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Potential of biofumigation for control of diseases caused by soil-borne sclerotial plant pathogens—a review

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Copy 14 of 14

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Contents

1 Executive summary

A literature search was undertaken to review work done and progress to date on soil biofumigation or soil amendment using Brassica crops for control of diseases caused by sclerotial plant pathogens, especially *Sclerotinia* spp. and *Sclerotium cepivorum*. There is much evidence that soil incorporation of *Brassica* green manure as a biofumigant reduces the viability of sclerotia of *Sclerotinia* spp. and *Sclerotium cepivorum* and infection on the economically important crops they affect (e.g. lettuce, onion). Yield and quality of these crops are also increased. However, results with this approach to management of soil-borne diseases have been inconsistent. Other benefits of biofumigants include the high biomass and deep tap root systems of the biofumigant crops, which could improve soil infiltration of water and added nutrients, and increase the organic matter and biological activity in the soil.

Further research is needed to investigate the effect of biofumigants (using *Brassica* spp.) on survival of sclerotia of *S. minor* and *Sclerotium cepivorum* in field soil. Further studies are also needed to find optimum soil conditions for the release of biofumigants, to standardise their methods of application, to understand the modes of action of bioactive compounds when released in the soil, and to optimise their effectiveness.

2 Introduction

Crop rotations are an essential component in sustainable vegetable production. Rotations can improve soil fertility and physical structure, and lower weed, insect and disease pressures. Crop losses caused by soil-borne plant pathogens in most cases would be minimal if related species were not grown in the same field more than once every 5 years, if processed organic materials (e.g. compost or barnyard manure) were incorporated into the soil each year as a source of plant nutrients and to maintain soil structure, and if pathogen-infested residue left by each crop was somehow eliminated.

The trend in modern agriculture, on the other hand, is toward short crop rotations, and even no break periods between crops of the same type. As a result, the variety and importance of root diseases have increased; the pathogens responsible are not new, but they are of increased significance. Fungal pathogens that produce sclerotia (such as *Sclerotinia* spp. and *Sclerotium cepivorum*) are a good example. Both *Sclerotinia minor* (the cause of Sclerotinia Lettuce Drop, SLD) and *Sclerotium cepivorum* (the cause of Allium White Rot, AWR) are economically important soil-borne diseases. Control of these diseases is very difficult because they produce sclerotia that can survive in the soil for many years. Dicarboximide fungicides are effective for control of diseases caused by these pathogens, but there is evidence of loss of efficacy when these fungicides are applied to soil to control these diseases (Beresford et al. 1996).

Modern agriculture probably cannot return to widespread use of crop rotation, and chemical fumigation is too expensive for many growers, except where very high value crops are grown. New methods for control of soil-borne diseases must be found. Biofumigation (or organic amendments) is one approach that could be used to control soil-borne diseases.

Biofumigation is a term to describe the control of soil-borne pests and diseases using *Brassica* plants (Kirkegaard et al. 1993). Brassicas contain a wide variety of glucosinolates (GSLs) in different parts of the plants in varying concentrations. Glucosinolates are precursors of isothiocyanates (ITCs), which inhibit the activity of many soil micro-organisms. The ITCs are released when plants are physically broken up, and during the subsequent hydrolysis of the plant residue in the soil. Biofumigation aims to use the effects of the inhibitory chemicals in Brassicas (fresh or otherwise) in order to reduce the impact of soil-borne pathogens.

The diversity and distribution of GSLs and ITCs among *Brassica* plants has been fully reviewed by Fahey et al. (2001) and Matthiessen & Shackleton (2005). Control of soil-borne plant pests using glucosinolate-containing plants has been reviewed by Brown & Morra (1997). Matthiessen & Kirkegaard (2006) also reviewed opportunities and challenges in biofumigation for managing soil-borne pests and disease.

This review summarises research work done and progress to date on soil biofumigation/amendment for control of diseases caused by sclerotial pathogens, especially *Sclerotinia* spp. and *Sclerotium cepivorum*. It also identifies areas requiring additional study to determine if biofumigation can be used successfully under New Zealand conditions.

3 Methods

A literature search of publications or related information on soil amendment or biofumigation was carried out using the Web of Knowledge, cross-searched using a broad strategy of: topic search = biofumigation AND (lettuce OR onion) or lettuce AND sclerot* AND amendment* or onion AND sclerot* AND amendment. We also had access to CAB Abstracts records from 1973 to the present via the Web of Knowledge.

4 Results

The search gave 16 papers on biofumigation or organic amendment pertaining to the control of *Sclerotinia* spp. and *Sclerotium cepivorum*. The information from the search and other sources is summarised below.

1. *Sclerotinia* spp. on lettuce

SLD (caused by *S. minor*) is a serious disease of lettuce in California, USA. Subbarao et al. (1998) found that incorporation of broccoli residues greatly reduced the number of sclerotia in the soil and reduced the incidence of SLD. Daugovish et al. (2004) found that the incidence of diseases caused by *S. minor* was reduced by 94 and 68% after biofumigation with yellow and oriental mustard, respectively. Incorporation of *Brassica juncea, B. napus* and BQ Mulch (fodder) also reduced SLD severity by 25% compared with an untreated control (Daugovish et al. 2006). Lettuce crop yield and quality were also improved after incorporating fodder radish, *Raphnus sativus*, in infected fields (Ctifl & Sileban 2000). However, Smith et al. (2005) found that mustard crops did not reduce the number of *S. minor* sclerotia and incidence of SLD in the Salinas Valley, California. Poor field results may be due to lack of detailed knowledge of the methods necessary to optimise the efficacy of bioactive compounds in the soil (Matthiessen & Shackleton 2005). In particular, inefficient field incorporation techniques, incomplete conversion of glucosinolates to ITCs, and insufficient ITC potency are thought to affect biofumigation outcomes.

For maximum efficacy, brassica residue must be fully macerated and immediately incorporated into the soil profile. Conversion of the residue to ITCs requires the hydrolysis of glucosinolates by myrosinase (Brown & Morra 1997); since these two compounds are separated in intact brassica tissues, the degree of maceration during incorporation and the moisture status of the soil can greatly influence ITC formation. The concentration of ITCs can also peak very quickly after tissue maceration. Brown et al. (1991) found that the concentration of ITCs peaked 2 hours after incorporation, and decreased by more than 90% within 24 hours. Lazzeri et al. (2004) reported that 40% or more of the initial glucosinolate content was lost if tissue was allowed to dry before incorporation. Delaying incorporation after maceration even by a few hours can therefore substantially reduce potential disease control. Rolling beds immediately after incorporation may also minimise potential volatilisation losses.

However, even with full hydrolysis and soil retention, the total glucosinolate content of many brassica residues is low compared to the active compounds contained in chemical fumigants. This may be offset by selecting varieties that have both a high initial glucosinolate concentration as well as a high overall ITC toxicity; the potency of ITCs can vary considerably between varieties. The distribution of glucosinolates in different parts of the plant may also influence potential disease control. In Tasmania, Villalta et al. (2004) found that BQ Mulch (a biofumigant crop) that produces high levels of ITCs in its roots was more effective in suppressing SLD infection than *Fumus* (mustard), which produces large amounts of ITCs in its foliage.

2. *Sclerotium cepivorum* (AWR) on onion

Smolinska (2000) found that when crushed *Brassica juncea* (mustard) was added to the soil it effectively reduced the viability of sclerotia and consequently reduced the incidence of AWR, raising onion yields. A volatile compound, prop-2-enyl isothiocyanate from mustard, was most toxic to the sclerotia (Smolinska 2004). The incorporation of rape plants as green manure into soil heavily infested with *S. cepivorum* decreased AWR appearance and increased yield compared with an infested untreated experimental control with no added plant residues (Smolinska et al. 2005).

3. Other diseases caused by sclerotial pathogens

Soil incorporation of broccoli residue resulted in fewer cauliflower plants infected by Verticillium wilt (caused by Verticillium dahliae). Plants were taller and had more extensive root systems (Subbarao & Hubbard 1996). Larkin et al. (2006) reported that incorporation of canola, rapeseed and oriental mustard as green manures in potato soil reduced powdery scab by 15–40% and black scurf by 50–85%.

4. Benefits to soil health

Adding crushed *B. juncea* increased the total number of beneficial bacteria, spore-forming bacteria, fluorescent pseudomonads, actinomycetes and beneficial fungi (e.g. *Trichoderma* spp.) in a soil (Smolinska 2000).

In addition to potential disease suppression, brassica cover crops can also result in significant agronomic and environmental benefits. Brassica covers can act as a nitrogen trap (Francis et al. 1998; Hartz et al. 2006), reducing nitrate leaching to ground-water aquifers. In many instances, Brassicas can trap from between 100 and 300 kg N/ha, depending on the final crop biomass and original N status of the soil. Winter covers in general can also significantly reduce surface runoff (Hartz et al. 2006; Miyao & Robins 2001), and therefore have a substantial impact on soil erosion and the loss of soluble and sediment-bound nutrients from fallow fields.

Incorporation of Brassica residue also returns plant-available nutrients to the succeeding economic crop. Increased organic matter can also contribute to improved soil aeration, water infiltration, and soil fertility (Colla et al. 2000; Martini et al. 2003; Pung 2003); all are factors vital to the health and stability of the soil, which is often challenged by intensive land management techniques used in vegetable rotations. Importantly, loss of soil health in itself can have substantial impacts on yield irrespective of increasing soil disease pressures.

5 Summary and recommendations for future research

There is increasing pressure to produce vegetable crops with minimum to zero pesticide input.

To ensure sustainable vegetable production, future control of sclerotial diseases will depend on use of a number of control methods such as biocontrol agents, biofumigant crops and soil amendments, together with reduced fungicide applications, as an integrated disease management strategy.

Reducing fungicide applications can minimise their expense, ensuring that they are only used when required, thus reducing the likelihood of pests becoming resistant to the chemicals.

Many studies have now demonstrated the potential of using Brassica crops for biofumigation purposes. While it is likely that Brassica biofumigation will not fully suppress the effects of soilborne diseases, this approach may lower disease incidence and severity to economically acceptable levels. Importantly, there are still aspects of the technology that require additional investigation to determine if it can be a viable and effective grower option.

The following are recommended for future study.

- Field trials should be done to evaluate the efficacies of a range of biofumigants (with or without biocontrol agents or fungicides) in control of sclerotial diseases in New Zealand soils.
- The effect of biofumigants (using *Brassica* spp.) on survival of sclerotia of *S. minor* and *Sclerotium cepivorum* in field situations should be analysed in New Zealand soils.
- Research should also focus on finding soil conditions and moisture levels that optimise the release of ITCs in order to improve their biological activities and assist in pathogen control.
- New natural soil fumigants (e.g. Biomax) should be evaluated for eradication of sclerotial pathogens in soil.
- Further research is needed to standardise the methods of application of biofumigants, to understand the modes of action of bioactive compounds in the soil, and to optimise their action.

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