Chapter 20
Back to the Future: Total System Management (Organic, Sustainable)

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Abstract Many soil disinfestation programs are implemented prior to crop cultivation due to the paucity of therapeutic interventions for controlling soilborne pests. In the 1950s a proliferation of chemical control options ushered in an era of soilborne pest control based upon a single or limited group of chemicals to control target pest organisms. Unfortunately, many chemicals also affected a broad and complex range of nontarget organisms comprising multiple trophic levels. This has necessitated their perpetual use to ensure pest control in agroecosystems where natural pest regulating mechanisms have been compromised. Presently, regulatory issues impact the availability of many chemical pesticides and urbanization of agricultural production regions restrict their use. Future trends further impacting growers include carbon sequestering and trading, increasing demand for biofuels and conservation of natural resources. An alternative, systems-based approach comprised of multiple economic, environmental and social goals is suggested for future crop production. In this total system management approach, creating and promoting conditions suppressive to soilborne pests and the damage they cause is incorporated into the design of the crop production system. For example, the establishment of long-term crop rotational sequences that enhance soil quality, mitigate damaging pest outbreaks, improve the quantity and quality of yields, increase soil carbon sequestration and provide sources of renewable energy. Examples of various approaches to soil disinfestation including a total system management approach are discussed.

Keywords Organic agriculture • Pest management • Soil disinfestation • Soil fumigation • Sustainable agriculture

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20.1 Introduction

Soil disinfestation is defined as any formal process of eliminating soilborne pests or the damage they cause prior to planting susceptible crops (Louvet, 1979; Shanks et al., 2004). Intended to minimize economic risk associated with soilborne pests, soil disinfestation may be achieved through physical (e.g. heat), chemical (e.g. pesticides), biological (e.g. 2,4-diacetylphloroglucinol producing fluorescent *Pseudomonas* spp.), and evasive (e.g. soilless cropping systems) methods. Soil disinfestation practices may combine several different methods of eliminating soilborne pests or the damage they cause. For example, soil solarization combines physical, chemical and biological methods to control soilborne pests (Stapleton, 1998). The common thread uniting soil disinfestation methods and the practices used to implement them is that activities take place prior to planting the susceptible crop.

Many different practices have been developed to accommodate the implementation of soil disinfestation methods. Over the past 50 years, soil fumigation with methyl bromide or mixtures of methyl bromide and chloropicrin has emerged as the most popular soil disinfestation technique world-wide due to its ease of application, low cost, broad spectrum of control and rapid dissipation from soils. With its implication as a major contributor to stratospheric ozone depletion and subsequent phase-out by the signatory countries of the Montreal protocol, considerable attention and resources have been devoted to identify alternatives and several comprehensive reviews of those efforts have been published (Ajwa et al., 2003; Martin, 2003; Schneider et al., 2003). Most studies have focused on 'drop-in' replacements for methyl bromide, i.e. substitutes requiring minimal modifications to existing crop production practices. While direct input substitution may provide the quickest path to replacing methyl bromide it may not be the most desirable. Arriving at more sustainable solutions to soil disinfestation will require the refocusing of attention to the approaches used to manage soilborne pests. In the context of this paper, approach refers to the particular manner in which activities are directed towards eliminating soilborne pests or the damage they cause to agricultural crops prior to planting the susceptible plant hosts. Five basic approaches to developing successful soil disinfestation programs are discussed below with an emphasis placed on a total systems management approach.

20.2 Migratory Approach

A migratory approach to managing soilborne pests has long been practiced in the form of slash-burn or slash-mulch agriculture. This evasive method of soil disinfestation has its origins several millenniums ago and is still practiced today, particularly in the tropics (Peters and Neuenschwander, 1988; Thurston, 1997).

The advantage of slash-mulch over slash-burn is that decomposing, unburned plant debris can exert effects on soil fertility and microbiology (hence disease suppression) over longer durations than the ash produced from burning. In Florida, a migratory approach was advocated up to the 1950s as a means of eliminating risks form soilborne pests in fresh market tomato production (Hayslip et al., 1952). The diminishing availability of new (virgin) land and environmental concerns regarding the destruction of native forests and animal habitats limit the long-term utility of this approach. Another drawback limiting the long-term benefits of this approach is reinfestation of soil by pests after several seasons of crop production. Despite its drawbacks, a migratory approach still has relevancy in modern agriculture. For example, an alternative low-input production system for fresh market tomato employing minimum tillage practices into established bahiagrass (*Paspalum notatum*) pasture was designed, tested and shown to be technically feasible on a large scale (Chellemi et al., 1999). Rotation with bahiagrass pasture was selected because of its regionally availability (>1 million ha) and evidence that extended rotations can significantly reduce the impact of some major soilborne pests of tomato including southern blight (incited by *Athelia rolfsii*), Fusarium wilt (incited by *Fusarium oxysporum*) and root-knot (*Meloidogyne* spp.) nematodes (Dickson and Hewlett, 1989; Rodriguez-Kabana et al., 1991; Brennehaman et al., 1995).

20.3 Farm-Based Approach

Prior to mechanized agriculture and the exploitation of fossil fuel, a farm-based approach was necessary to achieve soil disinfestation in many regions. This approach relies on resources available at the farm level to minimize the impact of soilborne pests. In most cases, physical and biological methods of soil disinfestation are employed. Crop rotation, multi-plantings, and organic amendments were integrated into farm management plans, partly for their benefits to pest management and plant health but also because they could take advantage of locally available resources (Glynne, 1965; Thurston, 1992; Nene, 2003). It should also be noted that prior to the twentieth century, energy constraints were a critical concern during the selection of soil disinfestation techniques and these concerns have recently resurfaced as the price of crude oil continues to rise.

Despite its long history, a farm-based approach is still relevant in present day agriculture. Organic agriculture makes use of this approach by integrating organically based soil disinfestation practices into a farm management plant. Strict requirements regarding the use of inputs necessitate a long-term view of soil disinfestation and the utilization of resources available at the farm site. Sustainable pest management also relies on a farm based approach because farmers must rely upon soil disinfestation practices that make the most efficient use of non-renewable and on-farm resources in addition to biological cycles and controls.

20.4 Single Tactic Approach

A proliferation of chemical control options during the mid twentieth century ushered in an era of soilborne pest control based upon the use of broad-spectrum biocides. The goal of this single tactic approach is to eliminate soilborne pests via a single pesticide application (Chellemi, 2000). Consequently, research objectives focused upon the development and improvement of pesticides and their application, most notably soil fumigants. Under this approach reliable, consistent and economical pest control was achieved with soil fumigants and their effectiveness has contributed directly to the success of many high value crop production systems.

Reliance upon chemical fumigants for soil disinfestation has environmental, social and health consequences. Disruption of soil microbial community structure and the creation of biological vacuums can further exacerbate pest outbreaks (Bollen, 1974; Marois and Mitchell, 1981), leading to the perpetual use of fumigant to ensure pest control. Chemical fumigants are potential ground and surface water contaminants (Federal Register, 2001) and can contribute to stratospheric ozone depletion (WMO, 2007). Agricultural industries dependent upon a single chemical or group of chemicals for soil disinfestation are vulnerable to sudden changes in regulatory policies or input costs. Finally, focusing academic and governmental research programs and the funding that supports them upon additional research to identify, develop and improve pesticides may come at the expense of opportunities and motivation for long-term, high risk ecosystems-based research.

20.5 Integrated Pest Management

Integrated pest management (IPM) involves the coordinated use of multiple tactics to maintain damage from specific pests below an economic threshold and to conserve beneficial organisms. Using concepts introduced by Stern et al. (1959), IPM strives to manage pests using the ecological principals of natural pest mortality factors, predator-prey relationships, genetic resistance and cultural practices. IPM evolved as a successful approach to manage arthropod pests in the 1970s but its adaptation to soil disinfestation programs has proven to be more difficult. In addition to arthropods, soilborne pests include plants (weeds), fungi, bacteria and nematodes. Thus, a broad, multidisciplinary effort is required to develop comprehensive IPM programs. Soilborne plant pathogens are cryptic in nature, limiting the economic and technical feasibility of sampling programs for their detection. Pest populations are regulated by complex interactions involving soil edaphic factors, biological and microbial communities at several trophic levels, and plant hosts. Thus, a further understanding of ecological theories including diversity/stability relationships is required to predict damaging outbreaks. Because soil disinfestation techniques are implemented before planting, economic injury and action thresholds must be made well in advance of the current season's crop.

This is further complicated by a paucity of systemic therapeutic interventions and the technical difficulty of delivering them to active infection courts.

20.6 Total System Management

Central to the total system management approach to soil disinfestation is the premise that indigenous biological communities in agricultural soils limit outbreaks of soilborne pests through naturally occurring, self-regulating ecological feedback mechanisms. As discussed by Levins (1986) and Lewis et al. (1997) a fundamental difference to this approach is that the role of therapeutic interventions, whether biological, chemical, or physical, is deemphasized and they are used only as an occasional supplement rather than the primary means of controlling pests. Suppression of plant disease and parasitic nematodes are regulated by multi-trophic interactions occurring at or near the soil/root interphase including antibiosis, parasitization, competition for infection sites, interference with saprophytic colonization and stimulation of resistance elicitors in the plant hosts. Biological balances among biological communities are maintained within functional fluctuating bounds through a series of feedback loops.

While attractive in theory, consistent, reliable achievement of desired biological balance requires a continuation of scientific efforts to linking soil microbial community structure to ecosystem function and identifying crop management practices that promote the establishment and resilience/stability of desirable soil microbial communities. In recent years, culture-independent, molecular methods have revealed an extraordinary diversity of soil microorganisms (Anderson and Cairney, 2004; Kirk et al., 2004) and have been used to look at the implications of crop and land management practices on soil microbial communities and disease suppression (Buckley and Schmidt, 2001; Saison et al., 2006; Borneman and Becker, 2007; Wu et al., 2007, 2008). There is mounting evidence that substrate-mediated shifts in microbial community structure and activities are critical to establishing and maintaining desirable biological balances. Plant disease incidence and damage from plant parasitic nematodes are generally lower in soils where microbial communities are stimulated by applications of organically-based soil substrates (Drinkwater et al., 1995; van Bruggen, 1995) and where cultural practices have been implemented to improve fertility and stimulate the diversity of soil biota (Abawi and Widmer, 2000; Kratochvil et al., 2004). Examples of general plant disease suppression via substrate mediated stimulation of native microbial communities (Cotxarrera et al., 2002; van Os and van Ginkel, 2001) and specific plant disease suppression through substrate-mediated stimulation of native populations of 2,4-diacetylphloroglucinol-producing *Pseudomonas* spp. (McSpadden Gardener, 2007; Rotenberg et al., 2007) support the concept of developing persistent disease suppressive soils through enhanced activities of resident soil communities. Additional benefits can be achieved via other crop management practices including planting sequences, rotational crops, soil tillage and water management (Mazzola, 2004; McSpadden Gardener, 2007).

Integrating multiple economic, environmental, and social goals into the design of agricultural production systems is a key feature of total system management and will require broad multidisciplinary cooperation to be successfully accomplished. Soil disinfestation goals must not only be compatible with other economic, environmental and social goals, they must support achievement of those goals. For example, in the US corn belt, only 18% of farmers reported using cover crops despite knowledge of their beneficial effects on pest suppression and soil fertility (Singer, 2008). Reasons for the low adoption rate include the cost and time required to plant and manage them. To encourage their use, selection criteria for cover crops should be expanded to include economic goals (e.g. generating immediate cash revenue) and environmental goals (e.g. carbon sequestration and renewable energy). For example, in the southeastern US, high seed oil producing plants are being integrated into methyl bromide dependent vegetable production systems as a beneficial cover crop that also meets environmental and social goals as a source of biofuels that does not impact food supply and economic goals by generating immediate revenue (D.O. Chellemi, 2007, 2008). Another example is the integration of nitrogen fixing cover crops into methyl bromide dependent vegetable production systems to offset the escalating costs and environmental consequences of petroleum-based synthetic sources of N (Teasdale and Abdul-Bakai, 1998).

20.7 Summary

Soil disinfestation is defined as any formal process of eliminating soilborne pests or the damage they cause to agricultural crops prior to planting the susceptible plant hosts. Five different approaches for developing and implementing soil disinfestation programs are discussed: migratory, farm-based, single-tactic, integrated pest management and total system management. The migratory, farm-based, and single tactic approaches have been used successfully over the years, each having their benefits and draw-backs. A total systems management approach with multiple economic, environmental and social production goals is suggested for future crop production systems. In the total system management approach, mitigation of soilborne pest outbreaks is incorporated into the design of the crop production system. For example, selection criteria for cover and rotation crops that suppress soilborne pests and improve soil quality will be expanded to include sources of renewable energy, increased soil carbon sequestration and other economic incentives.

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