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Disease management by Biofumigation in organic farming system

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Abstract
Soil borne diseases are very challenging to control, traditionally chemical soil fumigants were used to manage them but they are harmful to the environment and human health. Biofumigation is based on the incorporation of fresh plant mass into the soil, which will release several substances that would suppress soil-borne diseases. Commonly used biofumigant plants which include brown mustards, white mustards, radishes and rocket species, when these plants are finely chopped (chaffed) and incorporated into the soil, the glucosinolates (GSLs) are converted enzymatically into isothiocyanates (ITCs), the actual active ingredients. Biofumigants mainly target the active stages *viz.*, fungal mycelia, mobile nematodes or germinated weeds. Relative to soil fumigation, biofumigation is economical tool that would provide additional benefits such as, helping to reduce subsequent weed problems, increase soil organic matter, improve nutrient availability and control soil erosion. In this regard, by over viewing the advantages of bio fumigation, it can be used as alternative management strategy for soil borne plant pathogens, which is of utmost importance for the commercial and well developed agricultural sector in developed and developing countries.

Keywords: biofumigation, GSLs, ITCs

Introduction

Disease management is an essential component of the commercial farming. Disease tends to reduce the potential production levels of a crop as per its time of incidence and intensity. The disease management interventions need to be taken up at different stages of cultivation of a given crop. The issue of soil borne plant pathogens and nematodes is becoming more serious in the farming systems which involve narrow crop rotations. Various strategies are being employed to manage them under field conditions. Fumigation of soil using some chemicals is one among them. However, due to environmental hazards associated with fumigation through chemicals, it has become very essential to find some alternatives for the control of soil borne pathogens especially under organic farming. Environmental concern over management of soil borne diseases has led to more interest in finding environmentally friendly alternatives. Biofumigation, performed by the incorporation of rapeseed meal into the soil, has been proposed as an alternative method (Cohen *et al.* 2005; Motisi *et al.* 2010) [4, 18]. Biofumigation is a term that refers to the suppression of soil-borne pathogens by decomposing organic material, including agricultural by products or manure (Gabler *et al.* 2010). The volatile chemicals released during the process have the capacity to reduce fungal, bacterial and nematode pathogens (Matthiessen and Kirkegaard 2006) [13].

Bio-fumigation is a popular concept for the management of soil-borne plant pathogens in the developed countries. J. A. Kirkegaard coined the term biofumigation for the suppressive effects of *plant* species on noxious soil borne organisms that arose quite specifically through liberation of isothiocyanates from hydrolysis of the glucosinolates that is a characteristic feature of the Brassicaceae (Kirkegaard and Matthiessen, 2006) [13]. In a simplified way biofumigation attempted to ascribe, a mechanistic name to a particular part of a general phenomenon of Allelopathic (Whittaker and Feeny, 1971) [22] effects that have been observed in the Brassicaceae for centuries and given them a reputation as poor companion plants (Chew, 1988) [3].

Scope

It is within the broad framework of IDM or “clean and green” ideals, flexibility, choice, producer desires, economic and biological limitations in soil borne disease management solutions that biofumigation has been driven out from its initially descriptive meaning and empirical roots to have a more targeted development in recent years.

It has become a name for a tool that provides an opportunity for management of noxious soil borne organisms in a way that meets many disease management ideals (Brown and Morra, 1997, Kirkegaard and Matthiessen, 2004) [1, 9].

Biofumigants

For using plants as effective biofumigant, ensure that the crop has good growth to maximize biomass and toxins production. It should be well chopped to release biofumigant chemicals and incorporated immediately following chopping to avoid vapour loss. It should be mixed into moist soil to seal in biofumigant and should not be allowed to go to seed (Smita Puri, 2016) [20].

Table 1: Crop plants/fungus suitable for biofumigation and their effect on pathogen

Crop/fungus	Effect
Sorghum	Production of a Cyanogenic glucoside *p*-hydroxy-(*S*)-mandelonitrile-β-D-glucoside compound called Dhurrin, as a substrate of its secondary defensive system that breaks down to release toxic cyanide when plant tissue is damaged due to biotic or abiotic factors (Mojtahedi *et al.* (1993).
Mexican marigold	It can be successfully *used in the c*ontrol of *root-kno*t nematode in roses and It is also used as a trap *c*rop and its root cells react to mechanical and biotic damage by producing terthiophenes which block the development and metabolism of plant pathogens.
Muscodor albus	An endophytic fungus, *M. albus* is also used as a biofumigant for the management of post harvest diseases of fruits and vegetable. It is effective against a wide range of storage pathogens and controlling fungal decay. Biofumigation for 24 h or longer with rye grain culture of *M.albus* controlled brown rot of peaches, caused by *Monilinia fructicola*, and gray mold and blue mold of apple, caused by *Botrytis cinerea* and *Penicillium expansum*, respectively and postharvest lemon diseases (Mercier and Smilanick, 2005) [15].
Ceratocystis fimbriata	Soilborne ascomycete fungus. Recently, it is found that a variety of volatile organic compounds (VOCs) produced by *C. fimbriata* have strong bioactivity against a wide range of fungi, bacteria and oomycetes (Li *et al.* 2015). It a potential player in control of post harvest diseases of fruits through biofumigation. Butyl acetate, ethyl acetate and ethanol were identified as Volatile organic compounds isolated from this fungus.
Brassica spp.	*Brassicas* are the most widely used plant species as biofumigants. The profile, concentration and distribution of different glucosinolates varies within and between *Brassica* species and in different plant tissues, and consequently the concentration and type of biocidal hydrolysis products evolved also varies (Mithen, 1992) [16].

***Source*:** Smita Puri, 2016 [20]

Mechanism/mode of action of bio fumigant crops

Many cruciferous species produce significant levels of glucosinolates (GSLs), which are held in plant cells separately from the enzyme myrosinase and are in themselves not fungitoxic (Manici *et al*. 1997) [12]. However, when plant cells are ruptured the GSLs and myrosinase come into contact and are hydrolysed in the presence of water to release various products, including ITCs (isothiocyanates). ITCs have a wide range of biocidal characteristics and are acutely toxic to a variety of pests and pathogens (Chew, 1987) [3]. GSLs are β-thioglucoside N-hydroxysulfates, with a side group (R) and a sulphur-linked β-d-glucopyranose moiety (Fahey *et al.* 2001) [5] and are classified as aliphatic, aromatic or indole GSLs according to the type of side chain (Fenwick *et al*.). The R group is retained in the ITCs and influences its biological activity.

Among the degradation products of glucosinolates, the isothiocyanates have been generally reported as the most biologically active, being recognized since early in the twentieth century as broad-spectrum biocides (Rosa and Rodrigues, 1999) [19]. ITCs are related to the active ingredient in the commercial fumigants metham sodium and dazomet and are highly toxic to pests and pathogens (Brown and Morra, 1997) [1]. In addition to effect of GSLs related products as a result of incorporating large amounts of organic matter into the soil potentially resulting in improved soil structure, increased nutrient availability, increased water holding capacity and stimulation of beneficial / pathogen-suppressive microbial communities.

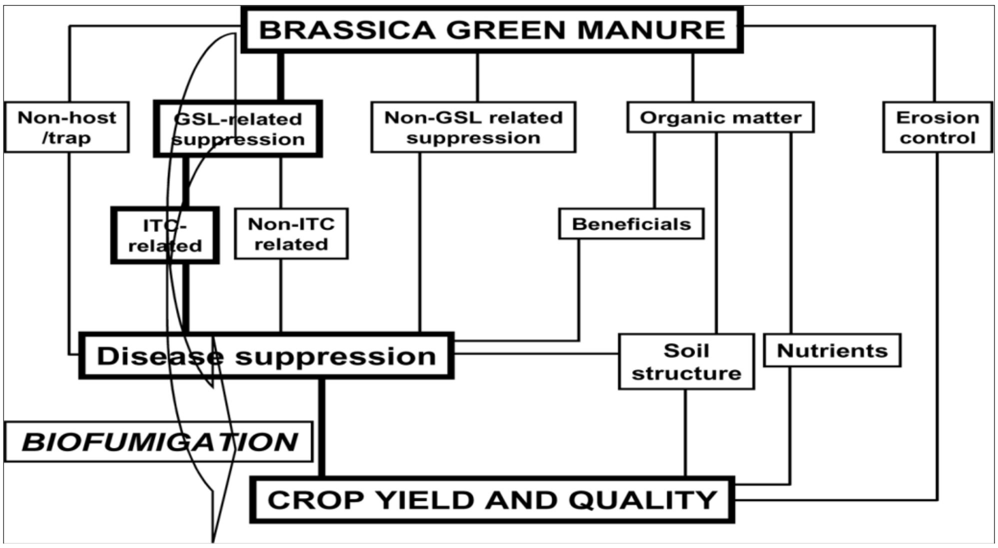

Fig 1: Mechanisms by which *Brassica* green manures can influence the growth and yield of following crops. The pathway by which biofumigation related to glucosinolates (GSL) and isothiocyanates (ITC) is shown by the large arrow. (Kirkegaard and Matthiessen, 2004) [9]

Different ways for use of biofumigant crops for disease control

1. Intercrops and crop rotation with bio fumigants

Several workers reported GSLs and ITCs produced form active rhizosphere which has been implicated in the suppression of pests and pathogens (van Dam et al., 2009) and soil organisms with myrosinase activity have been shown to mediate the conversion of GSLs to ITCs.

2. Incorporation of biofumigants

This is the most recognised use of biofumigant plants where a crop is grown specifically for incorporation with the aim of converting GSLs to ITCs. To achieve high levels of ITC release, comprehensive maceration of plant tissue is required followed by rapid incorporation into soil and addition of water if required to ensure complete hydrolysis (Matthiessen & Kirkegaard, 2006; Kirkegaard, 2009) [13, 8].

Steps involved in incorporation of biofumigants

- When the plants are flowering (60-80% of the stand is in blossom), the glucosinolate concentration in the biomass is at its highest. The above-ground growth must then be chaffed as finely as possible to break down all the plant cells and thereby release the maximum amount of glucosinolates. The chopped plant material should be immediately worked into the soil at a depth of 15-20 cm (e.g. by rotary cutter, disc harrow or spading machine). This can be done directly if the mass is coming from grown crop or with mass taken from other side and brought into the plot or field of interest. In the latter, the soil should be well prepared before the incorporation.
- Irrigating the soil at its field capacity.
- Covering the soil surface tightly with a transparent plastic film, this could be the same as the one used for soil solarization.
- The film is removed 3-4 weeks after and the soil slightly removed in order to permit the gases to escape from soil.
- Planting of the interested crop can be done 24 hours late.

3. Seed meals and other processed biofumigants

seed meal produced after the processing of brassica seeds for oil (e.g. in mustard crops) also offer a convenient source of high GSL material for soil amendment as the myrosinase required for hydrolysis to ITCs remains intact (Brown and Mazzola, 1997). These materials have shown promise against a number of soil borne plant pathogens including Rhizoctonia spp. (Mazzola *et al.* 2007) and Meloidogne spp. (Lazzeri *et al.* 2009) [10].

Conclusion

Biofumigation has good potential for management of a range of soil borne diseases but much more evidence-based research and development is needed to implement the technique more widely in order to address the main issue of variability. This concept could be used for the management of soil borne diseases under protected cultivation and may also have a future in organic agriculture sector in India. The use of biofumigation and biological disinfestation for pest and disease control should be disseminated to the farmers for proper implementation especially where solarisation and other chemical fumigation is not feasible.

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