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Biofumigation: A Potential Aspect for Suppression of Plant-Parasitic Nematodes

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Abstract**—***Plant-parasitic nematode cause economic loss to crops throughout the world. Biofumigation is the environmental friendly control option for the suppression of plant-parasitic as well as other pathogenic soil microbes. Glucosinolates are the main active compound present in some plants which are responsible for biofumigation process. To increase the efficiency of biofumigation selection of varieties containing more glucosinolates is highly desirable. Plant growth stage, soil temperature, soil texture, moisture, soil depth and soil microbes play important role in efficient biofumigation.*

Keywords— Biofumigation, glucosinolate compound, isothiocyanate compound, plant tissue, soil characteristics, soil microorganisms.

I. INTRODUCTION

Agricultural crops are attacking by different insects, fungi, bacteria, viruses and nematodes. Plant-parasitic nematodes are the most common enemy to agricultural production. The plant parasitic nematodes cause about $157 billion annual losses of economic crops worldwide (Abad *et al*.,2008). Chemical nematicides are considered the most effective method in suppressing nematodes population. The chemical nematicides including fumigants such as Ethylene Dibromide, 1, 2-Dibromo-3-Chloro propane, Chloropicrin, Metam-sodium, Dazomet, Methyl Bromide and Methyl Iodide whereas non-fumigants nematicides viz., Aldoxycarb, Carbofuran, Oxamyl, Fenamiphos, Cadusafos and Fosthiazate are the widespread applied methods. These synthetic soil fumigants are highly toxic to pests as well as many beneficial soil organisms (Schreiner *et al*., 2001).Many of these soil fumigants exhibit vertebrate toxicity, high cost, resistance phenomena and other damaging environmental effects (Cox, 2006). Thus, all these negative impacts drive the scientists to find alternative methods of management that are sustainable, economically viable and non-polluting. For sustainable nematode management, it is important to have a holistic approach; taking into consideration cultural, biological and chemical options as part of an integrated management approach. Biofumigation and modified/innovative biofumigation are a sustainable approach to manage soil-borne pathogens, nematodes, insects and weeds. Biofumigation is defined as a process that occurs when volatile compounds with pesticidal properties are released during decomposition of plant materials or animal products(Angus *et al*. 1994;Halberendt 1996; Kirkegaard and Sarwar, 1998; Bello et al., 2000; Piedra Buena *et al*., 2007). Numerous studies in literature confirmed the ability of certain plants to suppress nematodes through the nematicidal activity of the secondary metabolites (Chitwood, 2002; Zasada & Ferris, 2004). Most research on biofumigation, however, has focused on using brassicaceous crops (Kirkegaard and Matthiessen, 2004). The suppressive effect of brassicaceous biofumigants on soil borne pathogens, weeds, and plant-parasitic nematodes has been demonstrated in numerous laboratory, greenhouse, and field studies (Ploeg and Stapleton, 2001; Ploeg, 2008; Zasada *et al*., 2010). The mechanism responsible for the biocidal effect of decomposing *Brassica* crops is thought to be based on a chain of chemical reactions ultimately resulting in the formation of biologically active products (Underhill, 1980). Cruciferous plants belonging to *Brassica* spp. contain glucosinolate compounds which are β-D-thioglucosides, sulphur containing stable and non-toxic compounds located in the cell vacuoles distinguished from one another by differences in their organic side chains (R groups) and classified as aliphatic, aromatic or indole forms, occur in all parts of the plant and degrade via enzymatic hydrolysis (Chew, 1988; Brown *et al*., 1991;Zasada and Ferris, 2004; Padilla *et al*., 2007). Glucosinolates, upon tissue disruption they come in contact with myrosinase (= thioglucosidase), an enzyme endogenously present in *Brassica* tissues, but stored in the cell walls or the cytoplasm, away from the glucosinolates (Poulton and Moller, 1993). The enzymatic hydrolysis of glucosinolates produces volatile isothiocyanates (ITCs), nitriles, SCN-, oxazolidinethione, epthionitriles and organic thiocyanates (Cole, 1976; Fenwick *et al*.,1983; Wathelet *et al*., 2004). The fumigant action of these volatile compounds that are released, suppresses plant pathogens soil-borne pathogens (Sarwar *et al*., 1998; Kirkegaard *et al*., 1993; Kirkegaard &Sarwar, 1998; Piedra Buena *et al*., 2007).

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Although ITCs are considered the most bioactive products, other compounds such as non-glucosinolate sulphur containing compounds, fatty acids, nitriles and ionic thiocyanates may also affect pest and pathogen populations (Matthiessen & Kirkegaard, 2006) .The first observations of the unique properties of GSLs and ITCs were recorded at the beginning of the 17th century (Challenger, 1959). The Family Brassicaceae contains more than 350 genera with 3000 species of which many are known to contain GSL. However, GSLs are not confined to brassicas alone. At least 120 structurally different glucosinolates have been identified in 16 different families of angiosperms. At least 500 species of non-brassica dicotyledonous angiosperms have also been reported to contain one or more of the over 120 known GSLs (Fahey *et al*., 2001). Each of the GSLs has its own chemical property and can be placed in one of three different classes, namely aliphatic, aromatic or indole forms (Zasada &Ferris, 2004; Padilla *et al*., 2007). There are over 100 different types of glucosinolates (Manici *et al*., 2000; Underhill, 1980). A single *Brassica* species can contain several different types of glucosinulates (Sang *et al*., 1984), and the types and quantities of glucosinolates are highly variable between species and even varieties (Rosa *et al*.,1997). As a result, the quantities and types of biocidal ITCs resulting from the breakdown of glucosinolates are higly variable. The nematicidal effect of the tested mustard may possibly be attributed to their high contents of certain oxygenated compounds which are characterized by their lipophilic properties that enable them to dissolve the cytoplasmic membrane of nematode cells and their functional groups interfering with the enzyme protein structure (Knoblock *et al*., 1989; Salem *et al*., 2015).

II. BIOFUMIGATION PROCESS

Incorporation the fresh mass of plant residues into the soil can be done directly if the mass is coming from grown crop or plant mass taken from elsewhere and brought into the plot or field. If the mass is transported to the field, the soil should be well prepared before the incorporation. During transportation of these organic materials in the field, care must be taken to retain the gases produced from biodegradation, by covering the piles of the bio-fumigant with plastic until the time of application. Generally a dose of 50 t to 100 t per ha is recommended depending on nematode population in the field. The bio-fumigant should be distributed uniformly and the field should be watered until the soil is saturated and cover the soil surface tightly with a transparent plastic film for at least 2 weeks. 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 desired crop can be done 24 hours later.

III. ASPECTS THAT INFLUENCE GSL RELEASE AND ITC ACTIVITY

3.1. Plants containing GSL

Most GSL-containing genera, are within the Brassicaceae, Capparaceae and Caricaceae families (Rodman, 1981). The Family Brassicacea (brassicas) contains more than 350 genera with 3000 species, of which many are known to contain GSL. However, GSLs are not limited to brassicas alone. At least 500 species of non-brassica dicotyledonous angiosperms have also been reported to contain one or more of the over 120 known GSLs (Fahey *et al*., 2001). The GSL concentration in the cells of the various plants in the families differs substantially. Therefore, it is important to identify species that will be effective in suppressing soil-borne pests and diseases, including nematodes. The plant species that generally are considered for biofumigation are found mostly in the family Brassicaceae, and include *Brassica oleracea* (broccoli, cabbage, cauliflower, kale), *Brassica rapa* (turnip), *Raphanus sativus* (radish), *Brassica napus* (canola, rapeseed), cv. AV Jade, *Eruca sativa* (salad rocket, arugula), cv. Nemat, , *B. juncea* (Indian mustard) cv. Caliente 199, and various mustards, such as *Sinapis alba* (white mustard) cv. Braco (Sarwar *et al*., 1998; Zasada and Ferris, 2004; Hartz *et al*., 2005; Everts *et al*. 2006; Melakeberhan *et al*., 2006; Roubtsova *et al*. 2007; Ploeg, 2007; Monfort *et al*., 2007; Lopez-Perez *et al*., 2010; Kago *et al*. 2013; Edwards and Ploeg, 2014).

Kwerepe and Labuschagne (2003) found that cruciferous residues at 60 kg/ha caused a higher reduction of *M.incognita*. Youssef and Lashein (2013) reported that crushed cabbage leaves (*Brassica oleracea*) incorporated into the soil at 5 g per pot, 10 days before transplanting of tomato cv. Super Strain B under greenhouse conditions reduce root-knot nematode population.

A thorough distribution of the plant tissue prior to soil incorporation and sufficient soil moisture at the time of tissue incorporation is important (Brown *et al*., 1991; Poulton & Moller, 1993; Morra & Kirkegaard, 2002; Matthiessen *et al*., 2004). This may be explained by quick decomposition of the tested residue in soil on the basis that nematicidal activity by nitrogenous by products depends on the C: N ratio of the amendment (Stirling, 1991). One way to ensure the effective release of ITC is to slash the leaves with a slasher and then to plough the slashed residues into the soil as soon as possible, using a rotavator or disc harrows. A flail chopper ensures the best maceration results and, consequently, a good GL-MYS interaction for the release of ITC. The latter technique remains applicable particularly for the *Brassica* spp. such as mustards, which have a high GSL concentration in the above-ground parts of the plant.

The growth stage of the crop (emergence, rosette, flowering, seed filling, ripening), the amount of biomass produced and the correct incorporation into the soil all contribute towards the success of biofumigation (Bellostas *et al*., 2004).The flowering stage of the plant maintains a higher GSL content than the vegetative plant parts. The GL-MYS interaction can be expected to take place more effectively later in the growing season, prior to seed set. In the root tissue, the concentration of GSL is higher in the earlier root growth stage, with decreasing concentrations during the root growth cycle. Different types of GSLs are present in the roots and shoots of different plant species (Van Dam *et al*., 2009). Studies that were conducted by Van Dam *et al*. (2009), in which the root and shoot GSL of 29 plant species were evaluated for their GSL concentration and profiles, showed that the roots had a higher GSL concentration, as well as more diversity than the shoots. The root and shoot concentration of specific GSLs was found to differ from one another, with the most prominent indole GSL in the shoots being 1H-indol-3-yl GSL, and with the roots having higher concentrations of aromatic 2-phenylethyl GSL.

The inclusion of sulphur fertilizers may improve the nutritional value of *Brassica* spp. Sulphur forms part of the process that takes place in the formation of secondary metabolites. The level of GSLs is dependent on the genetic factors of the plant, but can also vary according to environmental conditions and the availability of soil sulphur (De Pascale *et al*., 2007).

3.2. Soil temperature

Lopez- Perez *et al*. (2005) used some plant residues of broccoli, melon, and tomato with addition of chicken manure in pot experiments with *Meloidogyne incognita* infested soils and was observed that biofumigation to control *M. incognita* is unlikely to be effective under cool conditions but that at soil temperatures around 25ºC, broccoli is more effective than melon and tomato, and that the addition of chicken manure at this soil temperature may enhance the efficacy.This corresponds with earlier results by Ploeg and Stapleton (2001) and with recommendations by Bello *et al*.(2004). Low soil temperature slows down the enzymatic reaction during biofumigation, and therefore incorporation of green manure is not recommended at soil temperatures close to 0°C. The presence of organic matter seems to have an immobilizing effect on the degradation products, thus preventing them from reaching the target pests.

3.3. Soil depth

Roubtsova *et al*. (2007) studied the direct localized and indirect volatile effects of amending soil with broccoli tissue on *M. incognita* infested soil. Amending a 10cm layer lowered *M. incognita* than in the non-amended layers of the tubes by 31 to 71%, probably due to a nematicidal effect of released volatiles of broccoli. These results suggest that the fumigant nematicidal activity is limited and its effect requires a thorough and even distribution of the biofumigant material through the soil profile where the target nematodes occur.

Furthermore, the concentration of ITCs produced is also influenced by soil texture, pH, and microbial community (Bending & Lincoln, 1999; Price, 1999; Morra & Kirkegaard, 2002; Bellostas *et al*., 2004; Griffiths *et al*.,2011).

IV. BIOFUMIGATION IN INTEGRATED PEST MANAGEMENT (IPM)

Biofumigation is a definite choice as part of an integrated approach for nematode management and can be implemented as a biological alternative or in combination with certain chemical options. This will reduce the demands on chemical nematicide use. The positive biological activity of the GSL degradation products used for the suppression of some pathogenic fungi (Manici *et al*., 1997) and nematodes (Lazzeri *et al*., 1993) serves as an integral part of IPM (Lazzeri *et al*., 2004), because it has been proven to be effective against weeds, pathogenic fungi and nematodes (Van Dam *et al*., 2009). In addition to providing some disease control, growing and incorporating the biofumigant plant improves soil structure, assists in weed control, reduces soil erosion and provides organic matter to the organic producer for controlling diseases and pests (Griffiths *et al*., 2011).The potential for Brassicaceous amendment as part of an IPM approach consists of the role of the active compounds, in the direct suppression of nematodes, and also the secondary effect in the soil. The secondary effect plays a very significant part in promoting microbial and other microorganism diversity in the soil, and therefore can be expected to have a positive impact on the stimulation of competition among soil-borne diseases in the rhizosphere.

V. MANAGEMENT OF PLANT-PARASITIC NEMATODES

Many *Brassica* spp. show nematicidal activity on plant-parasitic nematode species such as *M. incognita*, *M. javanica*, *Heterodera schachtii* and *Pratylenchus neglectus*, *C. xenoplax* and *Xiphinema* spp. (Thierfelder & Friedt, 1995; Potter *et al*., 1998; Riga & Collins, 2004;Monfort *et al*., 2007). A liquid formulation has also been developed from defatted *B. carinata* seed meal which has activity against *M. incognita* (De Nicola *et al*., 2013).

VI. CONCLUSION

Soil disinfestation is a major approach against soil borne micro-organisms. The practical value of using biofumigant crops to the farmers should be accessed through several factors which include extent of pesticide efficacy, effect on crop growth and yield as well as cost of production. The benefits of using biofumigant crops and agronomic practices in improving sustainable agricultural production require further exploitation of GSL and ITC to realize the goal of sustainable production with minimal environmental impacts.

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