Guide to

Brassica Biofumigant Cover Crops

Managing soilborne diseases in vegetable production systems

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Summary

Brassica biofumigant cover crops are increasingly considered in vegetable crop rotations as part of an integrated disease management strategy. The following summarises the key points on biofumigant cover cropping for vegetable rotations.

Biofumigant performance

- **Different biofumigant varieties** have different levels of activity against different soilborne pathogens
- **Biofumigant cover crops,** while traditionally a winter crop, can be grown year round in the Lockyer Valley and Bundaberg regions
- **Performance characteristics** of biofumigant cover crops vary with growing season
- **Growing season and days** to maturity are shorter in summer months providing an option for short cover cropping windows over summer
- **Biofumigants produce less biomass** in summer months, but trends are for higher levels of glucosinolates for the majority of varieties during summer months
- **Activity against soilborne pathogens** also varies with the time of year biofumigants are grown, with trends for most varieties to be more active against soilborne pathogens when grown during warmer months
- **Biofumigants** have shown some activity against beneficial soil microorganisms in the laboratory such as *Trichoderma* sp. and *Bacillus amyloliquefaciens* (Serenade® Prime)
- There are **regional differences** in biofumigation activity, pest and disease pressures and how they respond to different growing seasons.

Biofumigant management

- **Biofumigants require monitoring** for pests and diseases
- **Management practices** such as irrigation impact on the amount of plant biomass and activity against soilborne pathogens
- There are **multiple options for incorporation** of biofumigant cover crops that are as effective.

Introduction

Cover crops, also referred to as green manure crops, are crops planted as a break between commercial crops. They are grown and incorporated back into the soil rather than for products that are removed off-farm like commercial crops. Cover crops provide numerous farming system benefits including:

- Increasing soil organic matter
- Fixing nitrogen in the soil (legumes)
- Increasing soil microbial activity
- Improving soil structure such as improved water infiltration and soil porosity
- Scavenging nutrients that have leached beyond the root zone of commercial crops
- Preventing soil loss via water and wind erosion
- **Biofumigants are a unique type of cover crop that produce compounds with suppression effects on soilborne pathogens, pests and weeds.**

There are a variety of commercially available cover crop types, such as legumes and grasses. Brassica cover crops and specifically biofumigants are the focus of this guide. In addition to the normal benefits of cover cropping, biofumigants offer an alternative to synthetic fumigants for soilborne disease management if they can be successfully incorporated into vegetable crop rotations.

Biofumigant cover cropping is incorporated into vegetable rotations with higher seed costs and the assumption that these crops will contribute to disease management. This publication contains information to assist growers in understanding how biofumigants work and managing them for optimum efficacy against soilborne diseases.

The information in this guide has been developed through a series of field trials to assess biofumigants as cover crop options in vegetable systems. The majority of this work was conducted in south-east Queensland, particularly targeting summer cover cropping windows, to minimise soil loss off farm during storm events, as well as the benefits to soil health and disease management. While brassicas, including biofumigants are considered to be a winter cropping option, this work covered multiple growing seasons to see how different growing conditions effected the performance of biofumigant cover crops. This will broaden options for when biofumigants can be successfully incorporated into crop rotations.

The field work has evaluated various commonly used biofumigant varieties for:

- Biofumigant activity against known soilborne pathogens
- Growing window (or days to incorporation) across seasons
- Biomass production across seasons
- Concentrations of biofumigant compounds (glucosinolates).

This information can then be used to select the biofumigant variety most appropriate for individual situations including disease spectrum and cover cropping window or season.

The known soilborne pathogens included in this work comprise: basal rot (*Sclerotium rolfsii*), Onion white rot (*Sclerotium cepivorum*), charcoal rot (*Macrophomina phaseolina*), white mould (*Sclerotinia sclerotiorum*), Rhizoctonia species and verticillium wilt (*Verticillium dahliae*).

This guide also discusses and presents data on a range of agronomic management practices of biofumigant cover crops including pest and diseases, nutrient uptake requirements, irrigation and incorporation methods.

Figure 1. *DAF staff assessing for biomass production in Bundaberg.*

Figure 2. *Lab lab cover crop in south-east Queensland.*

Figure 3. *A fallow field in south-east Queensland showing soil movement from rainfall.*

Biofumigant cover cropping

Biofumigation is the practice of growing specialised cover crops for suppression of soilborne pathogens, pests and weeds. The cover crop produces naturally occurring compounds that are toxic to many soilborne pathogens that impact on Australian vegetable crops.

Some soilborne diseases can survive for many years, even in the absence of a suitable host. The resting stages of some soilborne pathogens, can remain dormant until conditions are favourable, resulting in the development of symptoms on the plant. For some diseases like white rot (*Sclerotium cepivorum*) in onion, the pathogen can survive in the soil for 20 years or more.

The challenge from a disease management perspective is reducing disease inoculum in the soil, whilst maintaining or enriching soil health so that crops are able to become more resilient to soilborne pathogens. An integrated approach utilising biofumigant cover crops can be an effective tool in the management of soilborne diseases in horticultural production systems. This offers growers a solution that does not involve the use of synthetic pest control.

Brassica species, such as mustard, radish and rocket, have been shown to suppress soilborne diseases such as basal rot (*Sclerotium rolfsii*), Onion white rot (*Sclerotium cepivorum*), charcoal rot (*Macrophomina phaseolina*) and white mould (*Sclerotinia sclerotiorum*). They achieve this through processes resulting in the release of naturally occurring chemicals contained in plant tissue.

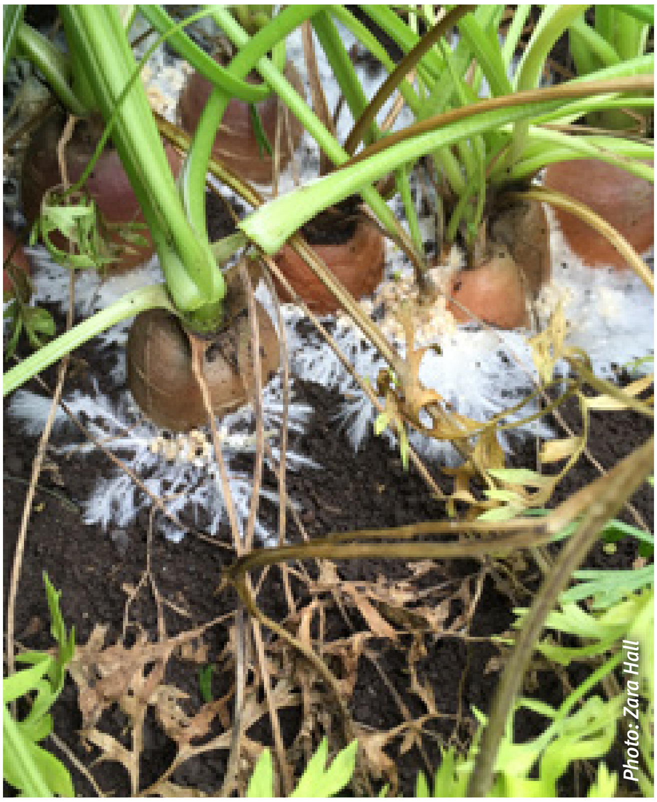


Figure 4. *Sclerotium rolfsii infected carrots.*

Figure 5. *Sclerotinia sclerotiorum in lettuce.*

Figure 6. *Sclerotinia minor in lettuce.*

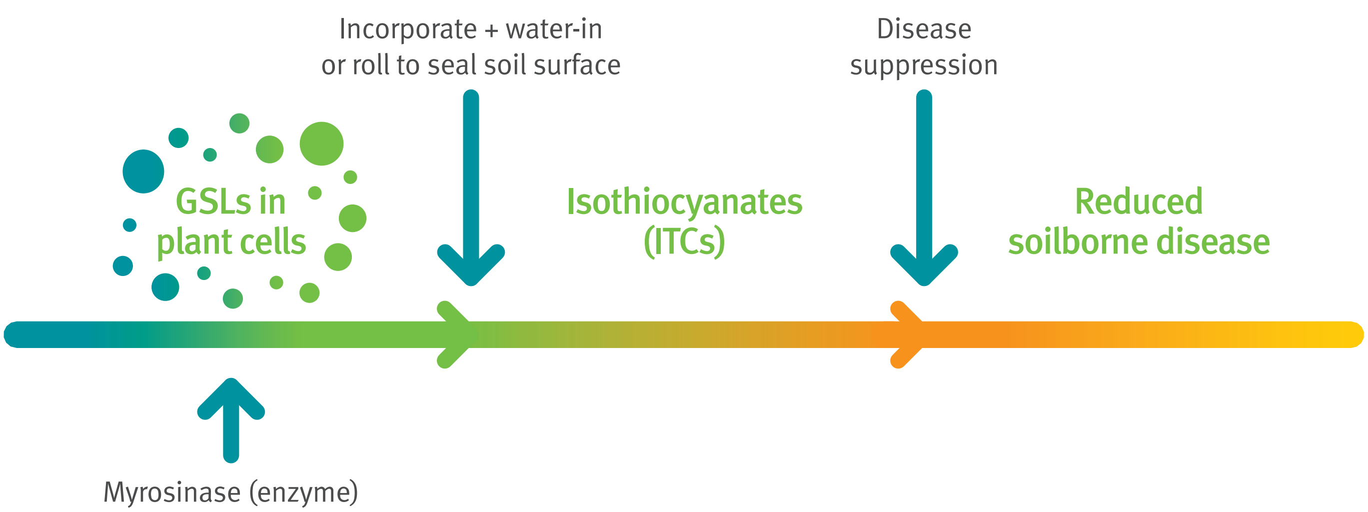
How biofumigation works

Brassicas naturally produce a group of chemicals known as glucosinolates (GSLs). The highest concentration of glucosinolates tends to occur at approximately 25% flowering, which is the recommended timing for incorporating biofumigants. Through the process of mulching and incorporation, glucosinolates are released from the plant cells. Once released from plant cells and with the addition of irrigation water, glucosinolates are converted by the enzyme myrosinase into isothiocyanates (ITCs), gases that are toxic to various soilborne pathogens and pests. Irrigation and/or rolling helps to seal the gas in the soil so that they are most effective in suppressing pathogens.

There are over 137 glucosinolate compounds commonly found in brassica plants. The concentration and type of GSLs will vary between varieties, as does the type of ITCs produced from the GSLs. The ITCs determine the biofumigants' toxicity to various soilborne pathogens and pests.

All biofumigant varieties have positive soil health benefits, but some may be better suited for a particular cropping program. This will depend on the soilborne disease being targeted as well as other considerations such as cropping window and agronomic management of the biofumigant.

Figure 7. *The biofumigation process in brassica plants.*



Biofumigant variety selection

There are many biofumigant varieties that are commercially available in Australia. These include oilseed radish, rocket and mustard varieties. New varieties are continuously being released by seed companies, as biofumigation is increasingly utilised and implemented as part of crop rotations.

Choosing the best variety for a particular cropping system will depend on various agronomic considerations, including compatibility with commercial cropping breaks and agronomic considerations such as soilborne pathogens or pests that require management. *Table 1* lists those varieties assessed in DAF trials.

The key considerations in choosing biofumigant varieties are:

- Soilborne pathogens to be managed
- Cover cropping window (time of year and length of time in the ground) – how much time do you have to grow a biofumigant cover crop.
- Agronomic management of the biofumigant crops
  - Pest and disease management
  - Irrigation requirements
  - Nutrition requirements
- Mulching and incorporation.

Figure 8. *Indian mustard biofumigant.*

Figure 9. *Nemat Rocket biofumigant.*

Figure 10. *Oilseed radish biofumigants Black Jack Radish (left), Terranova Radish (centre) and Tillage Radish (right).*

Table 1. *Common commercially available biofumigant varieties compared in DAF trials.*

Trade name	Variety	Species name
Biofum™	Doublet oilseed radish and Achilles white mustard mix	*Raphanus sativus* and *Sinapis alba mix*
Black Jack Radish™	Oil Radish	*Raphanus sativus*
Black Mustard	Black mustard	*Brassica nigra*
BQ Mulch®	Black mustard and Ethiopian mustard	*Brassica nigra* and *Brassica carinata*
Caliente™ including Caliente Rojo™	Indian mustard	*Brassica juncea*
Cappucchino™	Ethiopian mustard	*Brassica carinata*
FungiSol™	Ethiopian mustard and Terranova oilseed radish mix	*Brassica carinata* and *Raphanus sativus*
Mustclean™	Indian mustard	*Brassica juncea*
Nemat™	Rocket	*Eruca sativa*
Nemfix™	Indian mustard	*Brassica juncea*
Nemclear™	Fodder mustard	*Brassica napus*
Nemcon™	Fodder mustard	*Brassica napus*
NemSol™	Terranova oilseed radish and Nemat mix	*Raphanus sativus* and *Eruca sativa*
Terranova Radish™	Oilseed radish	*Raphanus sativus*
Tillage Radish®	Oilseed radish	*Raphanus sativus*
White Mustard	White mustard	*Sinapis alba*

Impact of varieties on disease suppression

The soilborne disease that requires management, and time of year available to plant a cover crop, will impact which variety is most suitable. The matrix (*Table 2*) is a tool designed to assist decision making about variety selection for disease management.

The table is based on key production breaks when a biofumigant cover crop is most likely to be included as part of a cropping system and the relative efficacy of biofumigant varieties against a range of soilborne diseases.

Table 2. *Matrix of biofumigant efficacy against known soilborne diseases.*

Varieties	Season	Biofum	Black Jack Radish	BQ Mulch	Caliente	Cappucchino	Fallow	Fungisol	Mustclean	Nemat	Nemclear	Nemcon	Nemfix	Nemsol	Terranova Radish	Tillage Radish
Sclerotium rolfsii (basal rot)	Summer	•	••	•	••	•	••	•	•••	•	•	•	•	ND	ND	•
	Autumn	•	ND	•	••	ND	•	ND	•	ND	•	•	•	ND	ND	•••
	Winter/Spring	•	••	•	•••	•	•	•	•••	•	ND	ND	••••	••	••	•
Sclerotinia sclerotiorum (white mould)	Summer	••••	••	••••	•••	••	••••	•••	•••	••••	•	••	••••	ND	ND	••••
	Autumn	•	ND	•	•	ND	•	ND	•	ND	•	•	•	ND	ND	•
	Winter/Spring	••	•	••	•	•	•	•••	•	••	ND	ND	•	••	••	••
Macrophomina phaseolina (charcoal rot)	Summer	•••	••	•••	••••	•	•••	•	••••	•••	•	••	•••	ND	ND	•••
	Autumn	•	ND	••	••	ND	••	ND	•	ND	•	•	•	ND	ND	•
	Winter/Spring	•••	••	•••	•••	••••	••	••••	•••	••••	ND	ND	•••	••	•••	••••

Legend: Percentage mortality

•	0–25
••	26–50
•••	51–75
••••	76–100
ND	No Data

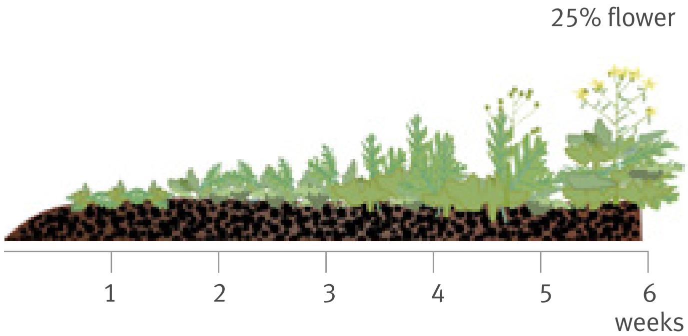
Days to incorporation

The days to incorporation were compared over multiple growing seasons and across two vegetable growing regions in Queensland: Lockyer Valley and Bundaberg. The days to incorporation varied between different varieties and growing seasons. Generally, biofumigants reached incorporation (or 25% flowering) faster and produced less biomass in summer compared to winter.

The planting window charts (*Tables 3 and 4*) are tools to assist in selecting a variety that will reach approximately 25% flowering at incorporation within a given planting window for cover cropping. The days to incorporation data includes spring-summer and autumn-winter planting windows.

Figure 11. *Graphic depicting biofumigant cover crop days to incorporation across different growing seasons in the **Lockyer Valley**.*

Summer



Winter

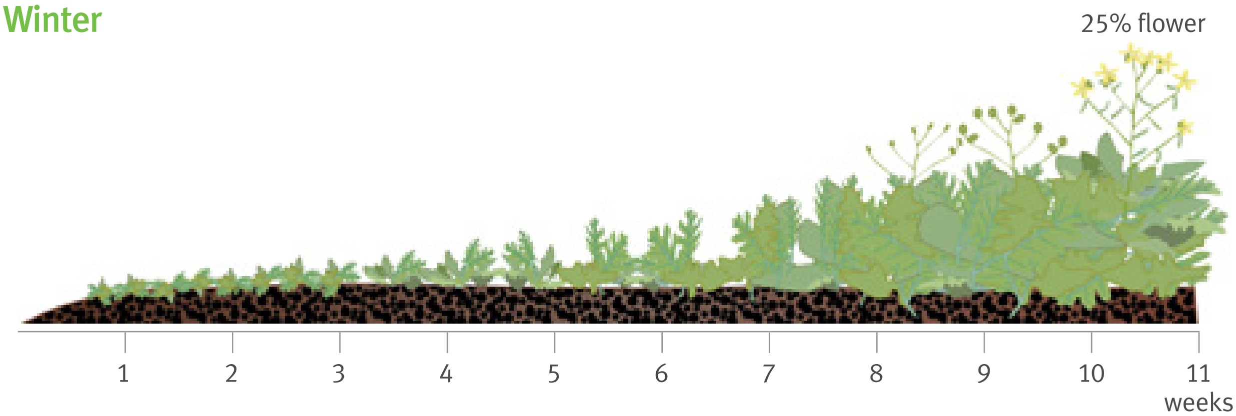


Table 3. *Days to incorporation for varieties in the* ***Lockyer Valley***.

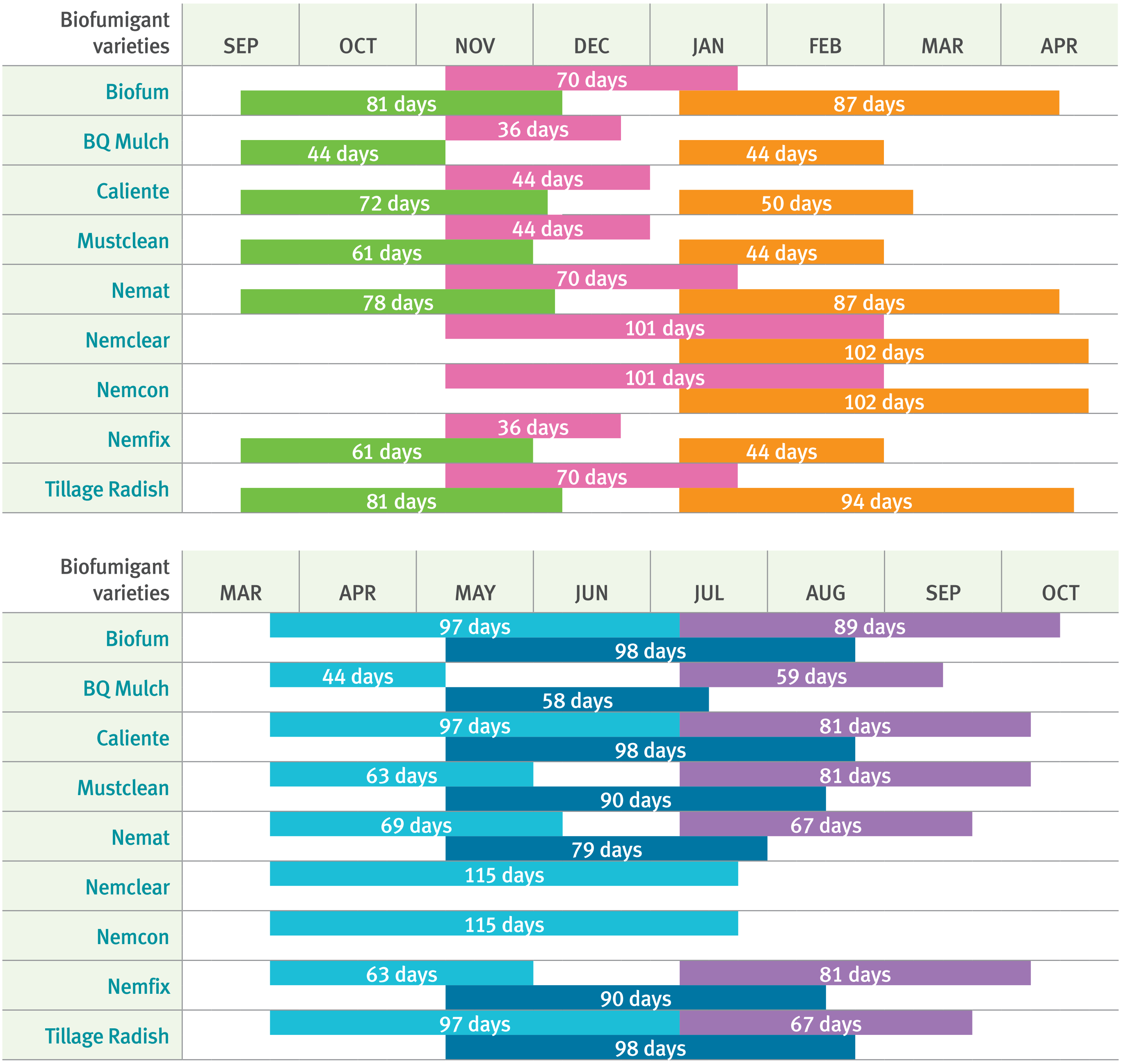


Table 4. *Days to incorporation for varieties in* ***Bundaberg***.

Biofumigant varieties	JAN	FEB	MAR	APR	MAY	JUN
Biofum	61 days		90 days			
Black Jack Radish	92 days		88 days			
BQ Mulch	36 days		53 days			
Caliente	42 days		73 days			
Cappucchino	92 days		93 days			
Fungisol	92 days		93 days			
Mustclean	36 days		53 days			
Nemat	92 days		81 days			
Nemfix	36 days		53 days			
Nemsol	92 days					
Terranova Radish	70 days		88 days			
Tillage Radish	92 days		88 days			

Biofumigant varieties	JUN	JUL	AUG	SEP	OCT	NOV
Biofum	97 days			70 days		
Black Jack Radish	103 days			70 days		
BQ Mulch	54 days			48 days		
Caliente	97 days			48 days		
Cappucchino	97 days			70 days		
Fungisol	103 days			70 days		
Mustclean	97 days			48 days		
Nemat	72 days			59 days		
Nemfix	72 days			48 days		
Nemsol	72 days			70 days		
Terranova Radish	103 days			70 days		
Tillage Radish	103 days			70 days		

Biomass production

Biomass production to build organic matter in soils is another key benefit from cover cropping. The biomass produced by biofumigants varies with varieties. Lablab and Fumig8tor were also grown in Lockyer Valley biofumigant trials as a comparison.

As brassicas are predominantly a winter-grown crop, biomass production is greater in the cooler months, compared to summer. This is evident in varieties such as Caliente, Mustclean and Nemfix in the Lockyer Valley, and the majority of varieties that were tested in Bundaberg. However, having high biomass does not mean that these varieties will produce more GSLs.

Figure 12. *Biomass for cover crop options for summer and winter growing seasons in the **Lockyer Valley**.*

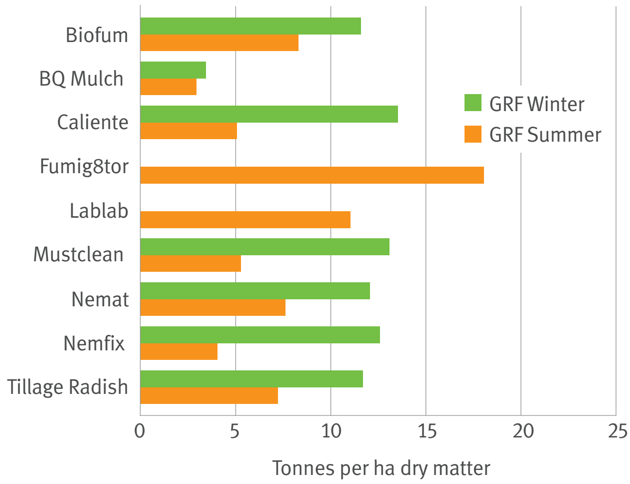
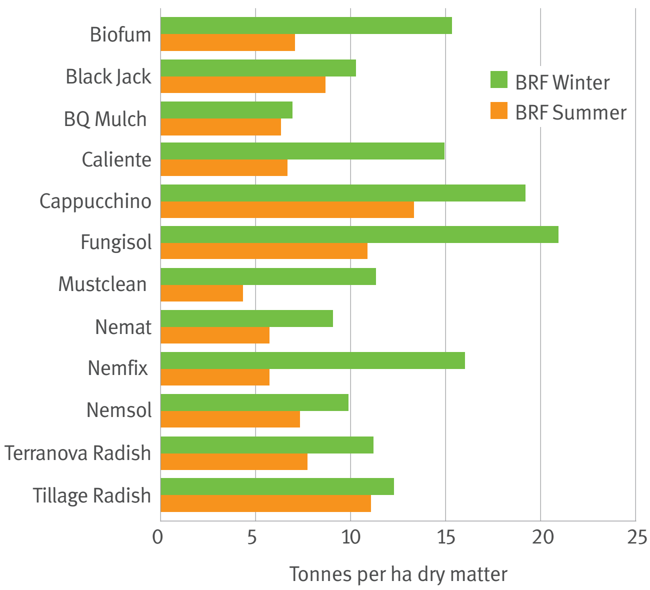


Figure 13. *Biomass produced for biofumigant varieties for summer and winter growing seasons in **Bundaberg**.*



Glucosinolate production

Glucosinolates or GSLs are the precursors to the toxic compounds, isothiocyanates or ITCs, that have suppressive activity against soilborne pathogens. As the ITCs are volatile gases, GSLs within the plant are measured instead as they are less volatile. Biofumigant varieties can have a range of individual glucosinolates, with varying concentrations. While some GSLs are known to be more toxic in the ITC they are converted to, glucosinolate data in this guide is presented as total glucosinolate concentration rather than individual GSLs. However, higher total GSLs does not necessarily equate to greater activity against soilborne diseases.

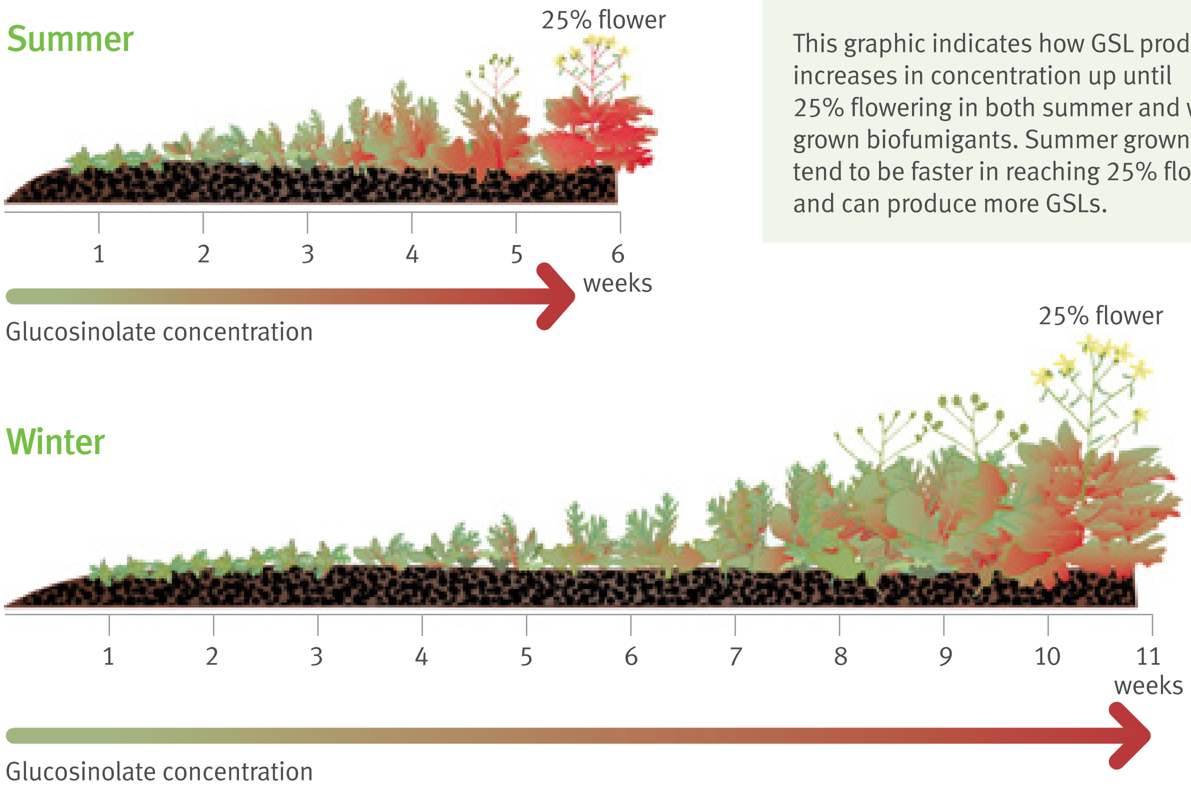
Generally, glucosinolate production was higher in summer compared to winter in south-east Queensland, however, there were some exceptions (Caliente and Nemfix). Varieties such as BQ Mulch, Biofum, Mustclean and Tillage Radish produced higher concentration of GSLs in summer in the Lockyer Valley compared with winter. The seasonal difference is important as summer is a key cover cropping period for vegetable crop production in south-east Queensland and highlights that biofumigants can be considered a summer cover cropping option in this region.

In Bundaberg, the opposite was observed with higher total glucosinolate levels per hectare in winter compared with summer.

The Indian mustards, Caliente, Mustclean and Nemfix produced more GSLs when grown in the Lockyer Valley, whereas Tillage Radish and Nemat produced more GSLs grown in Bundaberg compared to the Lockyer Valley. This shows that location can play a part in the amount of GSLs being produced and possibly efficacy against soilborne pathogens, an area of research that needs more work.

While biofumigant cover crops produce a range of different glucosinolates, this work did not identify which of the GSLs produce the most toxic compounds to individual vegetable crop pathogens.

Figure 14. *Graphic depicting glucosinolate production in summer and winter grown biofumigants in the **Lockyer Valley**.*



This graphic indicates how GSL production increases in concentration up until 25% flowering in both summer and winter grown biofumigants. Summer grown crops tend to be faster in reaching 25% flowering and can produce more GSLs.

Figure 15. *Total glucosinolates for each biofumigant variety for winter and summer growing seasons in the **Lockyer Valley**.*

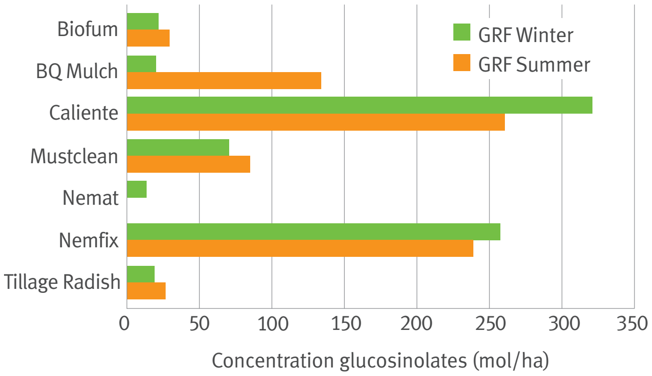
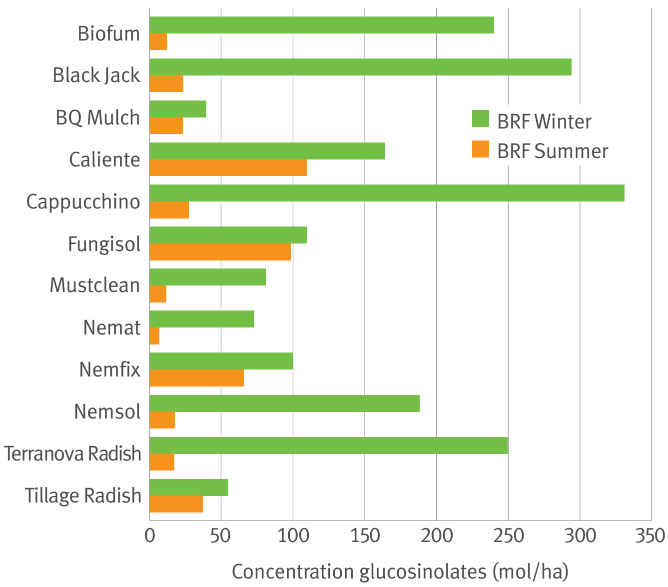


Figure 16. *Total glucosinolates for each biofumigant variety for winter and summer growing seasons in **Bundaberg**.*



Agronomic management of Biofumigants

Pest management for Biofumigants

Brassica biofumigant cover crops are prone to a similar pest spectrum as commercially grown brassica crops, such as broccoli and cabbage. Generally speaking, biofumigant cover crops will not require the intensive pest management of commercial crops for various reasons:

- There is greater flexibility in thresholds and acceptable damage limits in crops not destined for human consumption
- There are some benefits to the crop's performance as a biofumigant if it is allowed to experience a moderate level of stress, whether this is insect feeding or some other stress (such as water stress) – this results in some increase in potency in GSLs, but this is variety dependant
- The biofumigant cover crop can also provide functions beyond its soilborne disease suppression properties. For example, they can act as a nursery for beneficial insects, which would colonise vegetable crops and attack the relevant pests.

Appendix 2 is an index of pests and diseases observed in biofumigants. Chewing pests commonly encountered in biofumigant crops include caterpillars (Diamondback moth, Cabbage white butterfly, Centre grub, Cabbage cluster caterpillar and Cluster caterpillar), beetles (Flea beetle and Red-shouldered beetle) and Leaf mining flies.

Sucking and rasping pests commonly encountered in biofumigant crops include Aphids, Thrips, Rutherglen bug, Green vegetable bug, and Whitefly.

Management of insect pests in biofumigant crops is generally not required, and may be considered economically unfeasible. However, you should still monitor biofumigant crops if you wish to get the most benefit from growing them. Biofumigants are highly attractive to all beneficial insects particularly if flowers are present as many beneficial species are nectar feeders (e.g. parasitoids and hoverflies).

If a pesticide application is warranted, there are registered pesticides for both chewing and sucking pests in brassica leafy vegetables (mustards) (e.g. Belt® 480 SC and Movento® 240 SC). Before applying any chemical, always read, and comply with the label. For further information, please refer to the **APVMA website** or consult your local agronomist.

Figure 17. *Beneficial insects and pollinators are attracted to flowering biofumigants.*

Table 5. *Matrix of caterpillar, sucking, beetle and fly insect pests that affect brassica biofumigant crops.*

	Caterpillar insect pests			Sucking insect pests					Beetles and flies		
Crop	Cabbage cluster caterpillar and Cluster caterpillar	Diamondback moth	Centre grub	Aphids	Whitefly	Thrips	Rutherglen bug*	Jassid	Red-shouldered beetle*	Flea beetle**	Leaf minor
Biofum	✓	✓	✓	✓✓	✓	✓	✓	✓	✓	✓	✓
Black Jack Radish	✓	✓	✓	✓✓	✓	✓	✓	✓	✓	✓	✓
BQ Mulch	✓✓	✓✓	✓	✓✓	✓✓	✓✓	✓	✓	✓	✓	✓
Caliente	✓✓✓	✓	✓	✓✓✓	✓	✓✓	✓	✓	✓	✓	✓
Cappucchino	✓✓✓	✓✓✓	✓	✓✓✓	✓✓✓	✓✓	✓	✓	✓	✓	✓
FungiSol	✓✓✓	✓✓✓	✓	✓✓	✓✓✓	✓✓	✓	✓	✓	✓	✓
Mustclean	✓✓✓	✓	✓	✓✓	✓✓	✓✓	✓	✓	✓	✓	✓
Nemat	✓	✓	✓	✓✓	✓✓	✓	✓	✓	✓	✓	✓
Nemclear	✓✓✓	✓✓✓	✓	✓✓	✓✓✓	✓✓	✓	✓	✓	✓	✓
Nemcon	✓✓✓	✓✓✓	✓	✓✓	✓✓✓	✓✓	✓	✓	✓	✓	✓
Nemfix	✓✓✓	✓	✓	✓✓	✓	✓✓	✓	✓	✓	✓	✓
NemSol	✓	✓	✓	✓✓	✓	✓	✓	✓	✓	✓	✓
Terranova Radish	✓	✓	✓	✓✓	✓	✓	✓	✓	✓	✓	✓
Tillage Radish	✓	✓	✓	✓✓	✓	✓	✓	✓	✓	✓	✓

Legend

✓	Present at low levels
✓✓	Present and approaching damage levels
✓✓✓	Present at levels likely to cause significant damage

** Can be an issue from time to time but generally not a problem.*

*** Only an issue at the seedling stage but plant will out-grow the pest.*

Table 6. *Matrix of diseases affecting biofumigant cover crops that affect brassica biofumigant crops.*

	Fungal diseases			Bacterial diseases		Other diseases	
Crop	Downy mildew	Powdery mildew	White blister	Bacterial brown rot	Bacterial soft rot	Phytoplasma	Virus
Biofum	✗	✗	✓	✓	✗	✗	✗
Black Jack Radish	✗	✓	✗	✗	✗	✗	✗
BQ Mulch	✗	✓✓	✓	✓	✗	✗	✗
Caliente	✓✓✓	✓	✓✓	✓	✗	✓	✓
Cappucchino	✗	✓✓	✗	✓	✗	✗	✗
Fungisol	✗	✓✓	✓	✓	✗	✗	✗
Mustclean	✓✓✓	✓	✓✓	✓	✗	✗	✓
Nemat	✗	✗	✗	✗	✗	✓	✗
Nemclear	✗	✓	✗	✓✓	✗	✗	✗
Nemcon	✗	✓	✗	✓✓	✗	✗	✗
Nemfix	✓✓✓	✓	✓✓	✓	✗	✗	✓
Nemsol	✗	✗	✗	✗	✗	✗	✗
Terranova Radish	✗	✗	✗	✗	✓	✗	✗
Tillage Radish	✗	✗	✓	✗	✓	✓	✓

Legend

✗	Disease not detected
✓	Present at low levels
✓✓	Present and approaching damage levels
✓✓✓	Present at levels likely to cause significant damage

Fertiliser requirements for Biofumigants

Seed company recommendations for fertilising biofumigants is that they are fertilised as for any commercial brassica crop. For the purpose of the biofumigant cover crop assessments in Queensland the following was applied as a standard fertiliser program:

- a standard rate of 400kg/ha Incitec pivot CK 77 S as a pre-plant fertiliser
- 120kg/ha of ammonium sulphate at the 4–6 week growth stage.

As an indication of biofumigant nutrient requirements, crop nutrient uptake for the key macronutrients was calculated for a summer and winter cropping cycle for three biofumigants (Caliente, Nemat and Tillage Radish) planted at recommended field rates. Nutrient uptake data for nitrogen (N), phosphorus (P), potassium (K), sulphur (S), magnesium (Mg) and calcium (Ca) are presented in *Table 7* below.

Table 7. *Biofumigant nutrient uptake.*

			Plant nutrient uptake (kg/ha)			
Variety	**Planting**	**Biomass (fresh weight) (t/ha)**	**Nitrogen**	**Phosphorus**	**Potassium**	**Sulphur**
Caliente	Summer	63	224	23	245	50
	Winter	143	498	56	609	108
Nemat	Summer	63	243	30	284	75
	Winter	118	485	56	574	132
Tillage Radish	Summer	158	390	59	457	114
	Winter	146	458	69	463	89

Biofumigants have high requirements for nitrogen and potassium as well as sulphur, as the glucosinolates are sulphur containing compounds. Nutrient requirements for summer grown biofumigants were roughly half of that when grown in winter. This reflects the difference in biomass between growing seasons. Tillage radish was the exception with similar biomass and nutrient requirements whether grown in summer or winter. As biofumigants are fully mulched and incorporated, any applied nutrients will be available through nutrient recycling for future crops.

Figure 18. *Biofumigant varieties: Caliente (top), Nemat (middle) and Tillage Radish (bottom).*

Water requirements

Research looking at the effect of drought stress on GSLs and biofumigant efficacy has shown that moderate to high water stress increases the concentration of GSLs per kg of plant tissue, even though the amount of biomass is less. Comparison of biofumigants grown under high, medium and low irrigation frequencies showed biomass was reduced by 45–55% between high and low irrigation treatments for 3 out of the 4 varieties in summer. The impact of irrigation strategy on biomass was not as significant for winter grown biofumigants with at most a 24% lower biomass in Nemat with low irrigation frequency. Irrigation treatments were as follows:

- **Winter growing season:** The low irrigation treatment was established and then grown on rainfall only receiving 0.7–0.75ML/ha, medium irrigation received 1.57–2.27ML/ha and the high irrigation received 2.07–3.17ML/ha depending on harvest date.
- **Summer growing season:** The low irrigation treatment was established and then grown on rainfall only receiving 1.4–2.5ML/ha, medium irrigation received 2.5–3.2ML/ha and the high irrigation received 3.3–6.1ML/ha depending on harvest date.

Figure 19. *Biomass with varying water regimes for winter and summer growing seasons in the* ***Lockyer Valley****.*

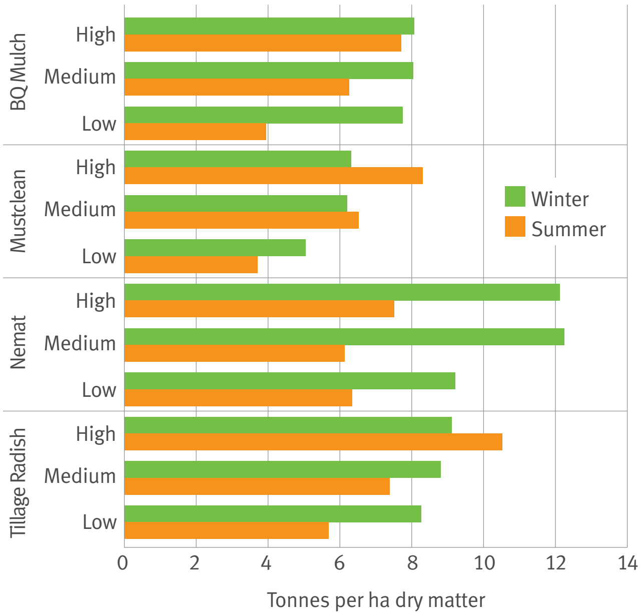
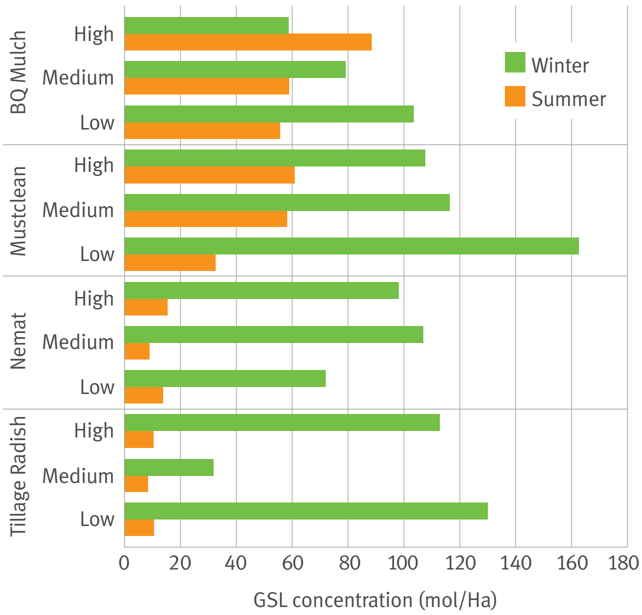


Figure 20. *Irrigation following incorporation is an essential step to convert the biofumigant compounds to an active form and to prevent compounds from being lost to the atmosphere.*

Biofumigants do not have to produce high levels of biomass to be effective in suppressing plant pathogens. Results from the irrigation trial showed that low irrigation produced a lower biomass crop yet the highest production of GSLs per hectare in 3 out of the 4 varieties with a winter planting. A summer planting was the reverse with 3 out of the 4 varieties producing more GSLs with the higher irrigation. While total GSLs have been measured, these values are only indicative and do not reflect the toxicity of the resulting ITCs on plant pathogens.

Figure 21. *Total glucosinolates with varying water regimes for winter and summer growing seasons in the* ***Lockyer Valley****.*



This information is beneficial when considering whether to grow a cover crop over summer or winter, as water availability can be a key consideration. Some water stress could improve disease suppressing qualities in biofumigants by increasing GSL concentration.

Weed management for Biofumigants

It is recommended that weeds are managed as per a commercial crop. Pre-emergent herbicides like Dacthal® 900 WG (Nufarm) (active ingredient: Chlorthal-dimethyl) is registered for use in mustard crops as is Dual Gold (active ingredient: s-metolachlor). Care needs to be taken when using herbicides as most will have plant back issues for following cash crops.

Biofumigant crops that are left to go to seed can be a weed in their own right. To avoid this, incorporate plant material at 25% flowering stage to maximise the disease suppression properties of the crop and to avoid plants going to seed and becoming weeds themselves.

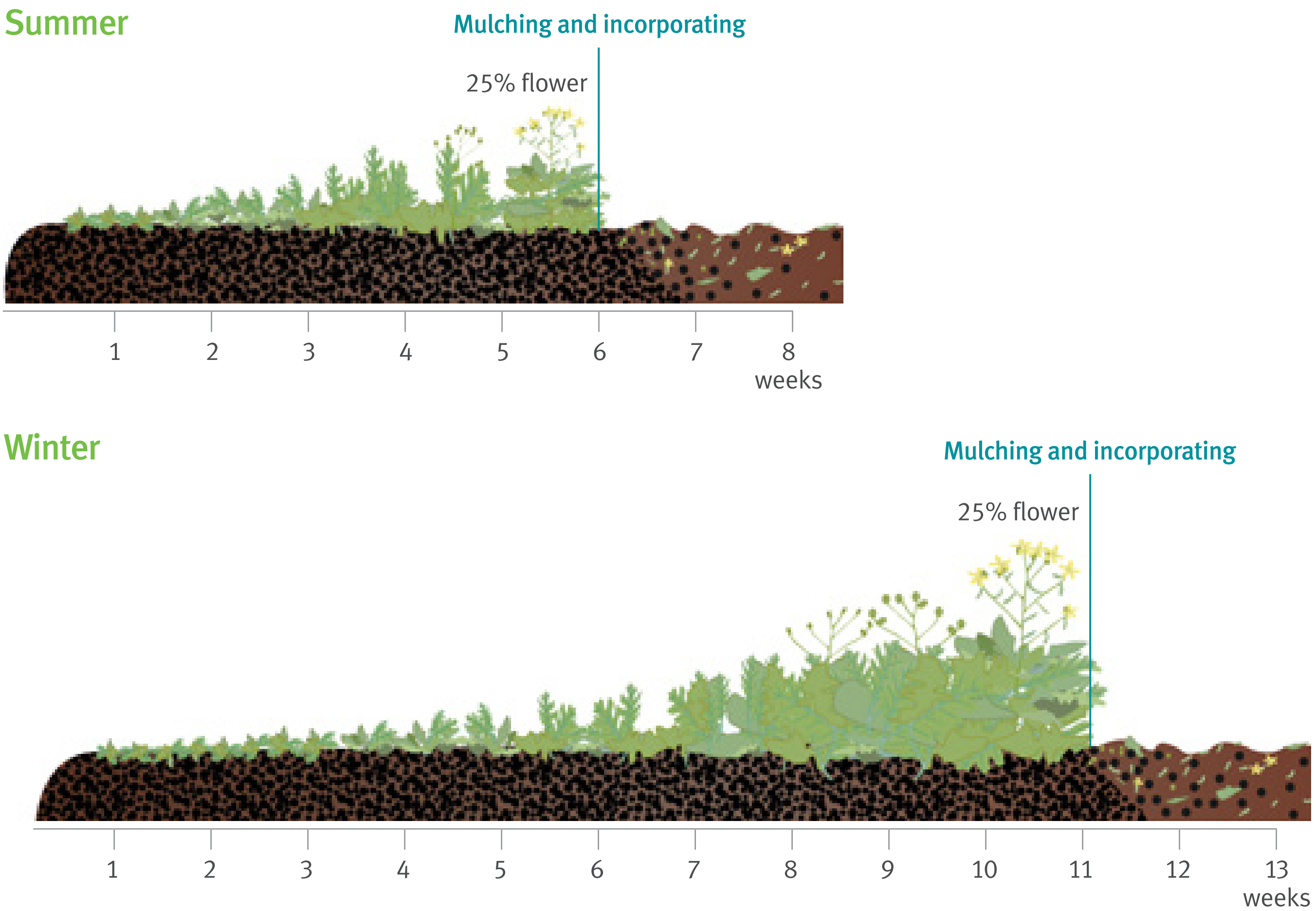
Before using any herbicide always read and comply with label requirements. For more information, consult the APVMA website.

Figure 22. *Biofumigant crop with weeds present, such as fat hen (Chenopodium album).*

Mulching, incorporation and final irrigation of the cover crop

It is recommended that biofumigants are incorporated at approximately 25% flowering. This is when, according to previous research, the concentration of GSLs in biofumigants are at their highest. Where a biofumigant cover crop comprises a mixture of varieties, and the varieties flower unevenly, incorporate the crop when the first variety reaches 25% flowering (this will optimise the cover crops performance and avoid any weed issues in subsequent crops). Flowering times are also seasonally dependant. Biofumigant crops will flower earlier in summer and later in winter due to the temperature affecting the speed of growth.

Figure 23. *Indicative process of biofumigant cover cropping in the **Lockyer Valley**.*
Note: indicative reduced soil disease levels (indicated by black dots in the soil) following mulching and incorporation.

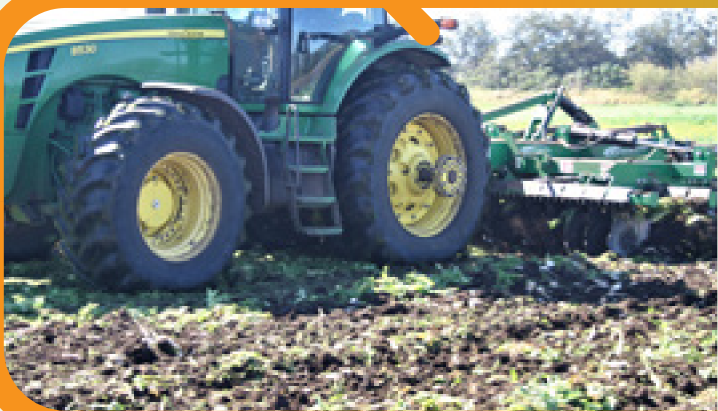


1 Grow to 25% flowering

Incorporate when biofumigants are at approximately 25% flowering when glucosinolates are reportedly at their highest. With mixtures, incorporate when first variety is at 25% flowering.

2 Mulch into small fragments

Incorporation underway. Simultaneous mulching of an Indian mustard crop on the left and incorporation with a rotary hoe on the right (Lockyer Valley, south-east Queensland).



3 Incorporate plant material

(Rotary hoe or disc plough)

Alternatively, the mulched biofumigant crop can be incorporated using a set of disc ploughs (Kalbar, south-east Queensland).

4 Irrigate or roll to seal in biofumigant gases

Irrigation afterwards helps to seal in the biofumigant gases. Rolling can be just as effective at sealing in the biofumigant gases, particularly if you can't irrigate the ground after incorporation (Lockyer Valley, south-east Queensland).

Photos: John Duff

Figure 24. *Steps involved in mulching and incorporation of biofumigant cover crops.*

Rotary hoe has been the recommended incorporation method for biofumigant cover crops. However, as not all vegetable growers have access to a rotary hoe, DAF also looked at a range of incorporation methods for biofumigant cover crops. These include: Mulching followed by Disc Plough or Rotary Hoe, then Irrigation or Rolling, and Strip till followed by irrigation. A single biofumigant variety, Caliente, was used for this comparison.

Activity of the biofumigants against known pathogens was compared for the different incorporation methods. Generally, all incorporation methods performed well against the known pathogens, with some exceptions. Strip tillage showed the most variability in biofumigant activity. Mulch/rotary hoe/irrigation and mulch/disc plough/irrigation were similar in their biofumigant activity. There was also little difference between irrigation and rolling post incorporation.

Table 8. *Efficacy matrix showing the extent of pathogen mortality after different methods of incorporation.*

Pathogen	Fallow (Field control)	Mulch + Disc plough + Irrigation	Mulch + Disc plough + Roll	Mulch + Rotary hoe + Irrigation	Mulch + Rotary hoe + Roll	Mulch + Strip till implement + Irrigation
Sclerotium rolfsii (basal rot)	•••••	•••••	••••	•••••	•••••	•••••
Sclerotinia sclerotiorum (white mould)	••••	•••	••••	••••	••••	•••
Rhizoctonia sp. (wire stem)	•••••	•••••	•••	••••	•••••	••••
Macrophomina phaseolina (charcoal rot)	••••	••••	•••	•••	••	••
Verticillium dahliea (verticillium wilt)	•••••	••••	••••	•••••	•••••	••••
Sclerotium cepivorum (onion white rot)	••••	••••	••••	••••	••••	•••

Legend: Percentage mortality

•	0–20
••	21–40
•••	41–60
••••	61–80
•••••	81–100

Spraying off the biofumigant cover crop was also evaluated to see if it still retained its suppressive characteristics once incorporated post spraying. The crop was sprayed off at 25% flowering and incorporated 4 weeks later. Total GSL levels were measured 2 weeks post spraying and 4 weeks post spraying (incorporation). Comparison of GSL data showed a progressive decline in total GSL levels by 50% at 2 weeks post spraying and by 90% at 4 weeks, incorporation.

Biofumigant activity against known pathogens varied greatly with the spray-off/incorporation methods. While some of these results reflect the significant decline in total GSL with time after spraying off, others do not. Further work on this as an option for biofumigant cover crop management is required.

Table 9. *Efficacy matrix showing the extent of pathogen mortality with different incorporation methods.*

Pathogen	Fallow (Field control)*	Spray-off + Disc plough + Irrigation	Spray-off + Disc plough + Roll	Spray-off + Rotary hoe + Irrigation	Spray-off + Rotary hoe + Roll
Sclerotium rolfsii (basal rot)	•••••	•••••	•••••	•••••	•••••
Sclerotinia sclerotiorum (white mould)	••••	•••	•••	•••••	•••
Rhizoctonia sp. (wire stem)	••••	••	•	•••••	•••
Macrophomina phaseolina (charcoal rot)	•••	••	•	•••••	•
Verticillium dahliea (verticillium wilt)	•••••	•••••	•••••	•••••	•••••
Sclerotium cepivorum (onion white rot)	••••	•••	••	••••	••••

Legend: Percentage mortality

•	0–20
••	21–40
•••	41–60
••••	61–80
•••••	81–100

**Fallow samples were taken at incorporation, 4 weeks after the biofumigant was sprayed-off.*

Beneficial soil microorganisms and biofumigants

As with all forms of fumigation, biofumigation can impact living organisms in the soil, such as beneficial microbes including earthworms. Biofumigant activity against beneficial microorganisms such as *Trichoderma* spp. and *Bacillus amyloliquefaciens* (Serenade® Prime) was assessed in the laboratory. The biofumigants tested were found to be more suppressive against *Trichoderma spp*. than *Bacillus amyloliquefaciens*. There was variability in the suppression of beneficial microorganisms between varieties with some varieties suppressing more than others. Caliente in particular, showed high levels of suppression of *Trichoderma* spp. There was a trend for greater activity against beneficial microorganisms from biofumigant material grown during summer, however, this was not always the case. Therefore, if using biocontrol products such as *Trichoderma* spp. or *Bacillus* spp., it is recommended to only use these products when planting your cash crop and not in conjunction with the biofumigation crop.

The suppression of soilborne pathogens has also been linked to factors other than biofumigation. These include competition by a range of copiotrophic soil microorganisms, which thrive under the addition of fresh organic matter, proliferation of *Streptomycetes* (filamentous bacteria that have a role in breaking down plant material), and elevated soil populations of ammonia-oxidising bacteria, or the formation of additional bioactive sulphur containing compounds.

Biofumigation activity is known to increase soil bacterial diversity, but also significantly reduces soil fungal diversity, possibly due to reduced pathogenic fungi. This will obviously depend on the biofumigant variety, as different varieties contain varying types of GSLs with varying levels of toxicity when converted into ITCs.

Figure 25. *Building a quality soil resource.*

Fallow

Fallow was also included as a comparison in all work conducted on the biofumigants and as indicated, also showed good activity against those soilborne pathogens tested. Suppression of soilborne pathogens occurs to some extent in all soils, providing varying degrees of biological buffering against soilborne pathogens.

Soils within the Lockyer Valley are inherently high in organic matter and soil organic matter plays an important role in maintaining the biological micro-organisms that regulate or suppress populations of soilborne pathogens.

Figure 26. *Fallow field in between commercial crop rotations.*

Conclusion

Brassica biofumigant cover cropping is an option for vegetable system rotations as part of an integrated disease management strategy. Key information from this guide highlights several key considerations for those wanting to incorporate brassica biofumigants into their rotation.

- **Biofumigant cover crops can be grown all year round** in the Lockyer Valley and Bundaberg although with different performance characteristics.
- **Days to maturity vary with season** for biofumigants, with shorter growing periods over summer months.
- **Biofumigant varieties differ in their efficacy** against known soilborne pathogens.
- **Biofumigants have shown some activity against beneficial soil microorganisms** in the laboratory such as *Trichoderma* sp. and *Baccillus amyloliquefaciens* (Serenade® Prime).
- **Management practices** such as irrigation impact on the biomass, total GSLs and activity against soilborne pathogens.

Planting biofumigant crops does come at an increased cost compared with retaining country as fallow, as well as cheaper cover cropping options. However, there are multiple benefits to using biofumigants in vegetable cropping systems, including:

- **Reducing top soil loss** through erosion from the summer rains
- **Good biomass production**, replenishing carbon in the form of biomass to the top soil to ensure water infiltration, organic matter and soil structure
- Prior planting with **a biofumigant cover crop minimises and manages the impact of soilborne diseases** of the subsequent cash crop
- **Reducing the use of harsh and potent chemicals** when controlling soilborne diseases by growing biofumigant crops as a break between cash crop rotations.

Although biofumigation has been practiced for over 30 years, there is a great deal of work that can still be done to demonstrate the benefits of using these types of crops as part of everyday farm management programs. There are regional differences in the biofumigation activity and across growing seasons. Pest and disease pressures also vary with regions, so the choice of biofumigant will vary both in the efficacy against soilborne pathogens, and in the range of pests and diseases they are affected by.

Growers are encouraged to investigate more into how biofumigation can be used and optimised for their own practices. Talk to other growers in your region who have used them successfully.

Additional information

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Blue text indicates online resource.

Glossary

Biofumigant	Plants that produce naturally occurring compounds that can suppress soilborne diseases, pests and weeds
Copiotrophic	A copiotroph is an organism found in environments rich in nutrients, particularly carbon. Copiotrophic organisms tend to grow in high organic substrate conditions
Disease	The development of symptoms as a result of a plant pathogen attacking a plant
Efficacy	How well the biofumigant controls/suppresses known soilborne pathogens
Glucosinolates/GSLs	Naturally occurring plant compounds found predominantly in brassica plants that are converted to toxic biofumigant compounds upon mulching and incorporation into the soil
Incorporation	Process of mixing mulched plant material through the soil
Isothiocyanates/ITCs	Toxic biofumigant compounds converted from glucosinolates, that suppress soilborne pathogens
Myrosinase	The enzyme that facilitates the conversion of glucosinolates to isothiocyanates
Pathogen	Disease causing microorganism
Sclerotes	Survival structure of a soilborne pathogen which can withstand adverse conditions for years until conditions are favourable for disease development

Appendix 1

Biofumigation checklist

What is the target disease to be managed?

Sclerotium rolfsii | *Sclerotinia sclerotiorum* | *Sclerotium cepivorum* | *Macrophomina phaseolina*

↓

What is your cropping window?

Summer | Autumn | Winter | Spring

↓

Which varieties are show activity against target pest during cover cropping window?

See Table 2 on page 10

↓

How will you incorporate the plant matter?

Mulch, Rotary Hoe, Irrigate | Spray-off, Rotary Hoe, Irrigate | Mulch, Disc/Moleboard Plough, Roll

Appendix 2

Summary of biofumigant insect pests and diseases

Caterpillars

Cabbage cluster caterpillar (*Crocidolomia pavonana*)

Cabbage cluster caterpillar is capable of very quickly stripping plants of foliage as larvae feed in clusters and move across a plant leaving only leaf mid-veins behind.

Regularly checking plants for eggs will allow timely management of large infestations.

Centre grub (*Hellula sp.*)

Centre grub needs to be monitored in very young seedlings as feeding at this stage can damage the growing point.

In older plants, a much higher tolerance exists for centre grub as the plant tends to be multibranching and some feeding can even encourage bushy growth.

Cluster caterpillar (*Spodoptera litura*)

Cluster caterpillar is capable of very quickly stripping plants of foliage, similar to the cabbage cluster caterpillar, as larvae feed in clusters when small and move across a plant leaving only leaf mid-veins behind. When older, the larvae wander off on their own and are typically recognised as large fat grubs with dark marking along the sides of their body.

Regularly checking plants for eggs will allow timely management of large infestations. Egg masses are covered in fine brown hair from the adult moth.

Diamondback moth (*Plutella xylostella*)

Diamondback moth can be present from seedling stage through to harvest. Pesticide application may be required if numbers are extremely high or if there is concern that the crop is harbouring Diamondback moth that may emigrate into nearby brassica crops. Cotesia and specialist parasitoids such as Diadegma will help to keep Diamondback moth in check.

Beetles and flies

Flea beetle (*Phyllotreta* sp.)

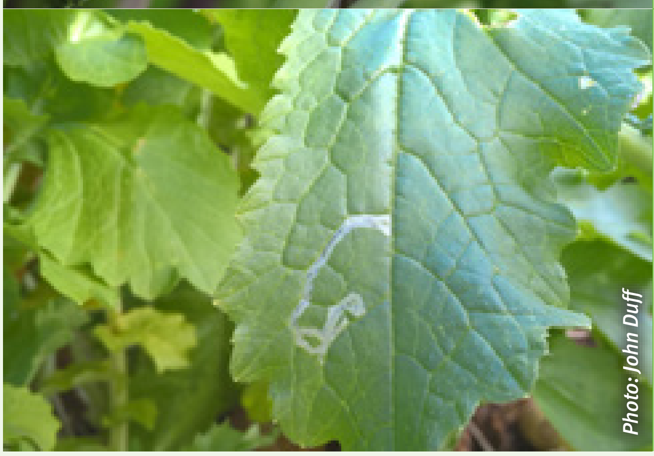
Beetles will 'spring' away if disturbed leading to their common name, flea beetle.

Feeding by adult flea beetles produce characteristic 'shot hole' damage in leaves. Beetles tend to prefer feeding on seedlings more than mature plants. Generally, damage by Flea beetles is tolerated in biofumigant cover crops even under high insect pressure.

Red-shouldered beetle (*Monolepta australis*)

Red-shouldered beetles can migrate into the crop in large numbers and strip the plants of foliage.

Regular monitoring for this pest is required in late summer and early autumn when they are most prevalent.



Leaf miner (*Liriomyza* sp.)

Leaf miners may be present from seedling stage onwards and generally do not reach populations that warrant management.

Characteristic feeding damage by Leaf miner are transparent tunnels below the leaf epidermis made by the feeding larval stage.

Appendix 2

Summary of biofumigant insect pests and diseases

Sucking and rasping pests

Aphids (Green peach aphid, *Myzus persicae*)

Aphids that have colonised the plant and reached large numbers in the absence of generalist predators or parasitoids are capable of affecting growth and may require pesticide application in some seasons. Large infestations can actually cause the death of biofumigants, particularly the Indian Mustard types. A pesticide application is generally warranted to control large infestations.

Rutherglen bug (*Nysius vinitor*)

Rutherglen bug sometimes reach large numbers during summer and cause severe wilting.

Pesticide applications for rutherglen bug may have limited efficacy as they tend to quickly re-colonise crops from neighbouring areas (weeds, sorghum etc) following sprays.

Whitefly (Silverleaf whitefly, *Bemisia tabaci*)

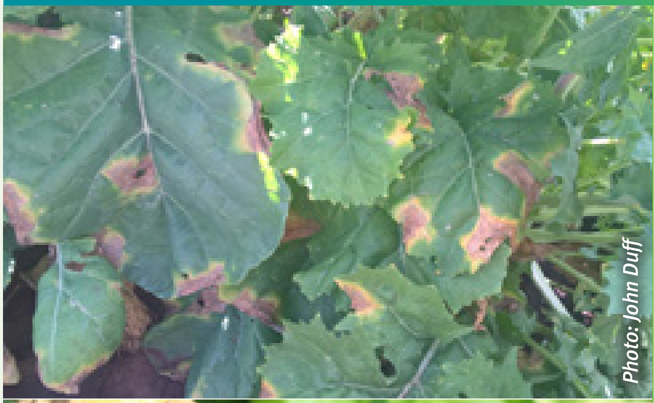
Whitefly can be present from seedling stage through to incorporation. Pesticide application is occasionally necessary when large numbers of juveniles on the undersides of leaves produce copious amounts of 'honeydew' which promotes the growth of sooty mould.

Thrips (Onion thrips, *Thrips tabaci*)

Thrips tend to be present from seedling stage onwards. They tend to be found close to mid veins on the underside of leaf and damaged leaves may have a silverish sheen following loss of the epidermal layer.

Generally Thrips will not warrant pesticide applications as some feeding damage is tolerated.

Bacterial diseases



Bacterial brown rot (*Xanthomonas campestris*)

Bacterial brown rot disease symptoms are yellowing areas at leaf margins. This will turn brown in older lesions.

Sprays of mancozeb and copper mix can prevent disease development. This disease is generally only an issue with mature plants.

Bacterial soft rot (*Erwinia carotovora*)

Symptoms include water soaked lesions that rapidly expand and cause break down of plant tissue. The decaying plant material may be slimy and produce foul odour characteristic of Erwinia diseases.

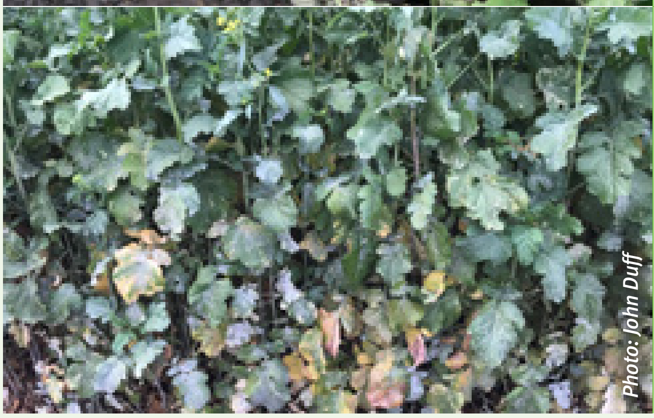
Hot, wet weather favours the spread of disease.

Fungal diseases

Damping-off (*Pythium* spp.)

Pythium spp. are extremely common in soils in both tropical and temperate regions. Damping-off occurs as the soft decay of the taproot or rootlets causes the plant to collapse at the soil level. Typically produces fine webbing or mycelium near the base of the plant. Warm wet weather can favour the development of this disease.

Typically found attacking seedlings and small plants.



Powdery mildew (*Peronospora parasitica*)

Powdery mildew symptoms are white fluffy mycelial growth on the top side of leaves.

Warm, dry and cloudy conditions favour disease development. This disease is mostly an issue with mature plants.

Appendix 2

Summary of biofumigant insect pests and diseases

Fungal diseases *(continued)*

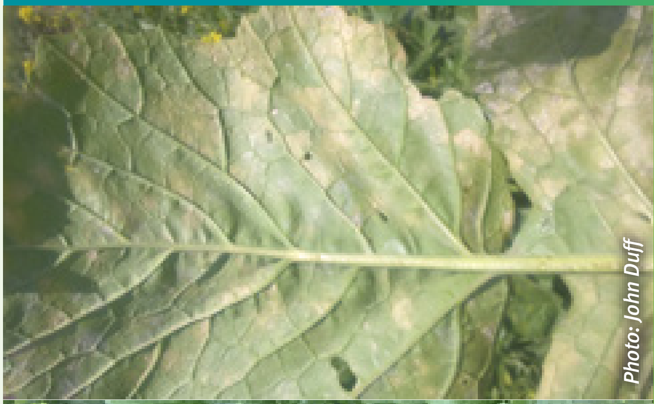


Photo: John Duff

Downy mildew (*Hyaloperonospora parasitica*)

Downy mildew symptoms are white mycelial growth that occurs on the underside of leaves and may progress to the top side of leaves as symptoms progress.

Indian mustard varieties are most susceptible to this disease and a fungicide is generally required to control it.

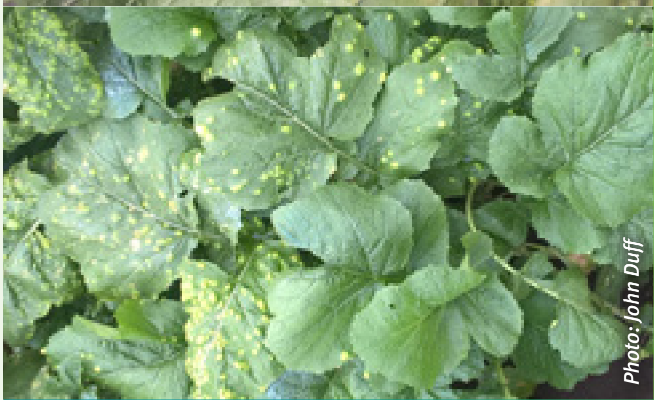


Photo: John Duff

White blister (*Albugo candida*)

White blister infection may be first noticed when yellow spots appear on the top side of leaves. The underside of the leaves have characteristic white raised fungal growths.

Virus and Phytoplasma

Photo: John Duff

Phytoplasma

Symptoms of Phytoplasma infection are floral structures that are green and resemble vegetative stages e.g. flowers that resemble leaves.

Phytoplasma is a type of bacteria spread by leafhoppers. Infected plants remain diseased for life.

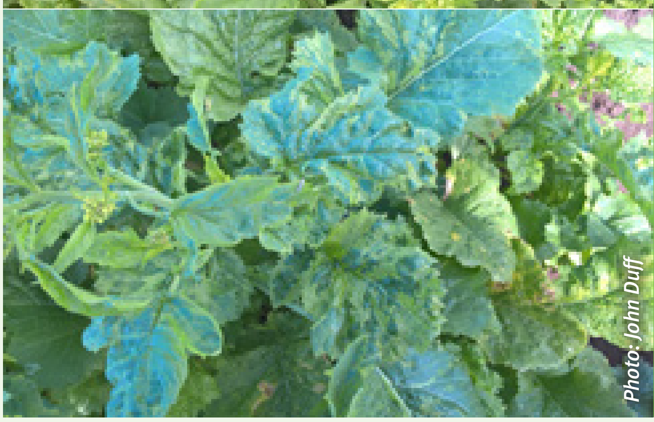


Photo: John Duff

Turnip mosaic virus (*Potyvirus*)

Virus infected plants have patches of very dark green on the top side of their leaves.

The virus is spread by aphids.

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