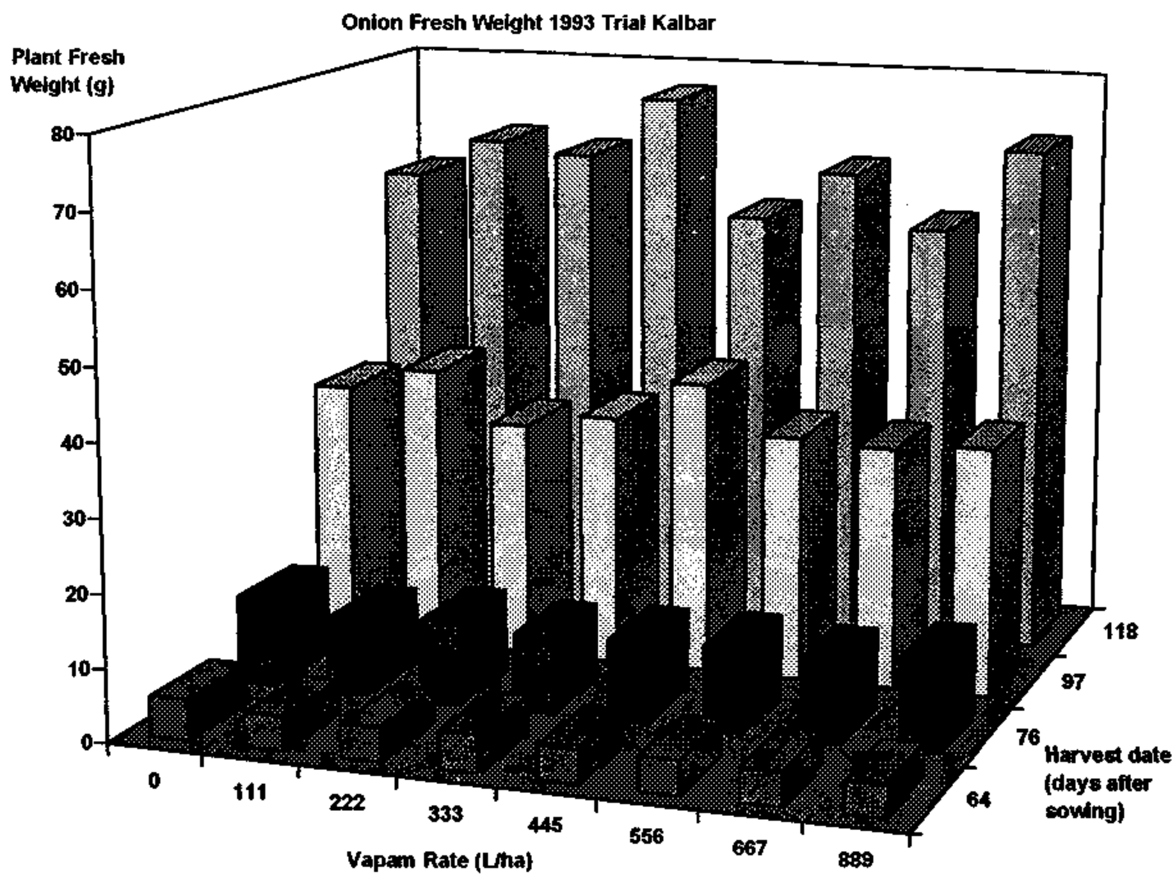


Figure 10

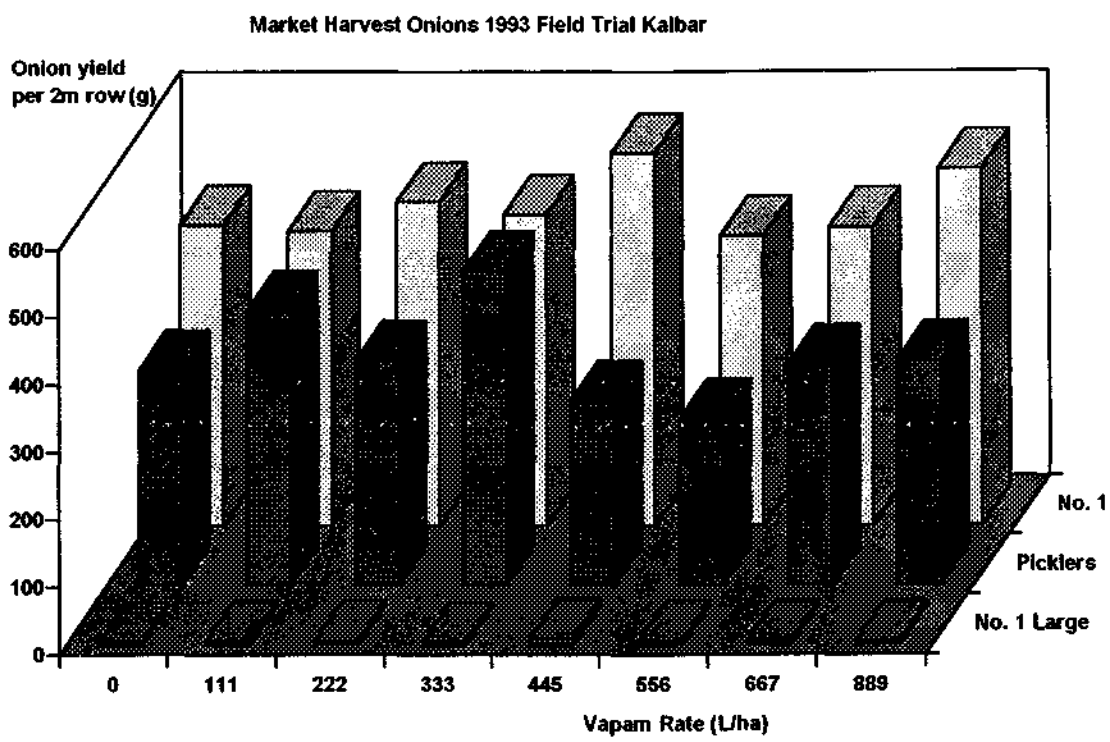
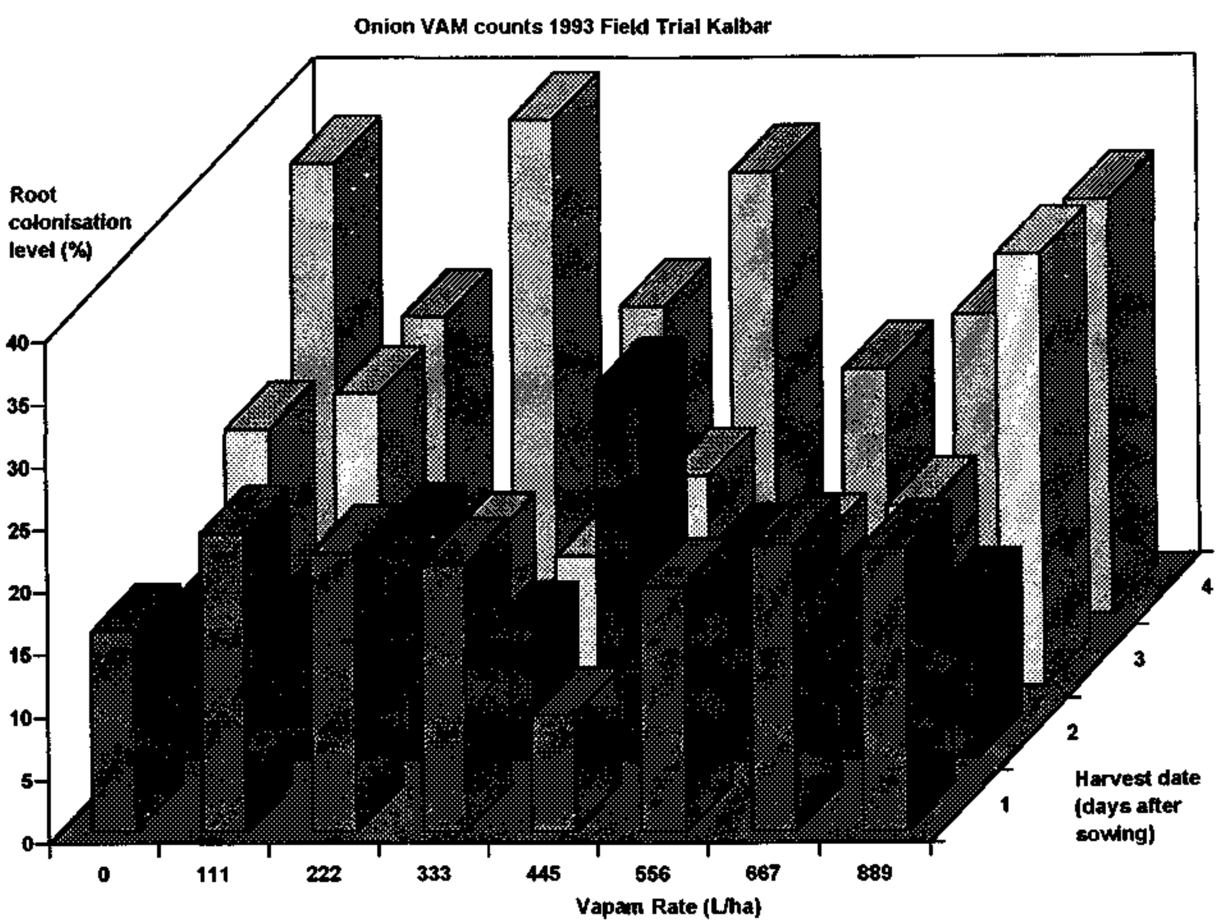


Figure 11



first field trial may have resulted in more effective action by the fumigant. Analysis of meteorlogicaldata from the nearest weather station (Amberley Air Base) indicated that ambient air temperature in was 3-4°C cooler when the first trial was fumigated than when the second site was treated. Use of metam sodium under cold conditions (< 5°C) can lead to residual phytotoxicity problems.

The failure of the fumigation treatments to influence crop productivity in the 1993 clearly demonstrated the role that VAM plays in the growth of both carrots and onions in soils of moderate fertility. In this trial, VAM levels were found to be uniform across all treatments reflecting the uniform crop performance indicators across the same treatments. In the first trial (1992) VAM activity as a function of fumigation also clearly reflected crop performance.

2.2 Influence of cropping sequence on onion growth

Introduction

Management strategies such as crop rotation and fallows are included in a farming system in an attempt to reduce disease levels and to maintain or enhance the soil structure. The type of crop grown can have a significant effect on soil micro-organisms such as VAM which can affect the growth of subsequent crops. Onions, sorghum, lettuce and many grasses are known to be dependent on VAM, whereas the VAM-dependence of heavy vegetable crops such as potatoes and pumpkin, although thought to be moderate, is less clear. Brassicas, such as broccoli not only grow independently of VAM, but are known to release glucosinolates from their roots. In the soil, the glucosinolates decompose, form chemicals which are believed to act as "natural" fumigants, similar to chemicals such as metam sodium, which may reduce the beneficial VAM population.

Research plots from two long-term experiments investigating the effect of different crop rotations on soil management and structure (Table 3) at the QDPI, Gatton Research Station, provided the opportunity to investigate the effects of cropping sequence on subsequent onion growth. These rotations reflect similar management practices to those used in onion production in the high-P soils of the Lockyer Valley. Our interest was the influence of alternate crops on the population of vesicular-arbuscular mycorrhizae (VAM) on subsequent onion crops. As broccoli is a major winter vegetable crop in the Lockyer Valley, we took the opportunity to study the effect of a range of crop sequences (some of which included broccoli) on the subsequent growth of onions.

Table 3 Source of soil samples used to assess the influence of cropping sequence on VAM colonisation of onion roots.

Broccoli rotation		*Management rotation*	
BS	broccoli-sorghum	**SBa**	sorghum-barley
BB	broccoli-broccoli	**PBa**	pumpkin-barley
BLS	broccoli-lettuce-sorghum	**WBa**	weedy fallow
		CBa	chemical fallow

Materials and Methods

Soil samples collected from each of these cropping sequences (April 16th, 1994, Table 3) were air-dried then sieved to remove undecomposed plant material. The soil was mixed with pasteurised sand (1:1, v/v) to aid drainage, and packed into 10 cm plastic pots. The pots were sown with onions (Yates hybrid Gladiator), then thinned to two plants per pot. The pots were watered automatically in the glasshouse.

Total onion fresh weights were determined by combining the fresh weights of onion roots and shoots after 12 weeks growth. Samples of the roots were stained and examined microscopically to determine the extent of VAM colonisation in the roots.

Results

There were significant differences in onion plant growth between crop rotation treatments (Figure 12). The lowest plant weights were produced in soils with fallow treatments (WBa & CBa) or with Broccoli as the immediate prior crop (BB). Crop rotations ending with either sorghum (BS & BLS) or barley (SBa & PBa) produced better growth. Onion plant growth performance was largely reflected by VAM activity (colonisation levels) on the root systems (Figure 13). The chemical fallow treatment (CBa) resulted in negligible VAM activity.

Discussion

The inclusion of sorghum in rotations leads to increased levels of VAM in soils as it is a good host and can be used as a nursery crop in VAM depleted soils. The reductions in VAM activity (and onion growth) in the fallow treatments clearly demonstrated the need for plant host (crop cover) to be maintained in fields to prevent VAM decline. The same situation in field crops results in a syndrome known as long fallow disorder. Broccoli is not a host for VAM. Repeated cropping with broccoli leads to reduced VAM activity which mimics a fallow situation. VAM dependent crops such as onions should not directly follow a broccoli (or any other brassica) crop. An intermediate crop with a good VAM host (sorghum or another cereal) will result in a restoration of VAM populations. Pumpkins do utilise VAM, however the patchy nature of their root systems in a field would not be conducive to building up VAM levels. This may explain the poor performance after the pumkin - barley rotation.

The relatively good performance of onions after the chemical fallow treatment suggested that the P levels in the soil were sufficiently high enough for growth to occur in absence of VAM. The differences observed in the relatively high-P soils of the Lockyer Valley would be expected to be magnified in onion crops grown in lower-P soils of the Western Downs region of Queensland.

2.3 Speedling Trial - Influence of VAM on Transplanted Onions in Treated Soils

Introduction

A wide range of vegetable crops grown in the Lockyer Valley are planted using advanced seedling (speedling transplants). With a great deal of interest being shown locally in the use of soil fumigants (particularly metam sodium), a field trial was established to investigate whether VAM could be effectively returned to the soil using inoculated speedlings in soils where depletion had occurred. Onions are sensitive to VAM depletion, and though not normally grown as transplants were

Figure 12

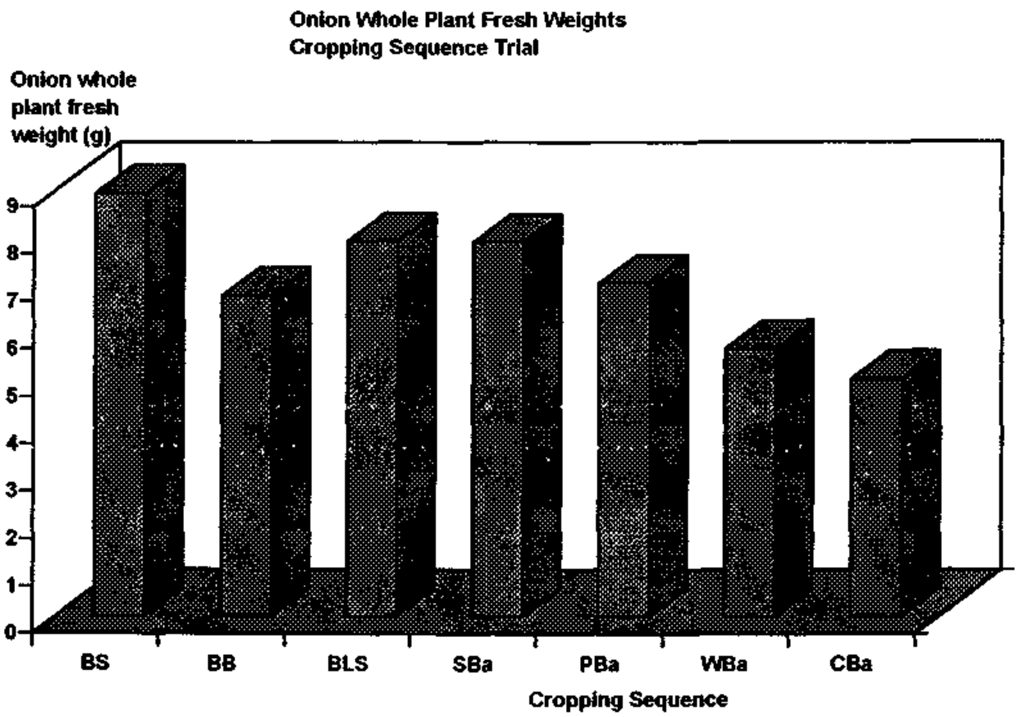
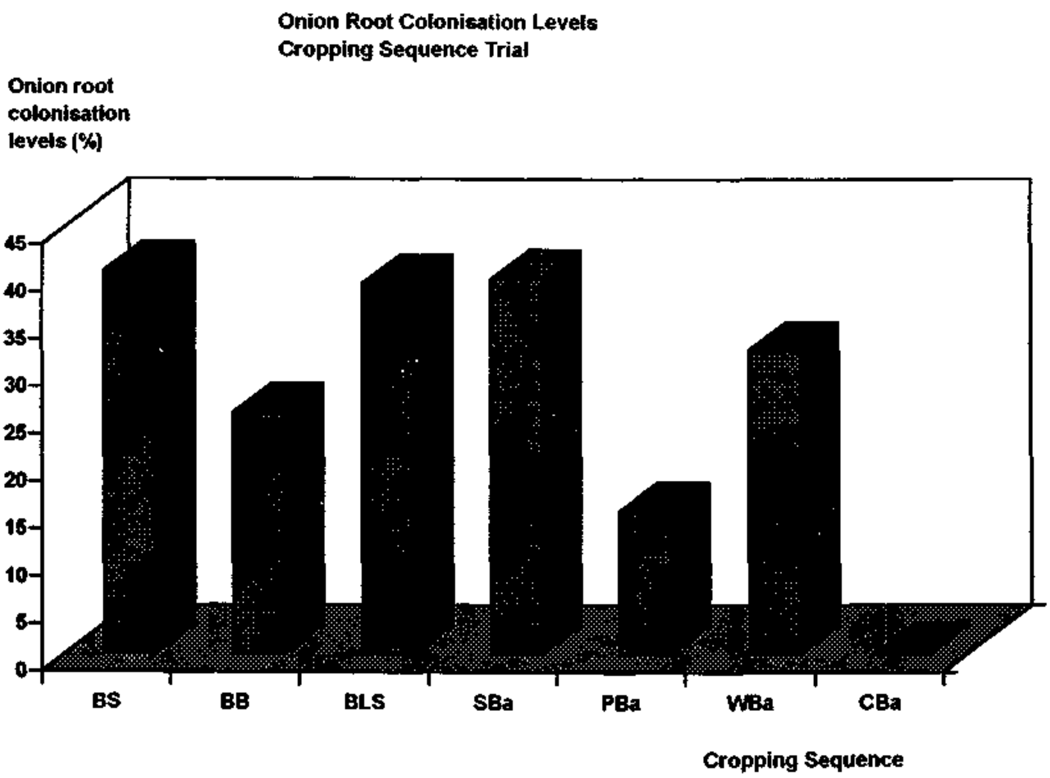


Figure 13



selected to establish the effectiveness of this process. A second objective was to gauge the sensitivity of this crop to VAM depletion in the Lockyer Valley soils.

Materials and Methods

Onions (*Allium cepa* cv. Early Lockyer White) were sown by a commercial nursery into 212 cell polystyrene seedling trays containing either 1.5% (w/v) mycorrhizal inoculum (VAM plus) or no VAM (VAM minus). Mycorrhizal inoculum was provided by Jason Olsen (QDPI Bundaberg) and comprised of *Glomus mosseae*, plus two other species (probably including *G. intraradices/ G. intraradix*). The seedlings were grown for six weeks at the University of Queensland (Gatton College) nursery.

The trial site was located at the QDPI, Gatton Research Station. The soil type was an alluvial plains soil (Lawes black earth) with high to v. high phosphorus (0.13 - 0.17% total P, > 100 mm.g.$^{-1}$ extractable P. The trial design was a randomised block with split plots (plot length 2.5 m). Five soil treatments (Table 4) included fumigation with metam sodium (Vapam) by irrigation at recommended and twice recommended rates (19/3/1994) and drenching with benomyl (Benlate) at standard and almost four times standard rates (30/3/1994).

Table 4 Soil treatments applied

Treatment	Application Rate	
	g.a.i./m^2	l/ha
metam sodium (R)	14.1	45
metam sodium (E)	28.2	90
benomyl (R)	0.9	--
benomyl (E)	3.5	--
control	0	--

(R = recommended and E = experimental rates of application)

Onion seedlings were transplanted (8/4/94) into 3 single rows within the plots at 50 mm spacings. The plots were split in half with random assignment of VAM treatments (+ or - inoculum).

Assessment

The first assessment of the trial was conducted when the crop was midway to maturity. Each plot was sampled by removing 10 plants from a transect allocated at random along the entire sub-plot. The plants were assessed for total and shoot and root fresh weight, shoot dry weight, and leaf number. Roots were collected for staining and assessment of VAM colonisation.

At maturity (17 weeks after transplanting), 2 m transects from each plot were harvested. The plants were assessed for factors such as leaf weight (fresh & dry), and graded using the Queensland standards before assessing bulb weight per class.

Results

In the un-inoculated treatments (VAM-) mean plant weights at the mid-trial harvest were greater in all plots treated either with Vapam or Benomyl (Figure 14). The results clearly showed that both chemicals improved plant growth to this stage. In the inoculated (VAM+) treatments, growth was not improved significantly by Vapam or Benomyl greatly when compared to the control treatment.

At the final harvest the yield of onions in all three grades (Picklers, No.1 and No. 1 Large) were essentially similar across all treatments indicating that the growth differences seen between treatments at the mid trial harvest had not carried through to crop maturity (Figure 15).

Discussion

In this trial, neither the soil treatment with Vapam and benomyl nor the addition of VAM inoculum to the system made any difference to the final yield of the crop in the absence of any recognised disease load. Although there were indications of VAM suppression by the chemicals used in this trial, the onions demonstrated their ability to recover from any setback. These results give a clear indication that onion growth and final yields are not likely to be adversely affected by the use of metam sodium if used within the recommended range in the fertile black soils of the Lockyer Valley. In soils where the residual P levels are lower, the use of inoculated transplants could prove useful where soil treatment leads to VAM population reduction.

3 GENERAL DISCUSSION

3.1 Extension / Adoption by Industry

A major outcome of this research has been the recognition that soil fumigation with metam sodium is a process which is far more complicated than using a gaseous compound like methyl bromide. In particular, the success of this process is extremely sensitive to factors such as soil temperature and soil moisture content. So much so that fumigation with metam sodium often result in variable performance levels.

Another finding is that in some situations, fumigation with metam sodium can lead to reduction in crop performance and that this is due to reduction of the activity of VAM in the soil. Furthermore, such damage can be caused by levels of metam sodium well within the range recommended by cemical companies and that the rates used by some growers (farmers rates) can lead to reduced crop performance and yield reductions.

The results from the major field trials at Kalbar (1992 & 1993) have been openly discussed with the farmer co-operator and have allowed him to reduce his rates application of metam sodium to a level which minimises crop damage. This information will be disseminated more widely through the publication a more detailed article through the QDPI in the near future. It is hoped that this information will be of use to those growers interested in moving across to metam sodium as methyl bromide is phased out of use in horticultural crop production.

3.2 Directions for Future Research

The variable performance of metam sodium as a soil fumigant needs to be adressed. A clearer understanding of the influence of factors such as soil type, soil temperature, soil moisture level and methods of application and incorporation are needed as this chemical is accepted as a

Figure 14

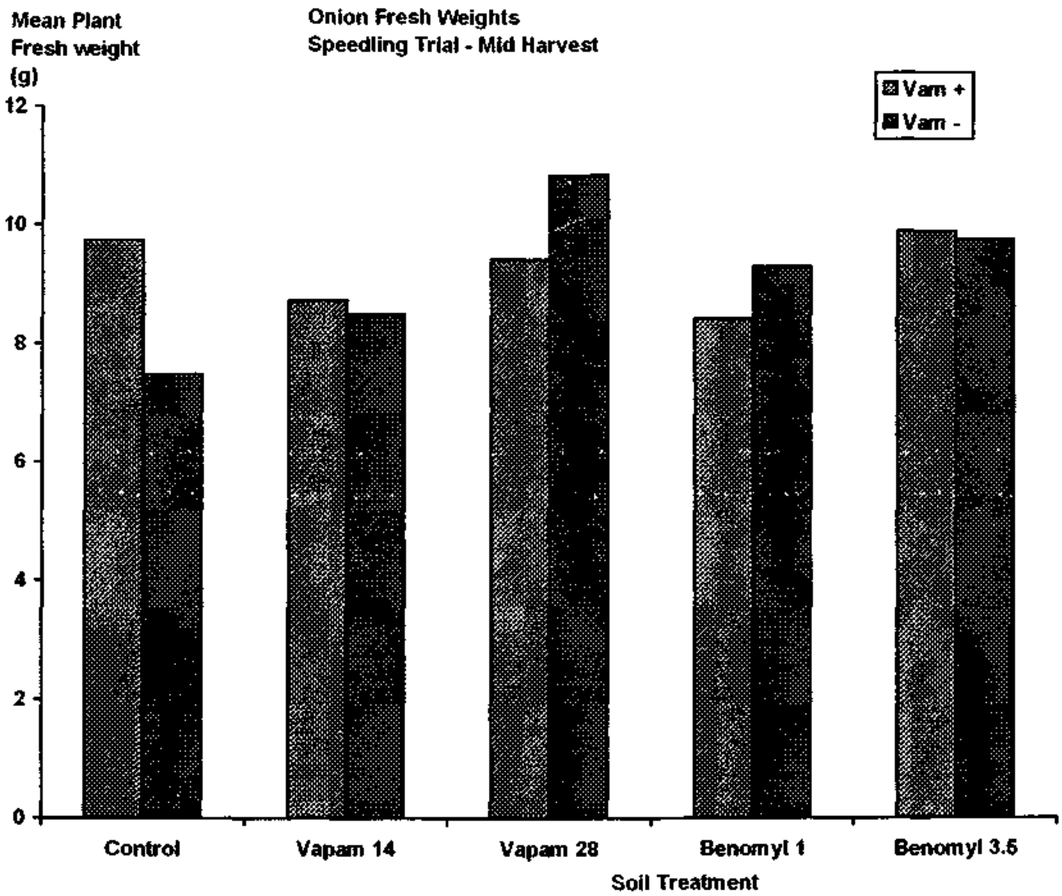
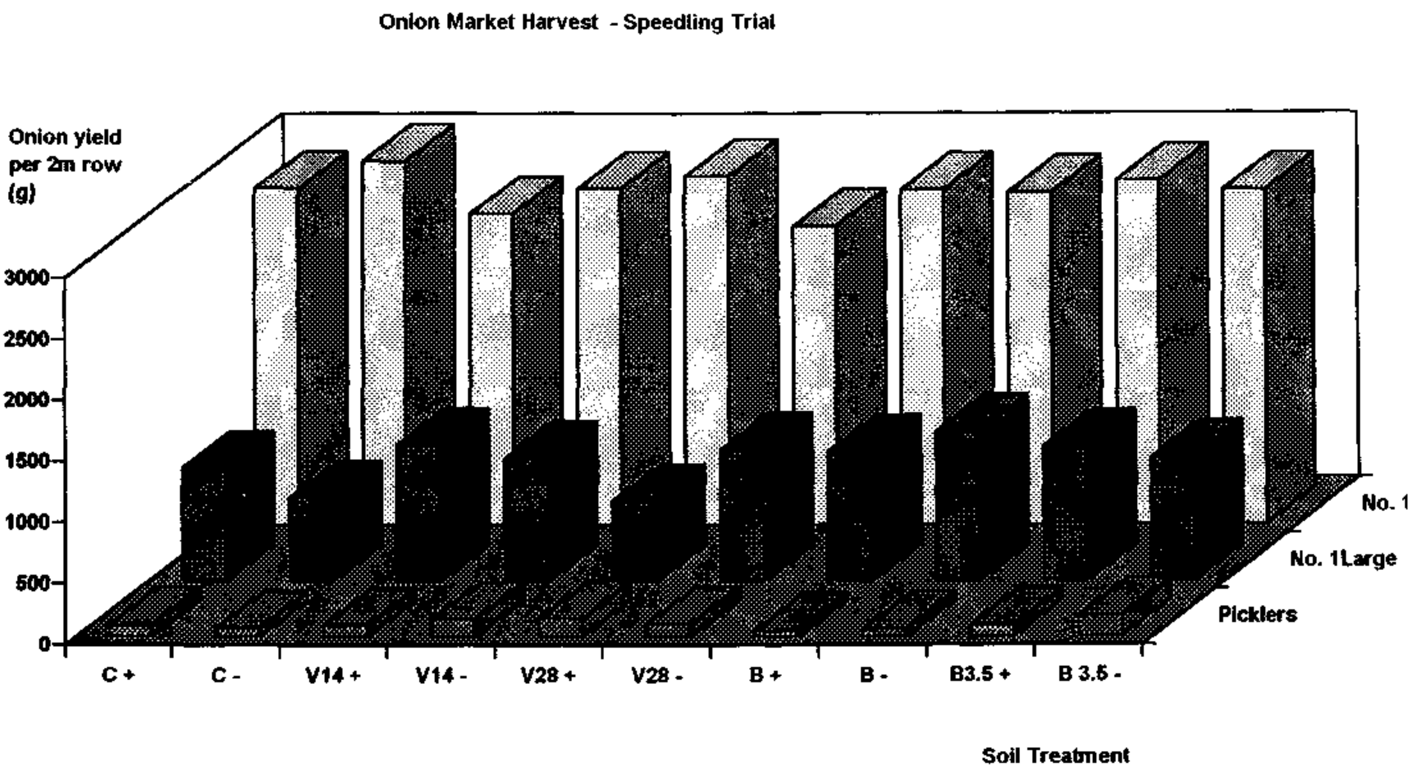


Figure 15



replacement for methyl bromide in the horticultural industry. At present many growers are aware of metam sodium but are usure about the technical details relevant to its application and have little understanding of its limitations.

Additional work is required to fine tune the rates of application for various cropping situations. In particular where crops are VAM dependent and soil P-levels are low, the rate of metam sodium application may be critical to crop establishment. The hazards of using metam sodium under conditions of low soil temperatures (<5°C) should be made clear to growers.

3.3 Financial / Commercial Benefits

A direct financial benefit to the growers as a result of this work will be a cost saving by reducing fumigation rates to a level where crop damage is reduced while maintaining crop quality parameters.

4 ACKNOWLEDGEMENTS

The Queensland Fruit and Vegetable Growers and Horticultural Research and Development Corporation are gratefully acknowledged for their financial support of this project.

The cooperation of Mr Craig Nielsen who provided field sites, labour, seed, equipment, technical expertise, fumigant and management input for the 1992 and 1993 field trials is acknowldeged.

The support from technical staff at the Univerity of Queensland Gatton College and QDPI Gatton Research Station is also recognised.

5 PUBLICATIONS ARISING FROM THIS PROJECT

A range of publications have arisen from this work. These are listed below and are also presented as appendices. Ms Eskdale will submit her Ph.D. thesis based on this work in 1996. It is anticipated that further publications will arise from this work in the form of journal articles and conference papers.

Appendix 1 "Heavy fumigation renders soil sterile: researcher". University (of Queensland) News, October 28, 1992, page 6.

Appendix 2 "Warning on soil fumigants". The Courier Mail, November 4, 1992, page 7.

Appendix 3 "Over-fumigation could result in damage to crops: research", Queensland Fruit & Vegetable News, November 19, 1992, page 5.

Appendix 4 "Metam-sodium could it increase cane production?", Australian Canegrower, January 24, 1994, page 19.

Appendix 5 Eskdale, J.W. ,Jackson, K.,J.,and Galea, V.J."Effect of fumigation on growth", Onions Australia, Vol 11, November 1994, pages 27-28.

Appendix 6 Eskdale, J.W., Galea, V.J. and Jackson, K.,J."Onions - trials show fumigation and mycorrhizal inoculation have little impact on yield", Queensland Fruit & Vegetable News, October 1995, pages 16-17.

Appendix 7 Eskdale, J.W., Galea, V.J. and Jackson, K.,J."Cropping sequence influences growth", Onions Australia, Vol 12, November 1995, pages 10-11.

Appendix 8 Eskdale, J.W., Galea, V.J. and Jackson, K.,J. Influence of Vapam® rates on VAM colonisation and productivity of field grown carrots and onions. (Oral presentation)) *Ninth Conference of the Australasian Plant Pathology Society, Hobart, July 1993.*

Appendix 9 Eskdale, J.W., Galea, V.J. and Jackson, K.,J. Dynamics of VAM in onions under different fumigation regimes. (Poster & Oral Presentation) *Ninth Conference of the Australasian Plant Pathology Society, Hobart, July 1993.*

Appendix 10 Eskdale, J.W., Galea, V.J. and Jackson, K.,J. Influence of Vapam® rates on VAM colonisation and productivity of field grown carrots and onions. (Poster) *Ninth North American Conference on Mycorrhizae, University of Guelph, Guelph, Ontario, Canada, August 1993.*

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7 APPENDICES

Appendix 1

"Heavy fumigation renders soil sterile: researcher". University (of Queensland) News, October 28, 1992, page 6.

Heavy fumigation renders soil sterile: researcher

VEGETABLE FARMERS over-fumigating their land against soil diseases and weeds could be ruining their future livelihood, according to a University of Queensland Gatton College researcher.

Dr Victor Galea said beneficial fungi known as vesicular arbuscular mycorrhizas (VAMs) which improved crop productivity were sensitive to certain agricultural chemicals, particularly soil fumigants such as methyl bromide and metham sodium.

"The fumigation process basically sterilises the soil, leaving it devoid of life," Dr Galea said.

"The use of soil fumigants is increasing in vegetable crop production in south-east Queensland with little understanding of the effect these processes have on beneficial organisms such as mycorrhizas."

Dr Galea said soil fumigation was a standard practice for growing carrots, but it was now being used by a few onion and potato growers to combat soil-borne diseases, particularly white rot of onions.

Dr Galea, a lecturer in plant pathology in the College's Plant Production Department and Dr Ken Jackson of the Queensland Department of Primary Industries (QDPI) at Gatton are investigating the role these beneficial fungi play in intensive vegetable production.

The project, funded under the University's Research Grants Scheme, has already demonstrated the need for VAMs in tomato, carrot and onion crops.

Dr Galea and Dr Jackson head a co-operative group for Mycorrhizal Studies in Horticultural Crops, which has developed from their mutual interests in this area.

Dr Galea said mycorrhizas (literally translated as fungus roots) were fungi that existed in a symbiotic relationship with plants. The root systems of plants were colonised by these fungi which increased the ability of the plant component to take up water and some soil nutrients such as zinc and phosphorus.

This process was due largely to the increased effective soil volume explored by the fungal component, resulting in more efficient use of the nutrients present in the soil around a plant's root system.

"Mycorrhizas are normally present in soils and it is probable that at least 80 percent of plant species (including crop plants) form mycorrhizal associations," Dr Galea said.

"However, the degree to which individual crop species rely upon these associations has yet to be determined in many cases. Some vegetables such as onions and carrots are known to be heavily dependent upon mycorrhizas for their nutrition, whereas other crops such as tomatoes may be indifferent to this process."

Dr Galea said management practices which encouraged soil mycorrhizas could, in most cases, lead to increased crop productivity.

He said no work had previously been done to investigate the role which mycorrhizas played in vegetable production in Queensland.

Experience by other researchers had shown the importance of mycorrhizas for the growth of field crops such as wheat, sunflower and linseed in the black earths of the Darling Downs region.

"Their value is best demonstrated by the reduced crop performance which results where mycorrhizas are absent from soils due to long fallow periods or through unfavourable crop rotations with non-host crops, including members of the *Brassica* family (such as canola, cabbages and broccoli).

Dr Galea said vegetable crops grown without VAM often expressed symptoms of nutrient deficiency. This led farmers to apply more fertilizers in the form of phosphorus and micronutrient foliage sprays. This process had been shown to actually inhibit the activity of VAM, further exacerbating the problem.

In laboratory and field studies in the Lockyer Valley and at Kalbar, Dr Galea, Dr Jackson, PhD student Ms Jocelyn Eskdale and fourth-year bachelor of applied science (horticultural technology) student at Gatton College Ms Linda Toovey are investigating the importance of VAMs in horticultural crop production.

"Linda's glasshouse studies found onions were extremely dependent upon mycorrhiza under conditions simulating low phosphorus levels — such plants grown without VAM practically failed to grow at all. However, those plants grown in the presence of VAM showed a 15-fold increase in dry mass," Dr Galea said.

"Jocelyn's studies have also demonstrated that soil fumigants are capable of reducing the presence of VAMs in carrot production sites. These reduced VAM levels can be linked directly to poor growth performance and nutrient deficiencies."

Dr Galea said the researchers were not seeking to denigrate the use of soil fumigants as they were important tools for the management of certain soil-borne diseases. However, the group believed that closer examination of their use under field conditions would lead to more efficient and effective procedures for their use. In essence, the research was targeting the management of plant disease while maintaining the presence of beneficial organisms, he said.

Dr Galea measures growth in an onion plant in the VAM study.

Overweight people sought to 'lighten up'

HUNDREDS OF overweight people will take part in a University of Queensland "Lighten Up" weight-control program.

The $50,000, 12-month project, headed by Dr Phil Harvey of the University's Nutrition Program, is being funded by the Queensland Health Department.

Dr Harvey said the object was to develop a public health intervention program somewhere between a media campaign of promoting fruit, vegetables and low-fat food and a clinical situation where overweight people went to dietitians or doctors for advice.

Existing popular weight-loss centres tended to be expensive and mainly concentrated on food, he said.

"We are really trying to get away from the idea that a person has to diet to lose weight. We are talking about serious long-term changes of behaviour that would include exercise, choosing lower-fat alternatives and recognising what can cause eating problems — stress, for example," he said.

Dr Harvey said the program would be implemented in three to six communities in one health region. All State regional health authorities had been invited to express an interest.

Participants in the eight-week programs would have to be at least 10 percent overweight and would weigh-in at registration when weight goals would be set.

There would be further health screenings mid-program, at program completion and at a follow-up, and all participants would be able to attend six different lifestyle workshops.

For further information, or to take part in the program, contact Dr Harvey (telephone 365 5404).

Appendix 2

"Warning on soil fumigants". The Courier Mail, November 4, 1992, page 7.

WEDNESDAY, NOVEMBER 4, 1992

THE COURIER-MAIL —

Some dangerous insecticides to be phased out

By CHERYL CRITCHLEY
in Canberra

POTENTIALLY dangerous insecticides widely used under Australian homes should be phased out in the next two years, health experts said yesterday.

Following a three-year inquiry the National Health and Medical Research Council said the chemicals took many years to break down and caused tumors in mice.

They include cyclodiene insecticides like aldrin, dieldrin, chlordane and heptachlor, developed in the 1940s and 1950s for houses and farms.

Chlordane and heptachlor are widely used to prevent termites under houses and although no longer produced aldrin and dieldrin are still stockpiled.

Their effect has been debated widely over the years amid claims of serious long-term health problems after prolonged exposure.

The council found long-term effects on people were unknown but warned parents not to let children crawl under houses.

Under its plan, expected to be adopted by the NHMRC's Canberra session today for referral to the Australian Agricultural and Veterinary Council:

- Aldrin and diedrin, which were used in agriculture, would be not be registered for any use once current stocks expire.
- Chlordane and heptachlor would only be permitted for termite use in new houses and buildings. Both would be phased out after two years if suitable alternatives were found.

In its draft report earlier this year the NHMRC had recommended a five-year phase-out but reduced it due to the likely development of alternative methods.

Chlordane and heptachlor imports are controlled and they can only be used by professional pest controllers under strict conditions.

NHMRC spokesman Professor Geoffrey Duggin said the moves would strengthen already tight restrictions on the chemicals' use.

Prof Duggin said tests showed cyclodienes stayed in soil for up to 30 years.

He said they were known to kill wildlife, although the effect on humans was less clear.

The only evidence was from several people who had drunk the chemicals and suffered fits and comas, but no long-term damage.

"It has been revealed that cyclodienes ... cause tumors in mice, they build up in the human body and we are not sure yet of the long-term effects," he said.

"The higher the concentration in the air, the higher the concentration in you."

Record sugar output

QUEENSLAND sugar production this season has been tipped to reach a record 3.8 million tonnes, a massive one million tonne recovery from the 1991 crop disaster.

The Queensland Sugar Corporation chairman, Robert Sutton, said yesterday crop yields had continued to increase dramatically as the harvest season progressed.

With crushing now more than 80 percent completed, the cane crop estimate has been lifted to 27 million tonnes.

Last season drought slashed the crop to a low 19.8 million tonnes which made 2.8 million tonnes of sugar.

Warning on soil fumigant

FARMERS who over-fumiga ed land against soil diseas risked losing entire crops researcher said yesterday.

Dr Victor Galea of the Un versity of Queensland's Gatto College said that chemic such as methyl bromide a metham sodium could ha fungi which were beneficial t crops.

Dr Galea said the probl for farmers was to apply right amount to the right s type to achieve the best result

He said the chemicals we being mis-used widely mai because more research w needed on application rates f different conditions.

The chemical was meant kill soil diseases and weeds.

"The fumigation proc basically sterilises the soi leaving it devoid of life," D Galea said.

"The use of soil fumigant increasing in vegetable cr production in south-eas Queensland with little unde standing of the effect th processes have on benefic organisms such as mycorr zas."

Dr Galea said soil fumigatin was a standard practice growing carrots but its use w growing quickly as potato a onion growers tried to comb soil-borne diseases.

He said no harm came consumers through the che cals' incorrect application.

Methyl bromide was a ozone destroying chemi which would probably phased out within four to f years.

"Over-fumigation could result in damage to crops: research", Queensland Fruit & Vegetable News, November 19, 1992, page 5.

CHEMICAL SAFETY

Over-fumigation could result in damage to crops: research

Vegetable farmers who over-fumigate their land to control soil diseases and weeds could be "killing their crops with kindness", according to research being carried out by the University of Queensland, Gatton College.

Lecturer in Plant Pathology Dr Victor Galea said soil fumigants such as methyl bromide and metham-sodium destroyed populations of highly beneficial soil-borne fungi, known as vesicular arbuscular mycorrhizas (VAMs).

Dr Galea said the VAMs often existed in a symbiotic, or mutually beneficial, relationship with plants, and improved the crop's productivity.

Dr Galea, Department of Primary Industries (DPI), horticulturist Dr Ken Jackson and PhD student Jocelyn Eskdale are conducting field and laboratory studies in the Lockyer and Fassifern Valleys to investigate the importance of the VAMs in intensive horticultural production.

He said their research indicated that VAMs could be essential for normal plant growth, but were sensitive to concentrated doses of some soil fumigants.

"The root systems of plants are colonised by these fungi, which increase the ability of the plant to take and use up water and some nutrients such as zinc and phosphorous," he said.

"This process results in a more efficient use of the nutrients present in the soil around a plant's root system.

"Mycorrhizas are normally present in soils and it is probable that at least 80 per cent of plants species, including crop plants, form mycorrhizal associations.

"Farm management practices which encourage soil mycorrhizas can, in most cases, lead to increased crop productivity.

"Their value is best demonstrated by the reduced crop performance which results when mycorrhizas are absent from soils.

"Vegetable crops grown without mycorrhizas often express symptoms of nutrient deficiency."

"Some vegetable crops such as onions and carrots are known to be heavily dependant upon mycorrhizas for their nutrition.

"Our glasshouse studies found onions were extremely dependent on mycorrhizas under conditions simulating low phosphorous levels.

"The plants grown in mycorrhiza-deficient soil practically failed to grow at all.

"However, those plants grown in the presence of mycorrhizas showed a 15 per cent increase in dry mass."

Dr Galea said he was not suggesting farmers should avoid using soil fumigants as they were important tools for the management of a range of soil-borne diseases.

Soil fumigation is now a standard practice in carrot production and its use by onion and potato growers is on the increase.

Dr Victor Galea compares the difference in growth between plants grown in phosphorous-poor soil - two with and two without the benefit of mycorrhizas.

Dr Galea said his research was aimed at determining the optimum level of fumigation, which would destroy a sufficient level of diseases, but not the beneficial soil organisms like VAMs.

"The results of fumigants in terms of crop production are sometimes variable - we want to iron the bugs out of the system," Dr Galea said.

"What we've been finding is that fumigants have been going on at too heavy a rate, killing the VAMs, resulting in severe nutrient disorders and poor growth in crops and so the crop nutrition goes all over the place.

"Closer examination of the use of fumigants under field conditions will lead to more efficient and effective procedures for their use.

"In essence, our re search was targeting the management of plant disease while maintaining the presence of beneficial organisms."

Dr Galea said his group expected to have more exact data on their research when the experimental crops were harvested in about a month.

Their research is currently unfunded, but supported by Fassifern carrot grower Craig Neilsen, who is supplying the land, the crops and the chemicals for the project.

Appendix 4

"Metam-sodium could it increase cane production?", Australian Canegrower, January 24, 1994, page 19.

Metam-sodium - could it increase cane production?

by BSES Media Services Officer Julie Lloyd

THE use of metam-sodium and its potential for increasing cane production were discussed during a recent two-day Bureau of Sugar Experiment Stations (BSES) workshop in Bundaberg.

Workshop participants, including BSES staff and other industry representatives, discussed the chemistry of the product and visited several Bundaberg trial sites.

Informative sessions during the two days were followed by group discussions. At the close, participants outlined opportunities for the sugar industry and possible approaches to a future metam-sodium review.

According to the organiser, BSES Research Associate, Dr Bruce Williams, the sugar industry needed to address the possible benefits that metam-sodium could provide the sugar industry.

"For instance, metam-sodium or vapam, has been successfully used in other high-value agricultural crops as a soil fumigant, and could help to reduce yield decline in cane," Dr Williams said.

"It is currently used extensively in Californian and Israeli horticulture. In Australia, metam-sodium is used in Western Australia and Victoria and around the Fassifern and Lockyer Valley areas."

During the workshop, guest speakers from the vegetable and sugar industries and Gatton College talked about metam-sodium's uses in Queensland.

Dr Vic Galea from Gatton College, said metam-sodium could potentially replace methyl bromide. However, he said that accurate application was vital and more work was needed on correct application methods.

"To achieve successful and economic fumigation with metam-sodium in cane, techniques such as soil injection will need to be trialled," Dr Galea said.

Carrot grower, Craig Neilson talked during the workshop about how metam-sodium had improved his business. He said he had not looked back since he adopted metam-sodium.

"It has meant that I am able to supply my market with a consistent number of quality carrots," Mr Neilson said.

"Previously my crop was inconsistent and a lot of carrots were discarded as waste.

"It has taken several years to fine-tune application of the product. Today I use certain techniques, such as application to soil beds followed by irrigation, and this has made metam-sodium more efficient and economical for me to use."

At the close of the workshop, the group agreed there was a need to carefully evaluate current trials and to try new approaches in future work.

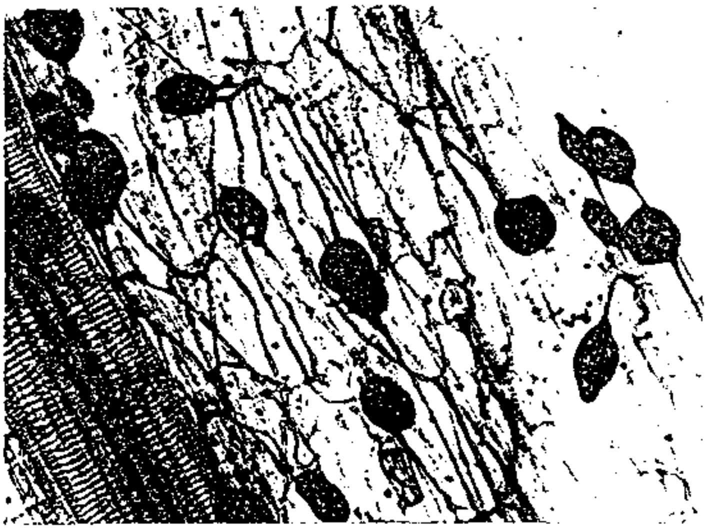
These include studies of how soil responds to metam-sodium and what the product will control in cane. Many other areas will also be addressed in these trials to determine the future of metam-sodium in the sugar industry.

Dr Vic Galea and Craig Neilson are pictured at the metam-sodium workshop.

Appendix 5

Eskdale, J.W., Jackson, K.,J and Galea, V.J..“Effect of fumigation on growth”, Onions Australia, Vol 11, November 1994, pages 27-28.

Effect of fumigation on growth



Microscopic view of onion root infected with the beneficial mycorrhizal fungus. a = edge of onion root; b = central vascular tissue of onion root; c = cell wall within onion root; d = hyphal network of the fungus within root cells; e = cluster of vesicles (storage organs) of the fungus. In the field the hyphae of the fungus extend from the root surface into the surrounding soil aiding plant uptake of nutrients.

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This project was funded by the QFVG and HRDC.

Fumigants such as metham sodium (Vapam®, Metham®) are being used increasingly as a management tool in intensive agriculture. The fumigant is applied as a pre-plant treatment to control soil-borne pests of a wide range of horticultural crops including germinating weed seeds, nematodes and fungal diseases such as pythium, phytophthora and rhizoctonia.

Metham sodium is believed to offer some control of white rot in onions. As a general biocide it also controls the growth of beneficial soil organisms including a group of fungi called mycorrhizas.

Mycorrhizas form beneficial associations with host plant roots. This virtually sees the formation of a fungus root capable of exploring and exploiting more of the soil volume and improving nutrient (particularly phosphorus and zinc) and water uptake. However the mycorrhizas must receive some nutrition from the host plant in the form of carbohydrates from photosynthesis. Onions are highly dependent on mycorrhizal associations for nutrition in some low to medium phosphorus (P) soils. This study was designed to investigate the effect of fumigation on onion production and mycorrhizal development since some farmers are already using metham sodium as a management tool in onion production.

In March 1994, polystyrene seedling trays were filled with sterilised nursery potting mixture. Half the potting mix was inoculated with a mixture of mycorrhizal inoculum from Jason Olsen (QDPI, Bundaberg). The seedling trays were sown with Early Lockyer White and grown in the nursery at the University of Queensland (Gatton College) for six weeks.

Meanwhile, an experimental site at QDPI Gatton Research Station (alluvial soils with high P levels) was fumigated with two rates each of metham sodium, V14 (14 g.ai./m2) and V28 (28 g.ai./m2), and benomyl, B1 (1 g.ai./m2) and B3.5 (3.5 g.ai./m2). Both chemicals are selective against mycorrhizas occurring naturally in the soil. The chemicals were mixed into the soil by rotary hoe, prior to the site being irrigated. A watered plot was included as a control. In mid-April, an army of volunteers transplanted approximately 14000 onion seedlings into the 10m x 3 row experimental plots. The plots were divided in half lengthwise, and each half was planted with either a mycorrhizal (+) or non-mycorrhizal (-) onions.

Various growth characteristics were measured during a mid-season and final harvest. The mid-season total fresh weight harvest (biomass) indicated that there were significant yield variations [illegible]

Jocelyn Eskdale (left) discusses maturity of Early Lockyer White with Ken Jackson (right) in split plots on a fumigation treatment on Gatton's Research Station.

yields observed at this harvest were in the high rates of metham sodium and benomyl. Most biomass values for treated plots were higher than those for the untreated, non-mycorrhizal control. The increased plant growth seen in fumigated, non-mycorrhizal treatments at mid-season is referred to as increased growth response (IGR). It has been suggested that IGR is due to either the reduction of unrecognised root pests, increased nutrient release (usually nitrogen from dead organisms), or due to reaction to the chemical itself. This increased growth at fumigation is often observed by producers.

The final harvest (Fig.2) indicates that there were no significant yield differences in any plot regardless of chemical treatment or inoculation. At harvest the benefit of mycorrhizal inoculation has equalised the yields. In lower P soils, the effect of mycorrhiza would have been expected to be far superior than non-mycorrhizal plants. It appears that mycorrhizas are less important at these rates of fumigation in maintaining yields on the high P soils used for onion production in the Lockyer Valley in Queensland. However, there is still a major concern about the imbalance caused to the microbial population following fumigation with biocides such as metham sodium, when the pathogen organism populations recover.

FIGURE 1: Effect of various rates of metham sodium (V14 and V28) and benomyl (B1 and B3.5) on mid-season growth of onions at Gatton Research Station.

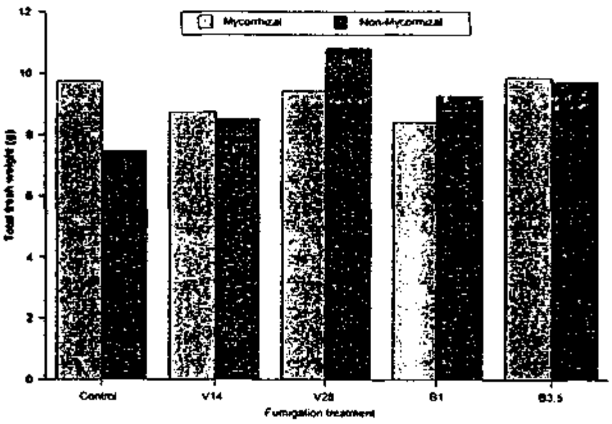
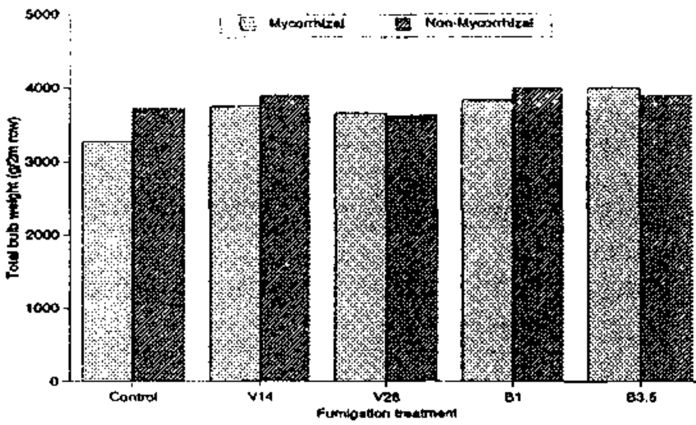


FIGURE 2: Effect of various rates of metham sodium (V14 and V28) and benomyl (B1 and B3.5) on total bulb weight of onions at Gatton Research Station.



Appendix 6

Eskdale, J.W., Galea, V.J. and Jackson, K.,J. "Onions - trials show fumigation and mycorrhizal inoculation have little impact on yield", Queensland Fruit & Vegetable News, October 1995, pages 16-17.

ONIONS

Trials show fumigation and mycorrhizal inoculation have little impact on yield

by JW Eskdale and VJ Galea (Dept of Plant Production, The University of Queensland - Gatton College) and KJ Jackson (DPI Gatton Research Station)

Jocelyn Eskdale and Ken Jackson inspecting Early Lockyer White plots after harvest. The adjacent Golden Brown plots were harvested at a later date.

Soil fumigation with metham sodium (Vapam, Metham) is gaining popularity as a management tool in intensive vegetable production.

In carrots, it is used to control germinating weed seeds, nematodes and soil borne diseases such as pythium and phytophthora.

In the Lockyer Valley, some onion growers have also used metham sodium in an attempt to control white rot.

However, there are two potential problems with fumigation.

First, previous experiments with carrots and onions in strip fumigated soil at Kalbar (65 km south-west of Brisbane) suggested that high rates of metham sodium retarded plant growth during the growing season.

Second, as a general fumigant like metham sodium reduces soil populations of both disease organisms such as white rot (partial reduction) and beneficial organisms such as mycorrhizae (severe reduction), there is concern that fumigation may reduce plant growth and yields.

Vesicular-arbuscular mycorrhizae (known as VAM) are fungi that develop a close relationship with, and effectively form an extension of the plant roots.

They help in plant nutrition and water absorption and thus subsequent yield.

VAM are believed to increase the efficiency of the root zone allowing increased absorption of nutrients, particularly phosphorus and zinc.

Both carrots and onions are known to be highly dependent on VAM in soils with low to medium levels of these nutrients.

The aim of the research, conducted at the Gatton Research Station in 1994, was to investigate the effect of fumigation on plant growth, VAM activity and yield of onions.

The site was free from the disease, white rot.

TECHNIQUES

As VAM cannot be inoculated onto onion seed, onion seedlings of the Early Lockyer White variety were grown in potting mix in polystyrene flats (212 cell) containing 'plus' or 'nil' VAM.

After six weeks, the seedlings were transplanted into pre-treated beds.

The beds were treated with three treatments:-

- recommended rates of metham sodium (Treatment No V14)
- standard rates of benomyl (Treatment No B1)
- double recommended rates of metham sodium (Treatment No V28)
- higher rates of benomyl (Treatment No B3.5).

Benomyl was included because it specifically controls VAM. A control treatment (no fungicide or fumigant) was included.

The total fresh plant weight was measured mid-season just prior to bulbing and the onions harvested at maturity and graded to determine marketable yield.

Roots of some plants were microscopically examined mid-season to determine the extent of VAM colonisation.

RESULTS

At the mid-season measurement, all fumigation and chemical treatments in the VAM "nil" plots significantly increased the total fresh weight of plants compared to the control. (Figure 1).

In the control plots, VAM 'pus' also

significantly improved plant size over VAM 'nil'.

However, comparison of the chemically treated plots showed a trend for the VAM 'nil' plots to exhibit equal or greater yields than those for VAM 'plus' plots.

This may be explained by the fact that VAM utilise energy from their host plants which decrease plant size in the VAM 'plus' plots.

In addition, chemicals such as metham sodium control many micro-organisms in the soil resulting in reduced competition for available nutrients and increased plant size.

Generally, plant size from the experimental (highest) rates of chemical application were greater than those from the recommended rates.

However, at harvest, the total yield of onions and weight of grade sizes No 1 and No 1 Large were not significantly better than the control, with or without VAM (see Figure 2).

These observations were confirmed by the results from a parallel experiment where the onion variety golden Brown was sown directly into VAM inoculated furrows following the same chemical treatments.

The mid-season microscopic examination of the roots showed that the VAM colonisation was significantly reduced but not eliminated by all chemical treatments.

The greatest reduction occurred in the experimental (highest) rate of benomyl (Treatment No B3.5).

There was no relationship between the amount of VAM colonising the roots and the mid-crop plant size in this trial.

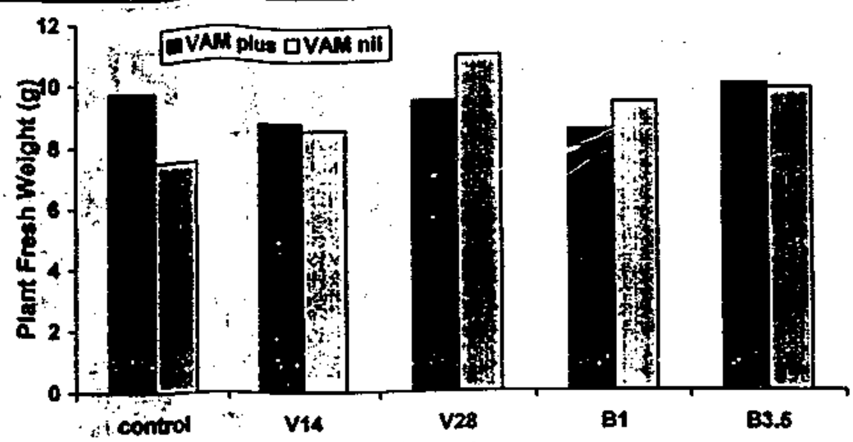


Figure 1

Effect of various rates of metham sodium (V14 and V28) and benomyl (B1 and B3.5) on plant fresh weight just prior to bulbing at Gatton Research Station.

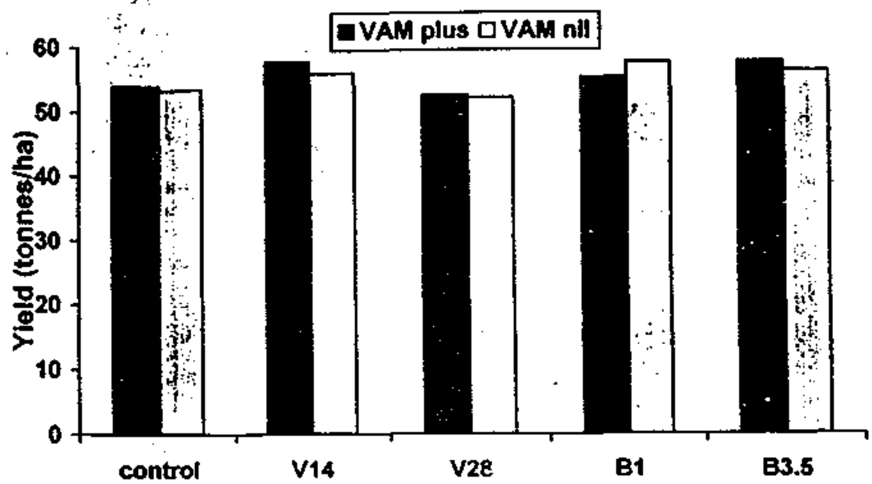


Figure 2

Effect of various rates of metham sodium (V14 and V28) and benomyl (B1 and B3.5) on onion yield at Gatton Research Station.

CONCLUSIONS

In this trial, fumigation and the benomyl treatment had no impact on harvest yield, in the absence of any recognised disease load.

The mid-crop plant size differences between VAM 'plus; and VAM 'nil' were not translated to harvest yield at maturity, regardless of chemical application.

Also, higher levels of chemical application did not improve yield.

These results show that, although VAM were suppressed by the fumigation rates used in this experiment, onion yields were not adversely affected.

This indicates that onion growth and yield are not likely to be affected by the use of fumigants if recommended rates are applied on the fertile soils of the Lockyer Valley.

While these rates of application showed no apparent adverse effects on the VAM population, they may have affected yield in lower P soils in onion growing districts such as the eastern Darling Downs and are likely to cause an imbalance in the total microbial balance of the soil.

It will require further studies to investigate the effect of fumigation with metham sodium on the eventual re-population of both beneficial and pathogenic micro-organisms in these soils.

It can be concluded that high levels of VAM are not required for successful onion production in the Lockyer Valley and that no advantage was achieved by soil fumigation, in the absence of any recognised disease load.

(Jocelyn Eskdale is a Ph.D. student at The University of Queensland (Gatton College). Victor Galea is a Senior Lecturer at The University of Queensland (Gatton College). Ken Jackson is a Senior Agronomist at DPI's Gatton Research Station. *This project was funded by QFVG and HRDC.)*

Appendix 7

Eskdale, J.W., Galea, V.J. and Jackson, K.,J. "Cropping sequence influences growth", Onions Australia, Vol 12, November 1995, pages 10-11.

Cropping Sequence Influences Growth

[illegible] is with the Department of Plant Production at the University of Queensland (Gatton College). Vic Galea and Ke[illegible] Jackson are with the Queensland Department of Primary Industries, located at the Gatton Research Station.

Management strategies such as crop rotation and fallows are included in a farming system in an attempt to reduce disease levels and to maintain or enhance the soil structure.

However, the removal of certain crop species from the soil influences the population of beneficial micro-organisms called vesicular-arbuscular mycorrhizae (VAM). Mycorrhizae are beneficial fungi that colonise the roots of dependent plants, and contribute to the uptake of nutrients like phosphorus and zinc by extending their hyphae into the adjacent soil. Onions, sorghum, lettuce and many grasses are known to be dependent on VAM. The VAM-dependence of heavy vegetable crops such as potatoes and pumpkin, although thought to be moderate, is less clear, while the brassicas, such as broccoli are not dependent on VAM.

The decline of VAM populations due to the removal of suitable host plants during a fallow period has been called "long fallow disorder". Some crops such as broccoli, release glucosinolates from their roots. In the soil the glucosinolates decompose, form chemicals which are believed to act as "natural" fumigants, similar to chemicals such as metam sodium, which may reduce the beneficial VAM population. The inclusion of these crops which are non-VAM dependent in a rotation may influence the VAM population similar to long periods of fallow. As broccoli is a major winter vegetable crop in the Lockyer Valley, we took the opportunity to study the effect of a range of crop sequences (some of which included broccoli) on the subsequent growth of onions.

Selection of Cropping Sequences

Research plots from two long-term experiments investigating the effect of different crop rotations on soil management and structure (Table 1) at the Gatton Research Station, provided the opportunity to investigate the effects of cropping sequence on subsequent onion growth. These rotations reflect similar management practices to those used in onion production in the high-P soils of the Lockyer Valley, south east Queensland. Our interest was the influence of alternate crops on the population of vesicular-arbuscular mycorrhizae (VAM) on subsequent onion crops.

Broccoli rotation		*Management rotation*	
BS	broccoli-sorghum	SBa	sorghum-barley
BB	broccoli-broccoli	PBa	pumpkin-barley
BLS	broccoli-lettuce-sorghum	WBa	weedy fallow
		CBa	chemical fallow

***Table 1** Source of soil samples used to assess the influence of cropping sequence on VA[illegible] colonisation of onion roots.*

Soil samples taken from each of these cropping sequences were air-dried then sieved to remove undecomposed plant material. The soil was mixed with sterilised sand (1:1, v/v) to aid drainage, and packed into 10 cm plastic pots. The pots were sown with onions (Yates hybrid Gladiator), then thinned to two plants per pot. The pots were watered automatically in the glasshouse.

Total onion fresh weights were determined by combining the fresh weights of onion roots and shoots after 12 weeks. Samples of the roots wer[illegible] stained and examined microscopicall[illegible] to determine the extent of VA[illegible] colonisation in the roots (Figure 1).

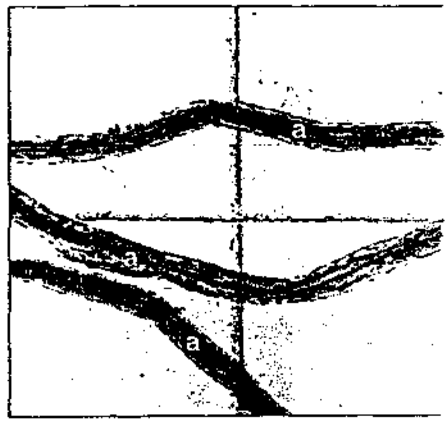


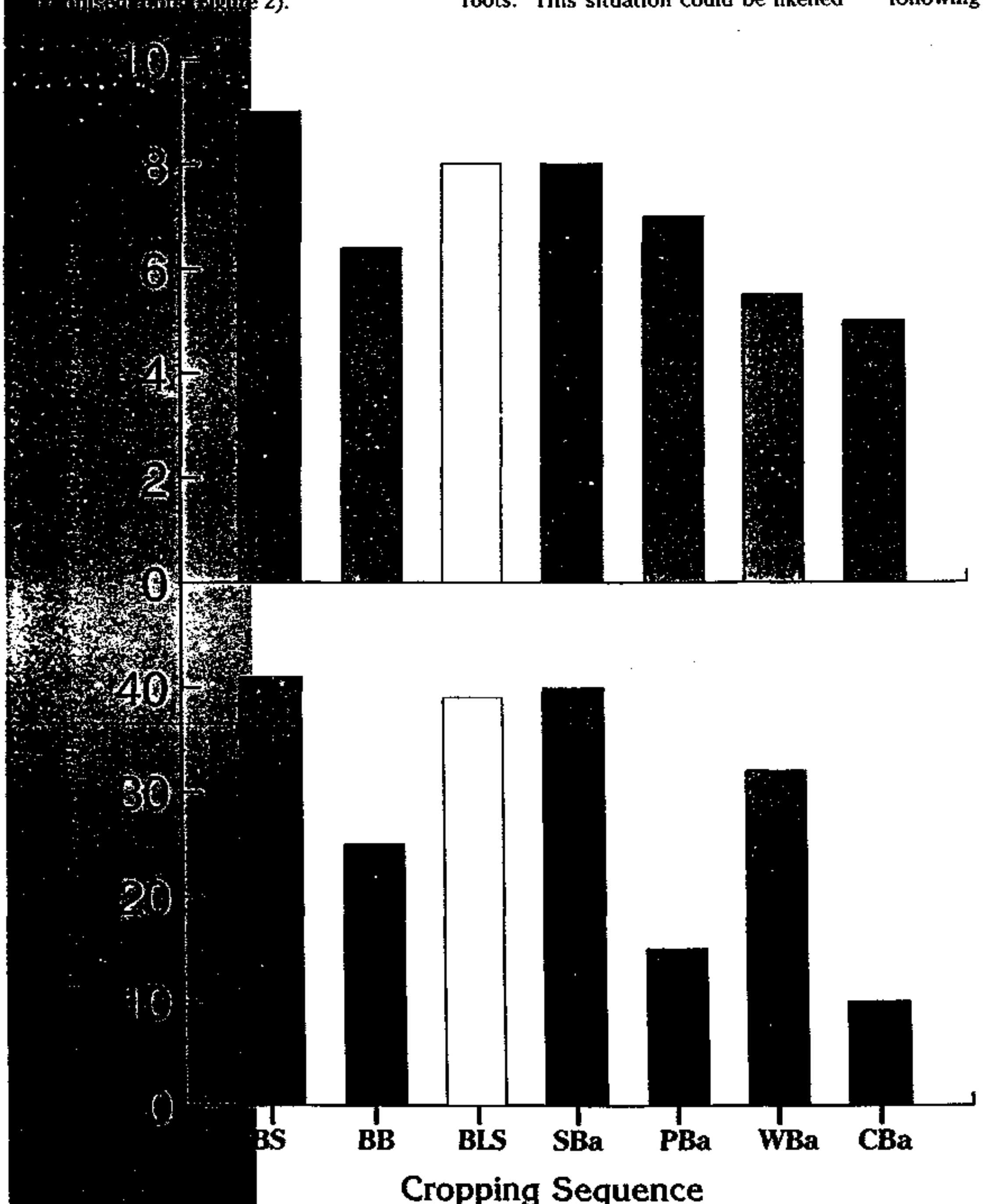
***Figure 1:** Microscopic view of three colonised (a) and one non-colonised (b) onion root segment[illegible]*

Influence of Cropping Sequences on Onion Growth

The inclusion of sorghum in th[illegible] rotation (BS, BLS, SBa) was positivel[illegible] correlated with increased total fres[illegible] weight and proportion of VA[illegible] colonised onion roots. The total onio[illegible] fresh weight was reduced followin[illegible] either chemical (CBa) or weedy fallo[illegible] (WBa), while the chemical fallow an[illegible] pumpkin (PBa) rotations reduced th[illegible] proportion of VAM colonising onio[illegible] roots. Onions following the continuo[illegible]

...(BS) rotation showed a ...reduction in both total fresh weight and proportion of VAM colonised roots (Figure 2).

The sparse nature of pumpkin roots means that a major portion of the soil under the crop is not inhabited by roots. This situation could be likened to that of a fallow. The proportion of VAM in onion roots following the pumpkin rotation reflected those following the chemical fallow. However, total onion plant weight following the pumpkin rotation was only slightly lower than the sorghum rotations. It is possible that the pumpkin rotation provided the break in the disease cycle, but the sampling method diluted the VAM population because of difficulty in collecting soil from around the root base of the pumpkin plants.



...opping sequence on total fresh weight (g/plant) and VAM colonisation (%) in the roots of ...ions. Rotations: BS = broccoli/ sorghum; BB = broccoli/ broccoli; BLS = broccoli/ lettuce/ ... / barley; PBa = pumpkin/ barley; WBa = weedy fallow/ barley; CBa = chemical fallow/ ...

Conclusion

The inclusion of VAM-nursery crops (one that rebuilds the VAM population), such as a summer cereal, in the rotations following fallows or brassica crop should enhance the subsequent yield of VAM dependent crops such as onions.

The principles employed in this investigation should be repeated on a larger scale including a broader range of crops and soil types. The differences observed in the relatively high-P soils of the Lockyer Valley would be expected to be magnified in onion crops grown in lower-P soils of the Western Downs region of Queensland.

Appendix 8

Eskdale, J.W., Galea, V.J. and Jackson, K.,J. Influence of Vapam® rates on VAM colonisation and productivity of field grown carrots and onions. (Oral presentation)) *Ninth Conference of the Australasian Plant Pathology Society, Hobart, July 1993.*

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20. Influence of metham sodium rates on VAM colonisation and productivity of field grown carrots and onions.

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A field experiment site on a carrot farm in south east Queensland was fumigated to investigate the interactions between the rate of application of metham sodium (Vapam®), vesicular arbuscular mycorrhizae (VAM) and its relation to production of VAM dependent vegetables. A complete randomised block design of 3 replicates x 8 treatments (0–38 g.ai./m^2) was used. Two VAM dependent vegetable crops (carrots and onions) were sown into the strip fumigated raised plots. Observation of crop growth and destructive sub-plot samples were collected at two-weekly intervals. Samples were assessed for total, shoot and root fresh and dry weights. The fine roots were harvested for microscopic examination. The rate of metham sodium applied significantly affected crop growth and final yield.

Key Words: VAM; fumigation; management; vegetables

Appendix 9

Eskdale, J.W., Galea, V.J. and Jackson, K.,J. Dynamics of VAM in onions under different fumigation regimes. (Poster & Oral Presentation) *Ninth Conference of the Australasian Plant Pathology Society, Hobart, July 1993.*

50. Dynamics of VAM in onions under different fumigation regimes.

Jocelyn W. Eskdale[1], Victor, J. Galea[1] and Ken J. Jackson[2]

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Field onions were sown in raised beds following fumigation by metham sodium (Vapam®) at 0, 14 and 28 g.ai./m2. Six destructive sub-plot samples were collected at two-weekly intervals from each plot. The presence of VAM and other microorganisms in stained root samples was assessed microscopically. Three x 1 metre rows were harvested from each plot for market assessment at the end of the season. The proportion of each market rating was determined. The relationship between VAM presence and market yield will be discussed.

Key Words: VAM; fumigation; production; onions.

Appendix 10

Eskdale, J.W., Galea, V.J. and Jackson, K.,J. Influence of Vapam® rates on VAM colonisation and productivity of field grown carrots and onions. (Poster) *Ninth North American Conference on Mycorrhizae, University of Guelph, Guelph, Ontario, Canada, August 1993.*

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ESKDALE, JOCELYN W.[1], VICTOR J. GALEA[1] AND KEN J. JACKSON[2].
[1]Department of Plant Production, University of Queensland, Gatton College, Lawes, Queensland, 4343 Australia.
[2]Queensland Department of Primary Industries, P.O. Box 241, Gatton, Queensland, 4343 Australia. Influence of Vapam® colonization and productivity of field grown carrots and onions.

A field experiment site on a carrot farm in south east Queensland, Australia was fumigated to investigate the interactions between the rate of application of metham sodium (Vapam®), vesicular arbuscular mycorrhizae (VAM) and its relation to production of VAM dependent vegetables. A complete randomised block design of 3 replicates x 8 treatments (0-890 l/ha) was used. Observation of crop growth and destructive sub-plot samples were collected at two-weekly intervals. Samples were assessed for total, shoot and root fresh and dry weights. The fine roots were harvested for microscopic examination. The two crops were harvested for market assessment at the end of the season. The plants were sorted by market ratings and the proportions of each determined. The rate of metham sodium applied significantly affected crop growth and final yield. There were also significant interactions between the application rate and VAM colonisation in onion roots.