Chapter 4

Managing Soil Health and Soil Health Bioindicators through the Use of Cover Crops and other Sustainable Practices

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The foundation of a healthy and productive cropping system relies on a healthy soil environment. Soil health is defined as the capacity of a soil to function within ecosystem boundaries to sustain biological productivity, maintain environmental quality, and promote plant and animal health (Doran and Zeiss, 2000). While the USDA Natural Resources Conservation Service (NRCS) Soil Quality Institute contends that soil quality is comprised of the biological, physical, and chemical properties of soil (USDA-NRCS Soil Quality Institute, 2001); soil health actually depicts soil as a living system, whose functions are regulated by diverse living organisms.

Characteristics of Healthy Soil

A healthy soil is a stable soil that can overcome stress, usually high in biological diversity, and capable of maintaining nutrient cycling. The greater the biodiversity within the soil, the quicker the soil ecosystem can return to initial conditions after exposure to disturbances. A healthy soil should be capable of supporting life processes such as plant anchorage and nutrient supply, retain optimal water and soil properties, support soil food webs, recycle nutrients, maintain microbial diversity, remediate pollutants, sequester heavy metals, and contribute to disease suppression. Disease suppression should be a function of soil health since suppression of pathogens through competition or antagonism helps sustain plant and animal health. From a farmer's perspective, the ability of a soil to remain productive in the face of stresses such as pest outbreaks and tillage is a testament of its health. In summary, soil health has been synthesized into six main characteristics: 1) high biological diversity, 2) high community stability that can provide resilience and self recovery to chemical and biological disturbance, 3) ability to maintain the integrity of nutrient cycling and energy flow, 4) suppression of multiple pests and pathogens, 5) ability to improve plant health, and 6) maintenance of water and air quality.

Soil Health Bioindicators

To evaluate soil health, reliable indicators that allow comparison across ecosystems are needed. Changes in soil quality or health over time are primary indicators of land management sustainability and can be useful information for land managers trying to mitigate practices that reduce the long term viability of their lands. To be a reliable indicator of soil health, an organism should be: 1) sensitive to variations in land

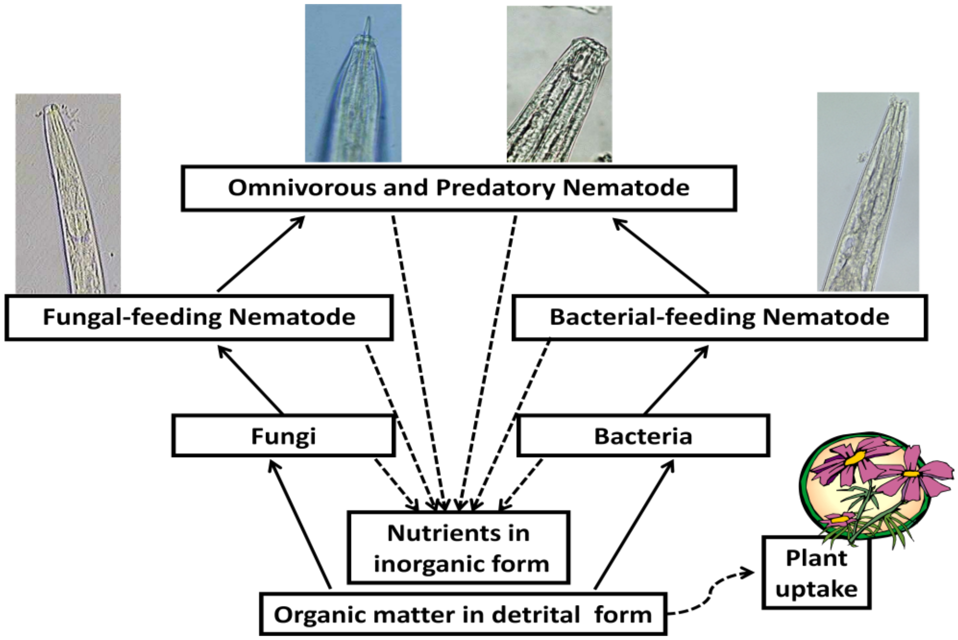

Figure 1. Functional Groups of Free-living Nematodes in a Soil Food Web in Relation to Soil Nutrient Cycling (modified from Ingham et al., 1985).

management, 2) correlated with soil functions, 3) useful for explaining environmental processes, 4) comprehensible and useful to land managers, and 5) easy and inexpensive to measure (Doran and Parkin, 1994). Many soil organisms meet this criterion and thus can be useful indicators of sustainable and non-sustainable land management practices. Nematodes and mites are probably the most studied biological indicators of soil health.

Nematodes as Soil Health Bioindicators

Nematodes can be used as effective soil health bioindicators because they are commonly found, easy to sample, and well classified into functional (feeding) groups, and nematode taxa are well classified. Nematodes have diverse life strategies, ranging from colonizers (short life but high reproduction rate) to persisters (long life, but low reproduction rate). Furthermore, they have the ability to respond readily to changes in the soil's physical and chemical properties. Some nematodes can survive harsh, polluted, or disturbed environments better than others, and some have short life cycles and respond to environmental changes rapidly (e.g., colonizers). Understanding nematode life strategies whether colonizers or persisters can provide information about the level of soil disturbances. Most importantly, nematodes have numerous interactions with other soil organisms and play important roles in soil nutrient cycling. Therefore, nematode faunal analysis provides an insight into soil food web conditions and associated soil health.

In terms of function, nematodes have different life strategies and feeding behaviors in the soil food webs (Figure 1). For example, at the bottom of the food chain are fast-growing, fast-breeding, bacteria-feeding nematodes (bacterivores) and at the top are slow growing, slow reproducing, predatory nematodes. Availability of nutrients from soil organic matter to plants relies on the mineralization (release) of nutrients from the organic matter (immobilized forms). Generally after a soil disturbance, the soil community is dominated by the fast-growing, bacteria-feeding nematodes, then it slowly transforms into a more diverse community consisting of nematodes with various feeding groups (i.e., bacterivores, fungivores, omnivores, and predatory nematodes). Omnivorous nematodes feed on various soil microbes including bacteria and fungi and smaller nematodes. Omnivorous and predatory nematodes are typically the last groups of nematodes to colonize a soil ecosystem after a disturbance. In general, a healthier soil is composed of a diverse mixture of nematode feeding groups.

Availability of nutrients from soil organic matter to plants relies on the mineralization (release) of nutrients from the organic matter. When organic matter is first added into the soil, it is in a form that is unavailable for plant uptake until it is decomposed by bacteria or fungi. After initial decomposition, some organic matter will be converted into an inorganic form that plants can uptake (Figure 1). However, these same bacteria or fungi may tie up (immobilize) nutrients in the soil until they are grazed by bacterivorous and fungivorous nematodes. However, overgrazing by these nematode groups can reduce the overall activity of bacteria and fungi. Fortunately, in the hierarchy of the soil food web, predators such as omnivorous and predatory nematodes, and mites, feed on these bacterivorous and fungivorous nematodes, thus allowing more nutrients to be released into inorganic form for plant to uptake. Thus, an increase in predatory nematodes may contribute to increased nutrient mineralization and associated plant productivity.

Comprehensive studies on nematode faunal analysis have been conducted over the last few decades to validate that nematodes are good soil health bioindicators (Bongers, 1990; Ettema, 1998; Ferris et al., 2001; 2010; Neher et al, 2001). Four nematode community indices commonly used as soil health indicators are maturity index (MI), enrichment index (EI), structural index (SI), and channel index (CI) (Bongers, 1990; Ferris et al., 2001). MI weighted mean of the colonizer-persister (c-p) values of nematodes in all trophic groups, it provides the stability of the nematode community in the soil food web (Yeates and Bird, 1994). EI depicts whether the soil food web is enriched with nutrients, whereas SI illustrates if the soil communities are stable and

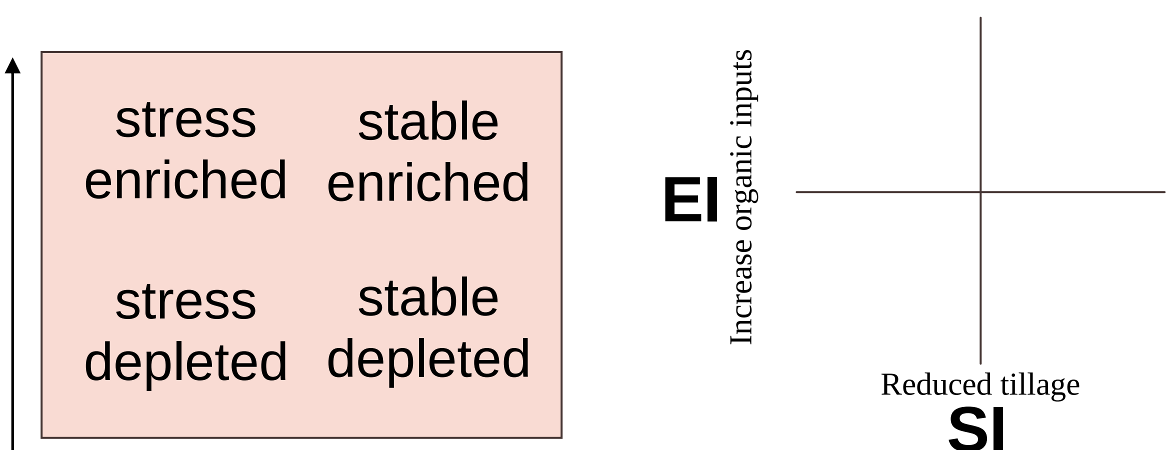

Figure 2. (Modified from Ferris et al., 2001). A Simplified Food Web Structure on Enrichment Index (EI) and Structure Index (SI) trajectories

undisturbed (Figure 2). CI indicates whether the soil food web is diminished by stress or limited in nutrient resources. To give a general perspective, perennial cropping, reduced-till farming systems, and undisturbed natural ecosystems such as forests usually have higher MI and SI than most conventional tillage agro-ecosystems. Conversely, soil recently amended with manure or other organic matter with high N content would have higher EI than those fertilized synthetically. Soil that is drier or being fumigated would have higher CI than soil without external stress. Without high biological diversity, a soil ecosystem would be vulnerable to environmental changes, disturbances and other stresses. Nematode community indices were correlated with concentration of many soil nutrients (Wang et al., 2004a), microbial biomass, plant growth, and even foliar insect damage. Therefore, using nematodes as bioindicators reflects both soil biotic and a biotic factors (e.g. toxin, nutrients), and provides insight into soil health.

Mites as Soil Health Indicators

In addition to nematodes, other soil organisms (e.g., earthworms, collembolans, and mites) play an important ecological role in soil health maintenance through nutrient cycling. Mites are among the most important group of organisms functioning within the soil and play important roles in soil biota interactions. They often constitute 80 percent of all soil arthropods (Peterson and Luxton 1982). Some soil mites are important predators in agro-ecosystems adept to regulating prey populations while others serve as indicators of soil quality, ecological disturbances, and anthropogenic impact (Koehler 1999). Similar to nematodes, mites are commonly found, species rich, and sensitive to soil disturbances. These characteristics make mites ideal candidates for assessing soil health. Furthermore, mites are relatively easy to sample and their taxonomy is well known. Soil mites contribute to the maintenance of soil structure and fertility primarily through grazing on soil fungi, bacteria, algae, eating plant and animal residues, eating each other, nematodes, and other taxa, producing fecal pellets and by transporting microbial propagules (Coleman et al., 2004). Mites influence decomposition by grazing on fungi and soil organisms, thus promoting the formation of humus in the soil. Humus is partially decomposed organic matter that improves the fertility and water retention of the soil and is therefore important for plant growth. As a result of the relationship between soil mite activities and ecosystem processes, changes in mite community can influence soil processes that affect plant productivity (Clapperton et al., 2002). Thus, it has been suggested that any management practice that influences soil mite abundance may impact organic matter decomposition and nutrient availability (Bedano et al. 2006).

Among mite taxa, Oribatidae are probably the most well-known free-living mites. Oribatid mites contribute significantly to nutrient cycling (e.g., mineralization) (Singh et al., 1996) and soil formation (Coleman et al., 2004). Their abundance, species richness, ability to colonize different soil habitats, occupancy of various trophic levels, and dispersal strategies make them ideal candidates for assessing the impact of farm management practices on soil health and quality (Behan-Pelletier, 1999). For example, many species of oribatids are extremely sensitive to cultivation practices (Ruf and Beck, 2005). Their abundance has been associated with changes in soil chemical and physical properties, which were, in turn, correlated with soil fertility and vitality of trees in commercial pine plantations (Hogervorst et al., 1993). Other mite taxa, such as Mesostigmata, consist mainly of predaceous species. Under temperate climate conditions, Mesostigmata mites outnumber other predatory mite groups in their contribution to energy turnover (Luxton, 1982). These small mesoarthropods may be found in soils, litter layers, and on plants (Ruf and Beck, 2005). They prey on other organisms found below the soil, including other arthropods, nematodes, enchytraeids, and small insect larvae and eggs. Mesostigmata and other predatory mites in soil play a major role in the mineralization of carbon (C) and nitrogen (N) (Berg et al., 2001). Predatory mites have variable life history traits. Their diverse habits and life history tactics makes them valuable organisms for biological evaluation and ecological assessment of soils (Ruf and Beck 2005). In addition, the predatory soil mite fauna also appears to be a reliable indicator of environmental quality in forest soils when judged by their life history traits (Ruf, 1998). Low number and diversity of these mites may indicate unfavorable soil conditions for plant growth.

Agricultural Practices That Influence Mites, Nematodes, and Other Soil Health Bioindicators

Free-living soil mites and nematodes comprise a large part of the soil fauna; however, agricultural practices often reduce their numbers and species diversity by altering soil conditions. Soils in agricultural fields are often disturbed and plant residues are not allowed to accumulate on the surface. These practices are detrimental to enhancing the number and diversity of free-living mites (Minor et al. 2004) and nematodes (Neher, 2001). Their abundance, species composition, and diversity in a particular ecosystem are important indicators of the stability of a soil environment (Minor et al., 2004; Neher, 2001). Agricultural practices such as tillage and herbicide applications are activities affecting soil biodiversity. These and other high input chemical and mechanical management practices cause perturbations that are not congenial to mite and nematode population growth. The intensity of soil cultivation and plant cover has been reported to impact the diversity and number of soil invertebrates more than fertilizers and herbicides (Andrén and Lagerlof, 1983). However, the negative impacts of tillage on soil mites may be short-lived, and could be followed by a recovery or increase in numbers if the soil condition becomes favorable (e.g., greater aeration and pore space) (Minor and Norton, 2004).

It should be noted that soil organic matter becomes the limiting factor for mites and nematodes in agricultural soils with low organic resources (Sanchez-Moreno 2009). This may occur in soils where limited plant residues are maintained in the soil (Bedano et al., 2006).

Other production activities indirectly influence nematodes and mites include the use of plastic mulches as weed barriers in crop fields. This may prevent litter from building on the soil surface, thus eliminating a habitat conducive for the establishment of oribatid mites (Minor and Norton, 2004). In general, less disturbed agricultural lands encourage the development of more diverse communities of decomposers which are expected to have a positive influence on soil ecosystem sustainability. Applications of urea and other synthetic N fertilizers may cause a short-term reduction in the soil fauna (Wang et al., 2004b) especially in dry conditions and is believed to result from osmotic stress and ammonia toxicity (Seniczak et al., 1994). The compost or manure applications have been shown to enhance the activity-density of Mesostigmata mites (Koehler, 1999; Minor and Norton, 2004) and nematodes (Neher, 2001).

However, the quality of manure could affect soil mites differently as unlike the composted manure, fresh manure can decrease their number and diversity (Bielska and Paszewska, 1997). This is because the oribatid mite community is mostly regulated by humus rather than other soil parameters. An increase in organic matter (OM) in the litter and humus layers causes an increase in fungal biomass which is the primary food source for oribatid mites (Princz et al., 2010). Thus, OM content indirectly affects juvenile mite production. Similar results were observed for nematodes (DuPont et al., 2009) where cover crop quality as well as quantity is an important determinant of the nature and magnitude of soil food web services using nematodes as indicators.

In summary, soil tillage, application of biocides, reduction of vegetation cover, and the changes in microclimate have been reported to have negative effects on survival and reproduction of soil microarthropods in arable fields. When cultivation is a constant part of production practice, it reduces the period available for the soil fauna to grow (Badejo and Ola-Adams, 2000). Low-input, sustainable agricultural practices such as those associated with organic farming and reduced tillage would enhance soil inhabiting animals compared to conventional farming practices (Bengtsson et al., 2005). Cover crops, crop residues, composts or other plant residue that serve as surface mulch, together with no physical disturbances provide an ecosystem greater opportunity of supporting and maintaining a soil food web that consists of numerous organisms in higher trophic levels (Sanchez-Moreno et al., 2009).

How to Use Cover Crops to Enhance Soil Health

Cover crops are non-cash crops that are typically grown during the offseason or in rotation with an annual cash crop and are typically turned under or sprayed with herbicide prior to planting the cash crop. Organic matter provided by cover crop supports most microbial activities and regulates most soil organisms. Thus, cover crops can be used as an effective tool to help regulate soil faunal composition and ecosystems services, increase functional diversity of the soil fauna, and its associated nutrient cycling.

However, performance of cover crops to enhance soil health varies based on cover crop quality and quantity, cultural practices, history of crop site, and time of planting. Several cover cropping strategies can be used to improve soil health. These include 1) using it

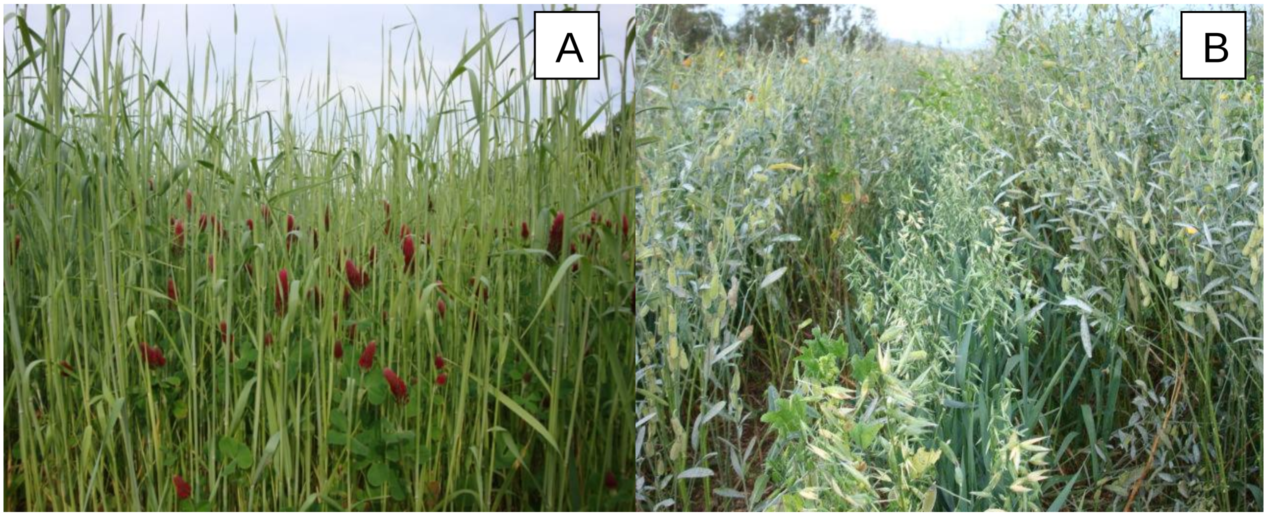

Figure 3. Mix Planting of Leguminous and Graminaceous Cover Crops: A) Crimson clover and rye; B) Sunn hemp and oat to integrate the benefits of high and low C: N organic amendments.

as a green manure which entails incorporating it into the soil prior to cash crop planting; 2) strip-till cover cropping system, where only the rows for planting the cash crop are tilled under and the remaining cover crop remains on the soil surface as a living or hay mulch; 3) no-till system where the cover crop is destroyed by chemical or physical means (e.g. flail mower, cover crop roller), prior to planting the cash crop with a no-till planter; or 4) as a dying mulch in which the cash crop is planted into a senescing cover crop. In the following sections, this chapter will describe how cover crops can be used to enhance soil health by increasing soil biodiversity.

Cover Crops as Amendments

The length of time that cover crop amendments can increase the active fraction of soil organic matter (SOM) after incorporation varies from a few weeks to months depending on the cover crop species. The main factor that contributes to this time difference is the carbon to nitrogen ratio (C:N) of the amendment. In general, leguminous cover crops possess low C:N, whereas, graminaceous cover crops contain high C:N ratio materials. Although amending soil with either of these cover crop materials will result in an increase in soil biodiversity, they have different effects on soil health conditions (Table 1). Based on these differences, there is an increased interest in planting cover crop mixtures with distinct C:N ratios (Figure 3).

Table 1. Effects of Cover Crops with Different C:N Ratios on Soil Health Conditions

Soil Health Conditions	Low C:N	High C:N
	Cover Crop Type - Legumes: (e.g. sunn hemp, crimson clover, vetch, soybean)	**Cover Crop Type - Grasses:** (e.g. rye, oat)
Impact on Nematode Population	Initially numbers of bacterivorous nematodes increase, followed by omnivorous and predatory nematodes; whereas, numbers of fungivorous nematodes increase when organic matter turned into recalcitrant forms.	Fungal decomposition pathways soon dominate after soil incorporation, and result in increasing numbers of fungivorous nematodes.
Speed/Rate of Mineralization	Nutrients in organic matter mineralized quickly and might result in nutrient leaching if timing of cash crop planting is late.	Nutrients in organic matter mineralized at a slower rate.
Fluctuation of Free-Living Nematode Population	Using sunn hemp as an example, abundance of free-living nematodes will peak in two weeks then drop, but it will remain at a higher level than in non-amended soil.	Overall abundance of free-living nematodes will remain relatively high over a longer period of time.
Overall Effect of Nitrogen Availability	Will result in N-enriched soil conditions, but this result will not last for long,	It might stimulate a sudden growth of bacteria that will result in tying up of N availability to plant.

Synchronizing nutrient availability from organic amendment to crop needs is a challenging research endeavor, but provides the greatest opportunity to maximize plant productivity. For example, sunn hemp (*Crotolaria juncea*) cover crop residues when incorporated into the soil caused a peak in bacterivorous nematode numbers two weeks after soil incorporation (Wang et al., 2006), indicating that soil nutrient would be most enriched during this time period. Accordingly, a crop should be planted at the time when it would best benefit from sunn hemp incorporation. A strategy that may be utilized to prolong the nutrient availability from cover crop residues is to use the cover crop as organic mulch. This will provide nutrients for a longer period of time and thus reduce the risk of planting the cash crop at a time when nutrients from the cover crop planting are not available.

Figure 4. Oat cover crop was mowed using flail mower and planting rows were ripped with a 25-mm wide ripper at 15-cm deep. Field was prepared to be transplanted with Kabocha pumpkin seedlings.

Cover Crop as Organic Mulch

Poor soil health is frequently observed with mechanical cultivation, particularly intensive tillage practices such as disc and chisel plowing, ridging, and deep ripping. These practices cause significant loss of organic matter, and create significant disturbance to beneficial soil organisms such as free-living nematodes and soil mites. Thus, conventional tillage practices may temporarily negate soil health benefits gained from cover cropping.

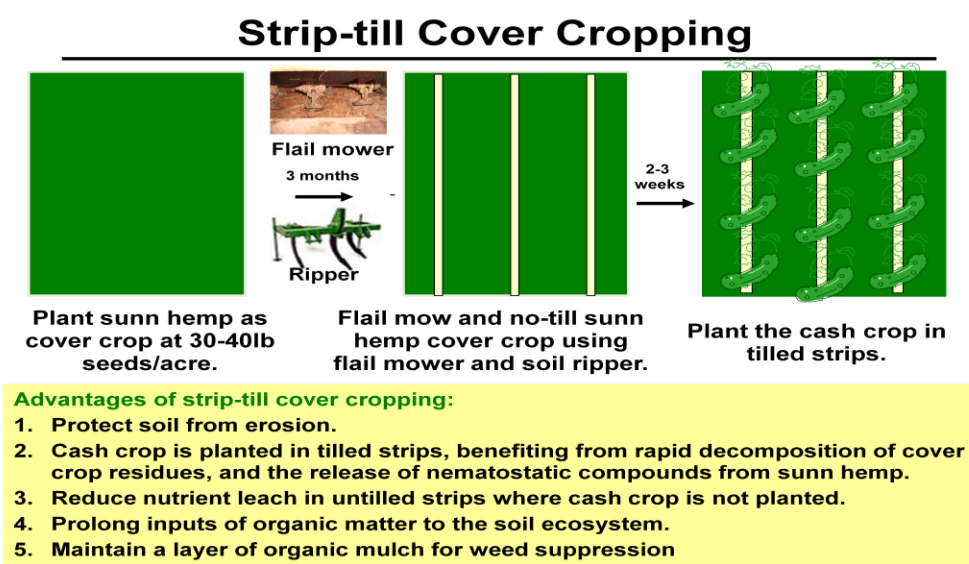

Figure 5. Strip-till of sunn hemp cover crops, followed by cucumber planting, and clipping of sunn hemp living mulch as surface mulch.

Cover crop residues that are allowed to remain on the soil surface as organic mulch in a no-till or strip-till system may provide additional advantages compared to a cover cropping strategy in which the cover crop is incorporated into the soil. Benefits may include slower and longer release of nutrients, maintenance of a layer of organic mulch for weed suppression, and prolonged inputs of organic matter to the soil ecosystem that can enhance free-living nematodes and other soil animals over a longer period of time. In addition, using cover crops as surface mulch mitigates greenhouse gas emission comparable to conventional tillage systems where residues are incorporated into the soil. Table 2 summarizes the impact of various cover crop mulching practices on soil health conditions.

Table 2. (Wang et al, 2008; unpublished data). Effects of Different Cover Crop Mulching Strategies on Soil Health Conditions in Annual Agro-ecosystems

Cover Cropping Strategies	Effects
No-till (Fig. 4)	• Surface mulch provides food source for nematodes and mites, prevents extreme changes in soil temperature, and reduces soil moisture loss. • No-till practice limits soil disturbances compared to conventional practices that include tilling the soil. Reduction in soil disturbance will maintain higher abundance of omnivorous and predatory nematodes and soil mites which are in the higher hierarchy of the soil food web. This allows greater nutrient cycling and helps maintain plant-parasitic nematodes below economically damaging levels. • Significant increase in soil nutrient recyclers through no-till will require more than one cropping cycle.
Strip-till *(Alternate rows of cover crop will be flail mowed, only a narrow strip of 1-2 inches wide will*	• Abundance of bacterivorous nematodes will be enhanced soon after soil incorporation. • Enhancement of omnivorous nematodes will be observed toward the end of the first cash crop cycle, whereas this will not occur in the first cycle in conventionally tilled systems. • Enhances bacterivorous, fungivorous, and omnivorous nematodes sooner and over a longer period of time compared

be tilled, remaining cover crop rows will serve as living mulch Fig. 5)	to no-till or conventional till practices. • Abundances of predatory and omnivorous mites will be significantly higher in no-till or strip-till organic plots as compared to tilled organic or conventional plots.

The strip-till practice described in Table 2 (Figure 5) is one example of terminating a cover cropping practice before cash crop planting. However, there are different tactics available to terminate a cover crop in conservation tillage systems. Of these, herbicides are the most commonly used tools. Non-chemical methods include winter kill, subsurface mechanical tillage, propane flamers, or mowing such as with a flail mower or roller chopper (Sullivan, 2010). For detailed descriptions of each of these approaches, please visit ATTRA website at http://attra.ncat.org/attra-pub/covercrop.html. A preliminary study on the impact of the herbicide glyphosate on nematode communities showed a significant drop in beneficial nematodes shortly after application. However, nematode population levels recovered to levels not different than no-herbicide treatments by the end of a bell pepper cropping cycle (Wang et al., 2006). Impact of each of these no-till practices on free-living nematodes or mites as soil health indicators have not been widely reported, and thus require further research attention.

Concerns of Cover Cropping: Focusing on Nematode Management

The benefits of cover cropping for soil health management need to be evaluated in terms of cash returns to the farm as well as the long-term benefits to agriculture sustainability. Seed and establishment costs need to be weighed against reduced nitrogen fertilizer requirements, the effect on cash crop yields (Sullivan, 2003), and ecosystem health. For more details regarding this evaluation, please visit http://attra.ncat.org/attra-pub/covercrop.html. Despite the potential benefits of cover cropping with respect to improving soil health, care must be taken in choosing the appropriate cover crop. For example, although crimson clover (*Trifolium incarnatum*) is a popular winter cover crop, it is highly susceptible to root-knot nematodes. Thus, growing crimson clover could increase population densities of root-knot nematodes that could prove damaging to the subsequent cash crop. Table 3 lists cover crops known to have nematode suppressive effects against common plant-parasitic nematodes. Farmers encountering nematode pest problems should select cover crops that will enhance populations of beneficial nematodes and predaceous soil mites without supporting populations of plant-parasitic nematodes.

Table 3. Winter or Summer Cover Crops with Nematode Suppressive Effects

Cover Crop	Common Name	Effect on Nematode Pests
<u>Winter Cover Crops</u>		
Aeschynomene americana	American jointvetch	Suppress root-knot nematodes (*Meloidogyne incognita* race 1, *M. arenaria*, and *M. javanica*), but not *M. incognita* race 3 which is a pest of cotton (McSorley et al., 1994).
Brassicacea	Rapeseed Mustard Oil radish	When incorporated into soil, their residues contain glucosinolates that will break down into isothiocyanates and nitriles that suppress nematodes. These cover crops were known to suppress stubby root (*Paratrichodorus* sp.), lesion (*Pratylenchus* sp.), and root-knot (*M. incognita*) nematodes (Brown and Morra, 1997).
Raphanus sativus	Oil radish	Act as a "trap crop" for the sugarbeet cyst nematode. Chemicals from its roots stimulate hatching of nematode eggs. The larvae that emerge are unable to develop into reproductive females, reducing the population densities for the following crop (Hafez, 1998). It also can be used as a green manure to reduce stubby root nematode and root lesion nematode in potato fields.
Brassica napus	Rapeseed	Used as green manure to suppress root-knot and lesion nematodes. Winter rapeseed should be incorporated in early spring (Cardwell and Ingham, 1996).
Lolium multiflorum	Italian ryegrass	Act as a non-host but increase egg hatching of soybean cyst nematode (SCN), *Heterodera glycines*, resulting in a depletion of the lipid reserves of the hatched SCN juveniles (Riga et al., 2001).
Pennisetum glaucum	Pearl millet (Canadian Hybrid 101)	Forage pearl millet (Canadian Hybrid 101) in rotation with potatoes resulted in fewer root lesion nematodes and increased potato yields than rotation with rye (Ball-Coelho et al., 2003).
Secale cereale	Rye	Rye is susceptible to sting nematodes (*Belonolaimus longicaudatus*) (McSorley and Dickson, 1989), but is suppressive to root-knot nematode. Cultivars Aroostook, Elbon, Oklon and Wrens Abruzzi were the most resistant rye cultivars to root-knot nematodes

		(Zasada et al., 2007). When incorporated into soil, the plant tissues release various forms of benzoxazinoids which are responsible for toxicity to root-knot nematodes.
Summer Cover Crops		
Sorghum bicolor × *Sorghum arundinaceum* var. *sudanense*	Sorghum×Sudan grass	When incorporated into soil, releases dhurrin that degrades into hydrogen cyanide, which is nematicidal (Widmer and Abawi, 2000).
Sesamum indicum	Sesame seeds	As a rotation crop with cotton, peanut, and soybean, it suppressed peanut root-knot (*M. arenaria*) and southern root-knot (*M. incognita*) nematodes but not Javanese root-knot (*M. javanica*) (Starr an Black, 1995). It is made into commercial products Dragonfire™ (oil), Ontrol™ (seed meal) (Poulenger, USA), and Nemastop™ (ground up sesame plant) (Natural Organic Products)*.
Crotalaria juncea	Sunn hemp	Act as a poor host of root-knot, reniform, soybean cyst (*Heterodera glycine*) nematodes and etc. When incorporated into soil, it releases monocrotaline that is nematostatic (immobilizes the movement of nematodes) (Wang et al., 2001; Warnke et al., 2008).
Tagetes spp.	Marigold	There are 14 genera of plant-parasitic nematodes suppressed by marigold, among which root-knot and lesion nematodes are most consistently suppressed (Hooks et al., 2010). Gommers and Bakker (1988) suggested that marigold as a standing cover crop (not after incorporation), releases α-terthienyl (nematocidal compound) when the roots are penetrated by nematodes. Marigold roots also enhance activity of endophytic bacteria that might be responsible for nematode suppression (Sturz and Kimpinski, 2004). Unfortunately, marigold is good host to many ectoparasitic nematodes include sting (*Belonolaimus*), stubby root (*Paratrichodorus*), and lance (*Hoplolaimus*) nematodes.
T. erecta	African magiold ('Cracker Jack')	Suppressed lesion nematodes when in rotation with potato (Ball-Coelho et al., 2003). However, it is a good host to reniform nematodes (Wang et al., 2003).
T. patula	French marigold ('Single Gold')	Suppressed many root-knot nematode species (Ploeg, 2002; Ploeg and Maris, 1999).

T. minuta		More tolerant of warm summer temperatures in Florida than the more commonly used marigold species.
Tagetes hybrid 'Polynema'		Suppressed many root-knot nematode species if soil temperature is below 30°C (Ploeg and Maris,1999).
Mucuna pruriens var. *utilis*	Velvetbean	Velvetbean has been shown to suppress some weed species in tropical production systems. In addition, it also releases nematicidal compounds against many plant-parasitic nematodes including root-knot nematodes (Zasada et al., 2006).

* Mention of a trade product does not imply a recommendation by the University of Maryland.

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