AHDB

Biofumigation for management of potato cyst nematodes (PCN)

POTATOES

Contents

What is biofumigation?

'Biofumigation' describes the suppression of soilborne pests, pathogens and weeds by toxic gases emitted from organic material. In the UK, biofumigation typically involves growing brassica green manure crops. The most common species are Indian mustard (*Brassica juncea*), rocket (*Eruca sativa*) and oil radish (*Raphanus sativus*). The usual growing period is 8–14 weeks within a mid-July to early November window. Biofumigant crops are then macerated and incorporated as they reach early to mid-flowering (Figure 1). See tables 2 and 3 for a summary of biofumigation recomendations for different growing windows.

Figure 1. Maceration and incorporation of a mid-flowering Indian mustard biofumigant crop using a flail-topper (A) and rotavator (B)

How does biofumigation work?

Brassicas contain sugar-rich glucosinolates within their tissues. Glucosinolates consist of glucose, nitrogen and sulphur chains and are non-toxic. Some glucosinolate by-products are toxic gases which practitioners use for pest management.

When a brassica plant is damaged, its cells release glucosinolates and myrosinase enzymes. When these mix in the presence of water, myrosinase splits the glucosinolate, removing glucose. This process is a hydrolysis reaction. Products of glucosinolate hydrolysis include isothiocyanates, thiocyanates, nitriles, epithionitriles and oxazolidine-thiones. The products of hydrolysis depend on the parent glucosinolate, of which there are at least 132 known examples. There are three classes: aliphatic, aromatic and indolyl/indole. The aliphatic and aromatic glucosinolates release isothiocyanates which suppress potato cyst nematodes (PCN). Indole glucosinolates do not release isothiocyanates and so have no role in biofumigation. Figure 2 illustrates the glucosinolate hydrolysis process.

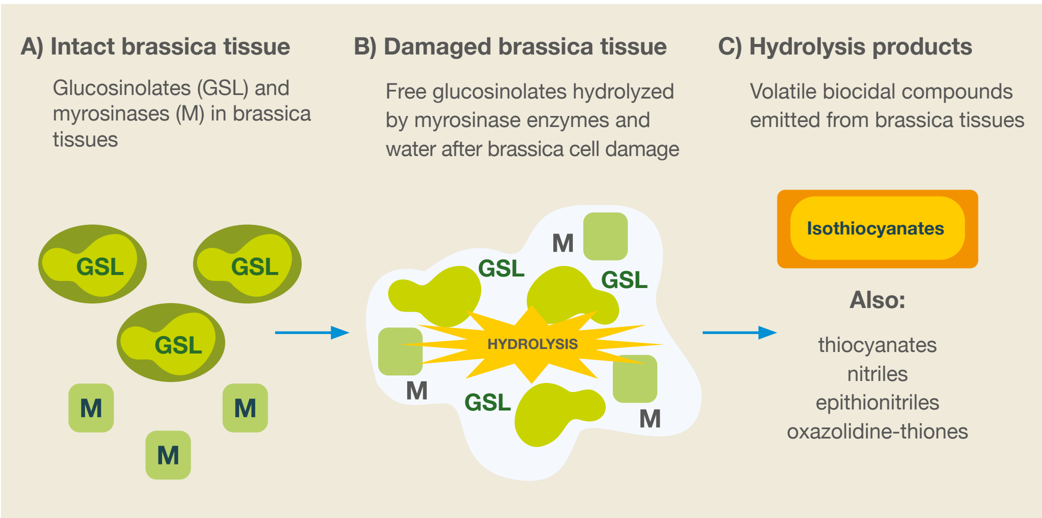

Figure 2. The biofumigation process (glucosinolate hydrolysis)

Isothiocyanates for potato cyst nematode management

Isothiocyanates inhibit cellular respiration and other PCN functions. They can cause juvenile PCN – the young wormlike stage which invades potato roots – to hatch from their protective eggs. This causes them to starve in the absence of a host. Isothiocyanates can also paralyse or kill juveniles outright.

Longer isothiocyanate exposure times and higher doses kill more PCN. Some isothiocyanates are more volatile than others, that is, they easily evaporate at normal temperatures. These isothiocyanates have lower molecular weights and are generally more mobile in soil. However, the less mobile isothiocyanates tend to be more toxic due to having more binding sites within PCN tissues. This means that trade-offs between toxicity and mobility may sometimes have to be made. The most toxic isothiocyanates to PCN in laboratory studies are allyl, 2-phenethyl and benzyl. The glucosinolate sinigrin (2-propenyl) produces allyl, gluconasturtiin produces 2-phenethyl and glucotropaeolin produces benzyl. Few field studies have investigated biofumigant varieties that produce these isothiocyanates. Allyl is similar in toxicity and volatility to methyl-isothiocyanate, which is encouraging for PCN management. Methyl-isothiocyanate is the gas given off from metam-sodium (METAM 510®, CERTIS) and dazomet (BASAMID®, BASF).

Biofumigant species for potato cyst nematode management

Several seed companies supply biofumigant species. Most research has been on the Indian mustard variety 'ISCI 99'. It produces high concentrations of sinigrin glucosinolate in its tissues. ISCI 99 can also produce high fresh biomass during the summer window (c.40–70 t/ha). Indian mustard and other biofumigant species are shown in Figure 3. Rocket and oil radish glucosinolates depend greatly on variety, whereas Indian mustards mainly contain sinigrin.

Rocket and oil radish varieties can produce fresh biomass of 30–40 t/ha, with oil radish having the greater biomass potential. White mustard (*Sinapis alba*) often produces high biomass. However, its main glucosinolate is glucosinalbin, which is of limited use for PCN management. Table 1 shows biofumigation efficacy against PCN for published field studies. Further information, including details of seed suppliers, can be obtained from the International Biofumigation Network.

Figure 3. Common biofumigant species investigated for PCN management: A = *Brassica juncea* (Indian mustard), B = *Eruca sativa* (rocket), C = *Raphanus sativus* (oil radish) and D = *Sinapis alba* (white mustard)

Table 1. Details of published biofumigation field studies focusing on potato cyst nematode management

Species (Common name)	Variety [supplier]	Dominant glucosinolates	Dominant isothiocayante	Recorded field efficacy (%)	Reference
Brassica juncea (Indian/brown mustard)	Caliente (ISCI) 99 [High Performance Seeds/Tozers]	sinigrin	2-propenyl/allyl	15–95	Ngala et al., 2014
		sinigrin	2-propenyl/allyl	23–37	Watts, 2018
	Variety 2 [Joordens Zaden/RAGT]	unknown	unknown	45	Watts et al., 2014
Eruca sativa (rocket/ arugula)	Nemat [High Performance Seeds/Tozers]	glucobrassicanapin	4-pentenyl	30–90	Ngala et al., 2014
	Trio [Joordens Zaden/ RAGT]	unknown	unknown	46	Watts et al., 2014
Raphanus sativus (oil radish)	Bento [P H Petersen]	glucoraphanin	(4-(methylsulfinyl) butyl/butyl	65–95	Ngala et al., 2014
		gluconsasturtiin	2-phenethyl		
Sinapis alba (white mustard)	Architect [Joordens Zaden/ RAGT]	unknown	unknown	41	Watts et al., 2014
	Zlata [Feldsaaten freudenberger]	unknown	unknown	0	Valdes et al., 2012
	Metex [P H Petersen]	unknown	unknown	16	Scholte & Vos, 2000

Biofumigation potential and accessibility

A biofumigant crop needs to meet its maximum potential before being macerated and incorporated into soil for the most effective biofumigation. Biofumigation potential depends on:

- The type of glucosinolate in the crop
- The glucosinolate concentration in crop tissues
- The biofumigant crop biomass

As previously mentioned, a biofumigant needs to have appropriate glucosinolates in its tissues for the pest being targeted with biofumigation. Choose a variety with a potential glucosinolate concentration in dry tissue of at least 100 µmol g (micromoles per gram). Look for seed suppliers that state the type of glucosinolate and its concentration.
A biofumigant should produce lots of biomass. Crops of 1.2–2.0 m in height usually represent in excess of 50 t/ha fresh weight, which is the goal. The more biomass produced, the more glucosinolates and the greater the potential biofumigant dose at incorporation.

- Use fertilisers to aid the production of glucosinolates and biomass

Apply nitrogen at rates of 100–150 kg/ha and sulphate at 25–50 kg/ha. Biofumigant crops should also be succulent at early to mid-flowering to aid maceration implements in cutting and pulping biofumigant material. Nitrogen helps to produce a lush canopy which breaks down easily. Irrigation can also help to prevent early senescence.

- Choose the right crop for the growing window

Leafy biofumigants such as Indian mustard and rocket are more easily macerated and so release isothiocyanates more readily. Large root crops, such as oil radish, do not break down easily. However, brassica roots release glucosinolates into soil during growth in what is known as partial biofumigation. Many brassica species, including Indian mustard, oil radish and rocket, have been shown to suppress PCN during the growing period.

Growing windows

Summer window

The optimum time to drill a biofumigant crop is between mid-July and mid-August. It then grows for 8–14 weeks for incorporation by early November. This window enables the establishment of a biofumigant after an early-harvested crop and leaves time for the establishment of a cash crop in the autumn, such as winter wheat. The summer–autumn window also enables a biofumigant access to long day lengths and high ultraviolet (UV) radiation, which is important for the production of glucosinolates and biofumigant biomass. This window allows incorporation of biofumigant material into warm soils (>10°C), which helps toxic isothiocyanate gases move through soil. For this window, use Indian mustard or rocket for their leafy biomass. If drilling is in good time, use Indian mustard. If drilling is late, use rocket rather than Indian mustard, or a combination of both biofumigants. Rocket matures more quickly than Indian mustard, although the penalty is lower biomass. Irrigation is sometimes needed for crop establishment in this window. When mixing biofumigants, consider seed size. The seeds of rocket and Indian mustard can separate out in the drill. Maximum efficacy for this window is usually between c.40–70%. This is subject to best practice and favourable environmental conditions.

Winter window

Autumn-established biofumigants for overwintering have lower potential than other biofumigant crops. The restriction is due to shortening days with lower UV exposure and limitations on fertiliser applications. Low soil temperatures and wet soils also limit efficacy. However, the winter window is suitable for oil radish to grow. Oil radish is difficult to macerate but is very cold-hardy and has a large storage capacity for glucosinolates in its root. If established by early to mid-September, oil radish can be grown over winter, during which it releases glucosinolates from its roots. These crops are usually incorporated ahead of potato planting in March–April, which provides a long window for low doses of isothiocyanates to interact with PCN, killing them. Maximum efficacy for this window has been found between c.10–30%, although there is limited data.

Spring window

Spring-established biofumigants are only realistic for growers with specialist crops that are harvested early in the year, such as overwintered or poly-carrots. While used by some growers, there is no recorded PCN efficacy data for biofumigants grown in this window. Crops are expected to be effective. Biofumigants grown in this window have access to lengthening days with high UV. Crops should exceed 50 t/ha fresh weight, if water and nitrogen are in supply.

Biofumigant maceration and incorporation techniques

Many options are available for biofumigant maceration and incorporation. Maceration techniques should pulp, twist or tear biofumigant material rather than just cut. This is to cause widespread rather than localised tissue damage. Isothiocyanates disappear within minutes, so incorporate immediately after maceration. The time gap should be no more than 20–30 seconds. Mix biofumigant material evenly into soil, to a depth of 25–35 cm. If the crop has high biomass, incorporate to 35 cm. Some spaders can incorporate to 40 cm. Then seal the soil to retain toxic gases. A rotavator hood or spader smear roll can create an effective soil surface seal. The best systems use a front-mounted haulm topper, followed by a rear-mounted rotavator or spader, (Figure 4). If a rotavator has a shallow working depth, follow it with a plough to mix the material to a greater depth. Then use a plough-press, power-harrow with packer roll, or other rolls to reseal the surface (Figure 5). Minimise the number of passes because each extra operation moves soil and allows escape of toxic isothiocyanate gas. Figure 4 shows a single-pass system. Figure 5 shows a multiple-pass system.

Figure 4. Single-pass biofumigation system: A = tine arrangement on a haulm topper, B = rotavator with rigid tines and S-blades, C = a single-pass system using front-mounted haulm topper and rear-mounted rotavator, and D = good-quality brassica residues following maceration

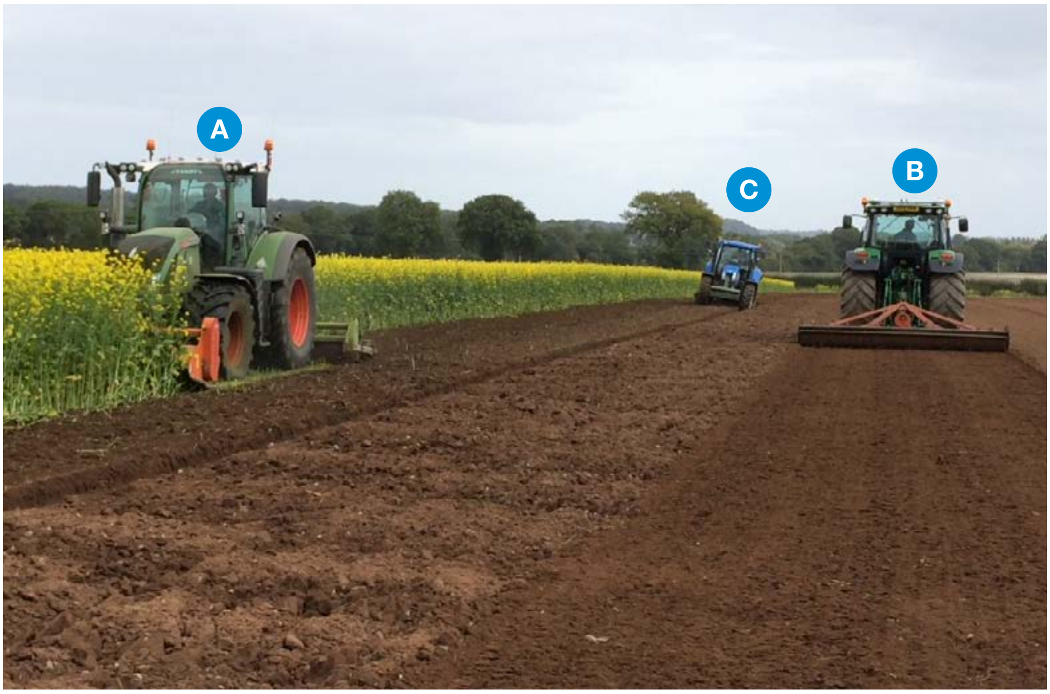

Figure 5. Multiple-pass biofumigation system: tractor A flail topping and shallow rotavating, followed by tractor B ploughing to 30 cm, followed by tractor C power-harrowing with packer-roll. The two implements on tractor A achieve full maceration and partial incorporation, allowing a short gap before tractor B fully incorporates and tractor C seals

Soil moisture at incorporation

Soil moisture at incorporation affects biofumigation success. In sandy loam soils, aim for 25–75% of field capacity. Soil at this moisture range feels damp and will hold its shape when moulded or pressed. Isothiocyanate gases escape too easily from drier soils and cannot spread as effectively through wet soils. Incorporate lower biomass crops in soil at 25–50% of field capacity. Incorporate higher biomass crops at 75% soil moisture.

Cost of spring, summer and winter biofumigation systems

Biofumigant seed usually costs £5–9/kg. Seed costs are £60–100/ha for Indian mustard, rocket and oil radish. Establishment costs £15–30/ha. For spring and summer systems, fertiliser improves efficacy. Nitrogen at 100–150 kg/ha costs £80–160/ha, and sulphate at 25 kg/ha costs around £25–50/ha. One 25 mm irrigation event would cost £85–155/ha. Machinery running costs are usually £100–150/ha. Total cost for a low-input overwintered system is about £270/ha for an expected efficacy of, at most, 10–30%. A spring or summer system is more likely to cost in the region of £400–450/ha but could extend to £675/ha. A maximum of 40–70% efficacy should be expected. Biofumigants also provide benefits from adding organic matter to the soil. A drawback of biofumigation is that it requires more time and attention from the grower than the use of synthetic nematicides. Biofumigation success is also subject to environmental conditions, more so than with granular nematicides. The combination of both management systems is advised for long-term PCN management.

Biofumigant crop damage: pests and pathogens

Biofumigants are susceptible to pest damage and disease, the same as any cash crop. Avoid rotations where biofumigant crops are close to each other or to oilseed rape (*Brassica napus*). Figure 6 shows potential problems, including damage from frost, pigeons, cabbage root fly larvae and clubroot, to biofumigants. Crops can recover from pigeon feeding, but it delays biomass production, enables weeds to compete and causes early senescence. Biofumigant crops can increase the risk of introducing clubroot to oilseed rape or vegetable brassicas. Request information from seed suppliers on varietal resistance to clubroot. Some oil radish varieties are resistant, but most mustards and rocket are not.

Figure 6. Biofumigant damage symptoms: A = frost damage in Indian mustard, B = pigeon damage in oil radish, C = cabbage root fly larvae damage in Indian mustard, and D = clubroot in Indian mustard

Table 2. Summary of biofumigation recomendations for spring and summer windows

Description of operation or crop management input	Comments
Biofumigant selection	Select a high-sinigrin-content Indian mustard biofumigant, and/or a rocket variety high in gluconasturtiin or glucotropaeolin glucosinolates
Preparation of soil and drilling	Drill biofumigants, between mid-July and mid-August, to a depth of 2–3 cm
Seed rate	Use a 8–10 kg/ha seed rate
Nutrient inputs	Apply nitrogen at 100-150 kg/ha, and sulphate at 25-50 kg/ha
Herbicides	Generally not required. If weed burden is high, seek advice from a qualified agronomist
Irrigation	May be required for establishment, to prevent early senescence or ahead of incorporation if soils are below 50% of field capacity (target 25–75% of field capacity)
Timing of maceration and incorporation	Macerate at early to mid-flowering when brassica foliage is still succulent. The best crops should be 50 t/ha of fresh biomass or greater, probably at 1.2–2.0 m in height
Foliage maceration	Use a flail or haulm topper for maceration, fitted with blunt hammer or solid V-tines. Front-mount maceration implements where possible. Keep tractor forward speed as slow as practicable to reduce the bite length of the macerator. The aim is to produce biofumigant pulp
Incorporation of residues	Ideally, rear-mount a rotavator or spader. Other incorporation implements can be used, provided material is well mixed into the top 30 cm of soil and incorporated within 20–30 seconds of maceration. Seal the soil either by smear-roll, heavy flat roll, or by the hood of a rotavator
Planting the next crop in the rotation	Leave at least 2 weeks between incorporating a biofumigant and planting a new crop. This is to avoid phytotoxic effects in the new crop from biofumigant organic matter breakdown

Table 3. Summary of biofumigation recomendations for winter windows

Description of operation or crop management input	Comments
Biofumigant selection	Select an oil radish rich in the glucosinolates gluconasturtiin or glucotropaeolin. Some Ethiopian mustards (*Brassica carinata*) may also be suitable. They are similar to Indian mustard, but hardier
Preparation of soil and drilling	Drill biofumigants to a depth of 2–3 cm between early and mid-September for best establishment
Seed rate	Use a 15–20 kg/ha seed rate (10 kg/ha-for Ethiopian mustard)
Nutrient inputs	Apply nitrogen at 30–40 kg/ha, and sulphate at 15–20 kg/ha
Herbicides	Generally not required. If weed burden is high, seek advice from a qualified agronomist
Irrigation	Typically not required
Timing of maceration and incorporation	Macerate ahead of planting a spring crop. Leave the biofumigant as long as possible to capitalise on partial biofumigation
Foliage maceration	Use best practice where possible. Efficacy is less than in summer and spring systems
Incorporation of residues	Use best practice where possible. Ensure residues are incorporated to at least 25 cm depth. Efficacy is less than in summer and spring systems
Planting the next crop in the rotation	Leave a minimum of 2 weeks between incorporating an overwintered biofumigant and planting a new crop. This is to avoid phytotoxic effects in the new crop from biofumigant organic matter breakdown

References

- International Biofumigation Network: **www.harper-adams.ac.uk/ research/ cipm/23/**
- AHDB PCN Grower Guide: **projectblue.blob.core.windows.net/media/ Default/ Imported%20Publication%20Docs/PCN-Guide659_181102_WEB.pdf**
- AHDB Biofumigation Report: **potatoes.ahdb.org.uk/sites/default/files/ publication_upload/R476%20Final%20Report_180419%20to%20publish.pdf**

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