Sarath Chandran C. · Sabu Thomas
M. R. Unni *Editors*

Organic Farming

New Advances Towards Sustainable Agricultural Systems

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Preface

Organic farming has received considerable attention recently, especially since 2000. Growing research and academic interest have led to considerable development in this field. With conventional agriculture also following a more sustainable direction, organic farming practices will be inspiring more people towards more ethical directions. With this concept in mind, the main aim of this book is to provide an overview of different perspectives like sustainability and food security, challenges in organic farming, and the role of organic farming in maintaining ecological justice. This book springs from the Inter University Centre for Organic Farming and Sustainable Agriculture, affiliated with Mahatma Gandhi University, Kerala, India.

This book provides an overview of the impact of organic farming practices on the quality of crop production, followed by a discussion on the role of organic farming in protecting water quality. This is followed by a chapter on current status and soil biology impacts of organic farming. The significance of biochar in organic farming and different organic strategies of pest and disease control are also discussed. Organic animal husbandry is then critically evaluated. Finally, the effect of pesticides and their degradation products are discussed in detail.

In short, the contribution of organic farming towards sustainable development, different pest and disease control strategies, organic animal husbandry, and side effects of various pesticides and their degradation products are answered in a unique and updated manner. The Inter University Centre for Organic Farming and Sustainable Agriculture wishes to thank all the authors of this book, and their efforts are gratefully acknowledged.

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Organic Farming in Protecting Water Quality

S. Sivaranjani and Amitava Rakshit

Introduction

Water is a basic necessity for human and ecosystem health, as well as the long-term ecological and socio-economic resilience of our food and farming systems. The agricultural sector bears a large share of responsibility for water consumption and contamination; thus, it must show leadership in conserving and protecting water resources. The use of chemical pesticides and fertilizers in food production leads to the continued deterioration of water quality and raises the costs for society. Efforts to reduce the contamination of ground and surface waters from agricultural sources remain a constant challenge. A large number of water treatment techniques are available, but not all are cost-effective or affordable for small farmers, which leads to the use of poor-quality water in agricultural fields. This chapter reviews how organic farming reduces the deterioration of water quality. Although some progress has been achieved, poor management practices continue to have a negative impact on water quality.

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What Are the Different Ways by Which Water Quality Deteriorates?

Five environmental problems are associated with the improper implementation of conventional and organic cropping practices:

- Nutrient leaching and runoff
- Soil erosion
- Pathogen transport into water bodies
- Pesticide leaching or runoff
- Heavy metal accumulation in soil

Organic Farming

Organic farming claims to have the potential to provide benefits in terms of environmental protection, conservation of non-renewable resources, improvements in food quality, reductions in the output of surplus products, and the reorientation of agriculture toward areas of market demand (Lampkin 1990). Governments have recognized these potential benefits and responded to them by encouraging farmers to adopt organic farming practices, either directly through financial incentives or indirectly through support for research, extension, and marketing initiatives. However, farmers' decisions on whether or not to make the switch from conventional to organic farming have not been studied extensively thus far.

Aims and Definitions of Organic Farming

There are many definitions of organic farming. Mannion (1995) referred to it as a holistic view of agriculture that aims to reflect the profound interrelationship between farm biota, agricultural production, and the overall environment. Scofield (1986) stressed that organic farming does not simply refer to the use of living materials, but emphasizes the concept of "wholeness," implying the "systematic connection or co-ordination of parts in one whole." As Scofield pointed out, the concerns that motivated the early adopters of organic farming included issues of soil health and structure, the exhaustible nature of artificial fertilizers, and human health. According to the Codex Alimentarius (Le Guillou and Scharpe 2001), organic farming involves holistic production management systems (for crops and livestock) that emphasize the use of management practices in preference to the use of on-farm inputs.

One of the most significant expositions of the aims and principles of organic farming is presented in the International Federation of Organic Agriculture

Movements (IFOAM) basic standards for production and processing (IFOAM 2002). According to the principle aims of IFOAM, organic farming involves a clear vision of a major change in society in order to make organic farming possible.

Organic Farming: Environmental Benefits

Water pollution is largely associated with the use and discharge of water in both animal and plant farming. For example, each time water is exchanged in a fish pond, wastewater is discharged to the surrounding surface waters. The wastewater carries a number of pollutants, as reflected in the selected indicators. These pollutants ultimately stem from the chemicals, fertilizers, and feed added to the ponds (Anh 2010). Therefore, in organic farming, water pollution is lower because there is greatly reduced eutrophication of the chemical inputs used in conventional farming systems, such as nitrogen and phosphorous. The soil structure on organic farms also is much better, which leads to less pollution from nitrates and is healthier for the crop plants because it is free of chemicals (Trewavas 2004).

Systems-based organic production practices conserve nutrients, protect water quality, and maintain biological diversity through a combination of the following:

- *Increasing soil organic matter* by returning organic materials to the soil and choosing practices that support a biologically active humus complex.
- *Composting* animal manure and other organic residues to form a more uniform and chemically stable fertilizer material.
- *Timing* the release of nutrients from organic-matter mineralization to coincide with the times when plants are actively growing and taking up nutrients.
- *Using crop rotations for nitrogen fixation* and to recycle nutrients from the soil profile, increase soil tilth through root growth, and provide a diversity of crop residues.
- *Using intercropping practices* to diversify crops in the field, enhance soil fertility, increase the efficiency of nutrient use, and decrease pest pressures.
- *Planting catch crops or cover crops* to recover nutrients that may otherwise leach into the subsoil.
- *Using conservation practices* that reduce the potential for water runoff and wind and water erosion.
- *Providing buffers or filter* areas between cropping areas and water bodies to protect against nutrient and sediment movement into lakes and streams.
- *Managing and monitoring irrigation practices* to enhance nutrient uptake, decrease leaching of nutrients, and minimize root and stem diseases.
- *Controlling pest populations* through cultural practices, enhanced pest-predator balances, and the use of biodegradable pesticides that have low toxicity to beneficial insects, fish, birds, and mammals.

  The keys to both effective crop production and water quality protection are high levels of soil organic matter and an active community of soil organisms.

Nutrient Leaching and Runoff

The two agricultural nutrients of particular concern to water quality and human health are nitrate and phosphorus, as mentioned previously. Nitrate, the common form of nitrogen in soils, is subject to leaching. Unlike potassium, calcium, and magnesium, which are positively charged, nitrate is negatively charged. Positively charged nutrients are able to bind onto most soil particles, including organic matter, because these soil particles have negative charges. Negatively charged nitrate, however, is repelled by negatively charged soil particles. Thus, it is easily transported down through the soil profile and into the groundwater.

Phosphorus is the nutrient of most concern for runoff and erosion losses because this nutrient is limiting in freshwater systems. Therefore, a modest addition of phosphorus to lakes, rivers, or streams can cause nutrient imbalances that stimulate the growth of algae, which in turn limits the access fish have to nutrients and oxygen.

Leaching affects crop growth when nutrients are moved beyond the reach of plant roots. It is of concern to water quality when nutrients are transported into groundwater. Leaching of water and contaminants into groundwater is favored by soils that:

- Are saturated
- Have a high water table
- Have a sandy or gravelly texture
- Have cracks caused by soil drying or tunnels formed by animals or earthworms

Various researchers have reported significantly greater nitrate leaching from conventional practices as compared with organic systems.

How Organic Farming Controls Nutrient Leaching and Runoff

Organic cropping systems control nitrate leaching by stabilizing nitrogen in crop plants used in rotations (Stolze et al. 2000). Adding organic matter to the soil stimulates the growth and reproduction of soil organisms, which also retain soil nitrogen in a relatively stable form (Drinkwater et al. 1998). As decomposition processes continue and the populations of soil organisms increase, they stabilize mineral nutrients in their bodies and in the soil humus fraction. Effective practices to promote the stabilization of nitrogen in this manner include using a legume and forage grass rotation or using non-leguminous plants as cover crops (Granstedt and L-Baeckstrom 2000). Wander et al. (1994) reported that high levels of biological activity in cover-cropped fields corresponded with a greater ability of the soil to hold nitrogen against leaching.

Positive Management Practices to Minimize Nutrient Leaching and Runoff

To ensure that organic production practices are implemented in a manner that protects the environment, the National Organic Practice Standards (National Organic Program 2002a) specifically state that raw manure "must be applied in a manner that does not contribute to the contamination of crops, soil, or water by plant nutrients, pathogenic organisms, heavy metals, or residues of prohibited substances." This requirement provides certifying agents the discretion to prohibit questionable practices, such as applying manure to ground that is frozen or too close to water resources. Sustainable and organic crop production practices used to control nutrient leaching and runoff include the following:

- Nutrient management planning
- Careful management of manure and plant-residue additions to the soil
- Crop rotations, cover crops, and catch crops
- Riparian buffers
- Establishing and managing manure and compost piles in ways that prevent the contamination of rainwater that moves through them

Soil Erosion

Soil erosion is the transportation of soil particles by wind or water. Because these forces most easily move lightweight particles, erosion removes more topsoil, reactive clays, and organic matter than other soil components. Thus, it degrades soil by removing its most fertile components. Soil erosion can also damage surrounding fields and contaminate adjacent water bodies.

Sediments transported by erosion carry attached nutrients, pathogens, and other contaminants. These sediments affect fish habitats by making water cloudy, altering water temperature, and becoming embedded in stream bank areas used for feeding and breeding. Nutrients transported by sediments also cause algae blooms, degradation of fish habitats, and eutrophication. Pathogens attached to sediments can degrade the quality of water for animal and human consumption and increase purification costs if lakes fed by contaminated streams are used as a source of drinking water.

Positive Practices That Minimize Erosion

To protect land against the forces of erosion, use practices that:

- Maintain a cover of growing plants or residues over the soil surface at all times

- Decrease the potential for water to flow off the land and increase the potential for water to infiltrate the soil
- Increase soil organic matter, soil tilth, and water infiltration

Pathogens

Pathogens (disease-causing microorganisms) are often found in manure. The organisms that are of most concern to human health include *Escherichia coli*, *Cryptosporidium*, and *Giardia* (Stehman et al. 1996; IFST 2001). These organisms cause gastrointestinal problems in people who consume contaminated food or water; they pose the greatest threat to young children, the elderly, and people whose immune systems are compromised.

Municipal purification systems chlorinate water to kill *E. coli* and protect the safety of drinking water. However, *Cryptosporidium* and *Giardia* form resistant resting stages (oocysts and cysts, respectively) that are not killed through primary water treatment processes, such as chlorination. Sand filters are required to remove these parasites from water.

The application of fresh manure to growing crops or shortly before planting can contaminate these crops with pathogens. Water from rivers or streams used for crop irrigation can also contaminate plants with pathogens if livestock production operations or septic systems upstream are not properly managed and have allowed fresh waste to flow into the water.

Positive Practices

Rigorously monitoring compost piles, protecting manure and compost piles from rainfall, and applying compost and manure according to standards will minimize or eliminate the risk of crop contamination by pathogens.

The National Organic Standards (National Organic Program 2002b) require that the composting of plant and animal materials occurs at temperatures high enough to kill most pathogenic organisms found in manure. Guidelines provided by the National Organic Standards specify that:

- Compost material must have an initial C:N ratio between 25:1 and 40:1 *and*
- A temperature between 131 °F and 170 °F must be maintained for 3 days using an in-vessel or static aerated pile system *or*
- A temperature between 131 °F and 170 °F must be maintained for 15 days using a wind row composting system, during which period the materials must be turned a minimum of five times.

The National Organic Standards (National Organic Program 2000) seek to minimize pathogen contamination of fresh produce by stipulating when manure can be added to fields. These standards require that when raw manure is used as a nutrient source, it is:

- Soil-incorporated “not less than 120 days before harvest of a crop whose edible portion is in contact with the soil or soil particles” *or*
- Soil-incorporated “90 days prior to harvest for a crop whose edible portion does not have such contact.”

Pesticides

For pest and pathogen control, organic production methods rely primarily on measures such as the use of pest-resistant varieties, cultural control methods, and practices that enhance balances between pests and predators. Pesticides are used as a last resort and are mostly limited to biologically derived substances with low mammalian toxicity. However, some botanical pesticides are toxic to nontarget organisms. Rotenone is toxic to fish, and pyrethrum kills both beneficial and disease-causing insects (Conacher and Conacher 1998). Diatomaceous earth controls insect pests because of its irritant, physically disruptive properties, but it can also be a strong irritant of human lung tissue if not handled with care. Even plant nutrients and substances with relatively low toxicity can become contaminants if applied at excessive rates, close to water sources, or during times when heavy rainfall or flooding is expected.

Positive Practices

Crop production practices that minimize environmental contamination and ecological disruption by pesticides include the following:

- Integrated pest management (IPM) practices that control pest and disease incidence through the use of crop rotations, good sanitary measures, disease-resistant varieties, predatory insect and nematode species, and the targeted application of least-toxic pesticides. For further information, see the ATTRA publication *Biointensive Integrated Pest Management* (Dufour 2001).
- Farm scaping practices that provide habitats for species that are predators of plant pests. For further information, see the ATTRA publication *Farm scaping to Enhance Biological Control* (Dufour 2000).

Heavy Metals

The term *heavy metals* refers to lead, cadmium, arsenic, copper, zinc, and iron. Although the latter three elements are required for plant growth in small amounts, an accumulation of these elements in the soil environment can be phytotoxic (Mikkelsen 2000) and damaging to the growth of soil organisms. The use of copper sulfate as a pesticide can result in the accumulation of copper in the soil. Animal manure can be a source of various other metals. The National Organic Standards (National Organic Program 2002b) prohibit the use of sewage sludge or biosolids because these products tend to have high concentrations of heavy metals. For many years, arsenic was the standard treatment for lumber to protect it against rotting and insect damage. However, public concern regarding the leaching of this toxic substance into groundwater has resulted in federal regulations prohibiting the sale of arsenic-treated lumber starting in 2003.

Other environmental concerns include the following:

- Irrigation practices
- Inappropriate or contaminated soil amendments
- Plastic

Conclusion

Organic farmers can protect against the contamination of water by using practices that conserve and recycle nutrients within the farming system. Such practices are most effective and sustainable when they are implemented as part of an integrated, systems-based approach. Maintaining nutrient balances within fields while minimizing water flows onto fields from off-farm areas, keeping water within fields, and capturing any water that flows away from fields will conserve nutrients on the farm while protecting the environment. The use of a diverse range of plants as rotation crops, cover crops, and intercrops enhances soil quality, facilitates nutrient capture, and helps recycle nutrients that would otherwise be leached through the soil. These crops also provide soil cover, which encourages water infiltration and decreases the potential for nutrient runoff and erosion. Accumulating stores of active organic matter and diverse communities of soil organisms will enhance the soil storage of nutrient reserves while decreasing the potential for transport of these nutrients to ground or surface waters. Composting organic materials will provide a more uniform nutrient and organic-matter source that is less likely to cause biosecurity risks than fresh manure. During storage, both manure and compost piles should be sited on concrete slabs or soils with a low leaching potential, with collection or treatment areas for contaminated runoff water. By using practices that conserve nutrients in your crop fields, you are also protecting the environmental quality of nearby streams, lakes, and rivers.

References

Anh, P. T. (2010). Water pollution by intensive brackish shrimp farming in south-east Vietnam: Causes and options for control. *Agricultural Water Management, 97*(6), 872–882.

Anonymous. (2002). *IFOAM basic standards for organic production and processing*. Victoria: International Federation of Organic Agriculture Movements (IFOAM). 68 pp. http://www.ifoam.org/standard/norms/ibs/pdf. Accessed 12 Dec 2004.

Conacher, J., & Conacher, A. (1998). Organic farming and the environment, with particular reference to Australia: A review. *Biological Agriculture and Horticulture, 16*, 145–171.

Drinkwater, L. E., Wagoner, P., & Sarrantonio, M. (1998). Legume-based cropping systems have reduced carbon and nitrogen losses. *Nature, 396*, 262–265.

Dufour, R. (2000). Farmscaping To Enhance Biological Control (Pest Management Systems Guide). Appropriate Technology Transfer for Rural Areas (ATTRA). pp. 1–8.

Dufour, R. (2001). Biointensive Integrated Pest Management (IPM). Fundamentals of Sustainable Agriculture. http://www.atta.ncat.org/atta-pub/ipm.html (HTML). http://www.atta.ncat.org/atta-pub/PDF/ipm.pdf (pdf).

Granstedt, A., & L-Baeckstrom, G. (2000). Studies of the proceeding crop effect of ley in ecological agriculture. *American Journal of Alternative Agriculture, 15*(2), 68–78.

IFST Public Affairs and Technical & Legislative Committees. (2001). *IFST: Current hot topics. Organic food*. Institute of Food Science and Technology (UK). Accessed at: http://www.ifst.org/hottop24.htm

Lampkin, N. (1990). *Organic farming*. Ipswich: Farming Press. 701 pp.

Le Guillou, G., & Scharpe, A. (2001). *Organic farming: Guide to community rules*. Luxembourg: European Commission. 28 pp.

Mannion, A. M. (1995). *Agriculture and environmental change: Temporal and spatial dimensions*. Chichester: Wiley. 40S pp.

Mikkelsen, R. L. (2000). Nutrient management for organic farming: A case study. *Journal of Natural Resources Life Science Education, 29*, 88–92.

National Organic Program. (2000). Soil fertility and crop nutrient management practice standard, Section 205.203. In: *National organic program final rule*. December 21. Accessed at: http://www.ams.usda.gov/nop/nop2000/nop2/finalrulepages/finalrulemap.htm

National Organic Program. (2002a). Production and handling. Subpart C—Organic crop, wild crop, livestock, and handling requirements. Crop production. Accessed at: http://www.ams.usda.gov/nop/nop2000/Final%20Rule/preamble/pre-prodhandling.htm

National Organic Program. (2002b). National list of allowed and prohibited substances. Subpart 205.600 Evaluation criteria for allowed and prohibited substances, methods, and ingredients. National organic program final rule. Accessed at: http://www.ams.usda.gov/nop/nop2000/Final%20Rule/regtext/reg-natlist.htm

Scofield, A. (1986). Organic farming – The origin of the name. *Biological Agriculture and Horticulture, 4*, 1–5.

Stehman, S. M., Rossiter, C., McDonough, P., & Wade, S. (1996). Potential pathogens in manure. In J. S. Popow (Ed.), *Animal agriculture and the environment: Nutrients, pathogens, and community relations*. Ithaca: Northeast Regional Agricultural Engineering Service.

Stolze, M., Piorr, A., Haring, A., & Dabbert, S. (2000). *The environmental impacts of organic farming in Europe. Organic farming in europe: Economics and policy* (Vol. 6, p. 127). Stuttgart: University of Hohenheim.

Trewavas, A. (2004). A critical assessment of organic farming-and-food assertions with particular respect to the UK and the potential environmental benefits of no-till agriculture. *Crop Protection, 23*(9), 757–781.

Wander, M. M., Traina, S. J., Stinner, B. R., & Peters, S. E. (1994). Organic and conventional management effects on biologically active soil organic matter pools. *Soil Science Society of America Journal, 58*, 1130–1139.

Current Status and Soil Biology Impacts of Organic Conservation Tillage in the US Great Plains

Shabeg S. Briar, Patrick M. Carr, Greta G. Gramig, Fabian D. Menalled, and Perry R. Miller

Introduction

Conservation-tillage practices are replacing conventional-tillage practices throughout semiarid regions in North America and elsewhere because of reductions in soil erosion, increases in stored soil water and organic matter, carbon sequestration, and other ecosystem services. For example, over 50% of the area used for dryland crop production is currently under no-tillage (NT) management in a major portion of the US northern Great Plains (Hansen et al. 2012). These results have spurred interest among farmers and researchers in North America and Europe in replacing conventional tillage with NT farming methods in organic settings so that the benefits which result following this conversion can occur in such systems. Reflecting this, several papers have recently been published which describe efforts by researchers to develop NT organic farming systems (Carr et al. 2013b; Delate et al. 2012; Halde and Entz 2014, Halde et al. 2015; Mischler et al. 2010; Nord et al. 2011).

Research on organic farming has focused on rotational-NT systems, where tillage is not used when growing some crops but is employed when growing others

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(Halde et al. 2014; Mirsky et al. 2012). Success has been reported following adoption of organic rotational-NT systems in subhumid and humid regions of North America (Moyer 2011; Reberg-Horton et al. 2012), and soybean (*Glycine max* L.) production seems particularly suited to rotational-NT (Carr et al. 2013b). Conversely, only mixed success has been reported in drier regions where grain yields were depressed when wheat was grown in an organic rotational-NT system compared with an organic tilled system in Manitoba, Canada (Vaisman et al. 2011). Similarly, grain/seed yields were reduced to >90% when buckwheat (*Fagopyrum esculentum* Moench) and dry bean (*Phaseolus vulgaris* L.) were grown in organic rotational-NT systems compared with tilled systems in the US northern Great Plains (Carr et al. 2013b). Weed competition, lack of plant-available nitrogen, and soil-water deficits have been suggested as explaining the poor performance when crops are grown using organic rotational-NT compared with tilled systems in some environments (Carr et al. 2012; Delate et al. 2012; Vaisman et al. 2011).

Vegetative mulches are relied on heavily to suppress weeds prior to planting grain and seed crops in organic rotational-NT systems. Both broadleaf and grass species have been evaluated for use as cover crops (Shirtliffe and Johnson 2012; Carr et al. 2012; Silva 2014), but the most widely grown cover crops have been winter rye (*Secale cereale* L.) and hairy vetch (*Vicia villosa* Roth) in organic rotational-NT systems (Mirsky et al. 2009, 2012; Mischler et al. 2010; Reberg-Horton et al. 2012). A weed-suppressive, vegetative mulch is created after cover crops are terminated using a roller-crimper (i.e., a steel cylinder with blunt metal blades oftentimes mounted in a chevron pattern) or a mower (Silva 2014). Typically, a winter rye cover crop is rolled-crimped, and then soybean is direct seeded into the vegetative mulch created by the killed cover crop (Nord et al. 2011). Another common practice has been to direct seed maize *(Zea mays* L.) into a vegetative mulch produced by rolled-crimped hairy vetch (Moyer 2011), although the hairy vetch cover crop/maize grain crop sequence has not always been successful (Delate et al. 2012).

It is essential that adequate amounts of aboveground dry matter are produced by cover crops so the vegetative mulch which results following rolling-crimping can suppress weeds adequately. Previous research suggested that somewhere between 5000 and 6000 kg ha^{-1} of vegetative mulch was needed to suppress annual grass weeds and perhaps as much as 12,000 kg ha^{-1} to suppress annual broadleaf weeds (Teasdale 1996). More recently, excellent weed suppression occurred when at least 7000 kg ha^{-1} of the aboveground dry matter was produced by cover crops (Reberg-Horton et al. 2012). Even so, Nord et al. (2011) argued that it was not reasonable to expect a vegetative mulch produced by killed cover crops to be adequate in providing effective weed control without additional tactics being used, particularly in the case of established perennial weeds. We have observed Canada thistle (*Cirsium arvense* (L.) Scop.) emerging through 45-cm-thick wheat straw placed on the soil surface to prevent weed emergence and growth (unpublished data). Rather, the vegetative mulch produced by killed cover crops should be one of several practices used for adequate weed suppression in an organic rotational-NT system.

Organic Continuous-NT Systems

Continuous-NT is common in the US northern Great Plains and similar regions in environments where synthetic fertilizers and pesticides are used. Continuous-NT offers many soil conservation and other ecosystem services compared with tilled systems (Carr et al. 2009; Tanaka et al. 2010). There are environments where persistent wet soils and other factors favor periodic tillage (Hill 1998; Omonode et al. 2006), and there is evidence that some ecosystem services can be maintained when intermittent tillage is used in otherwise continuous-NT systems (Venterea et al. 2006). Other research indicates that some ecosystem services are compromised when even occasional tillage is used. For example, Wortmann et al. (2008) found that a single tillage operation reduced arbuscular mycorrhizal populations by almost 50% when compared with continuous-NT.

Few efforts have been made to eliminate tillage completely when growing crops organically, and results are far from encouraging. Halde et al. (2015) reported results of a 6-year study conducted at Carmen, Manitoba, Canada, where an organic continuous-NT system was compared with an organic tilled system as well as conventional NT and tilled systems where synthetic fertilizers and pesticides were used. Grain yield was 13% lower in the organic continuous-NT system compared with the organic tilled system by the 2nd year of the study. By the 5th year of organic continuous-NT, grain yield had dropped by almost 67%. Severe weed pressure in continuous-NT plots forced abandonment of the study in the 6th year. The researchers concluded that organic continuous-NT was possible over a 4-year period in some environments, though they acknowledged that grain yield would be reduced in this system compared with organic tilled systems.

We completed a study recently in southwestern North Dakota to determine if organic continuous-NT was possible in the US northern Great Plains. Grain yield depression of crops occurred earlier in the organic continuous-NT system in our study than in the earlier Canadian research reported by Halde et al. (2015). For example, no difference in grain yield was detected in the 3rd year of organic continuous-NT compared with tilled treatments in the Canadian study, whereas grain study was depressed by over 40% in the NT plots in our study. However, grain yield reductions of over 60% occurred by the 5th year in both studies, and severe weed infestations in organic continuous-NT resulted in termination of both studies by the 6th year. Failure of rolled-crimped cover crops to provide adequate amounts of vegetative mulch to suppress weeds in some years was reported by Halde et al. (2015), and a similar problem was encountered in our study (unpublished data).

A shift from annual to perennial weed species frequently occurs when tillage is eliminated from a cropping system (Carr et al. 2013a; Melander et al. 2013). Dandelion (*Taraxacum officinale* Weber) became prevalent in organic continuous-NT plots relative to organic tilled plots in the 6-year study conducted at Carmen (Halde et al. 2015). Likewise, infestations of perennial weeds were common in organic continuous-NT plots in our study, particularly over time. In our study, late-season evaluation indicated that dandelion along with Canada thistle and field bindweed was particularly prevalent in continuous-NT plots but was largely absent in tilled plots. Among perennial grass species, crested wheatgrass (*Agropyron cristatum* [L.] Gaertn.), fescue (*Festuca* spp.), and foxtail barley (*Hordeum jubatum* L.) dominated the weed spectrum. This shift to a greater abundance of perennial weed species in organic NT systems may explain partially why Mirsky et al. (2012) and others (Brainard et al. 2013) suggested that organic continuous-NT cannot be achieved.

Annual species tend to dominate the weed spectrum in tilled systems. Barnyard grass (*Echinochloa crus-galli* [L.] Beauv.), green foxtail (*Setaria viridis* [L.] Beauv.), shepherd's purse (*Capsella bursa-pastoris* [L.] Medik.), and wild buckwheat (*Polygonum convolvulus* [L.]) were among the annual species that dominated the weed population in tilled plots in the study reported by Halde et al. (2015), as well as in our study. While annual species contributed a much smaller proportion to the total weed density in NT compared to tilled plots, downy brome along with prickly lettuce (*Lactuca serriola* L.) and tansymustard (*Descurainia pinnata* [Walt.] Britt.) occurred in relatively large numbers in organic continuous-NT plots in our study.

It is worth noting that an integrated weed management program was used in both studies where organic continuous-NT was compared to organic tilled systems. In addition to the production of a vegetative mulch produced by cover crops, sheep (*Ovis aries*) grazed plots every 2 (our study) to 3 (Canadian study) years during selected periods when cover and grain crops were not grown to suppress weeds. Sheep grazing has been used for weed control in cropping systems in the US northern Great Plains (Barroso et al. 2015; Hatfield et al. 2007), but only recently within the context of organic systems (McKenzie et al. 2016). Further, a 20% acetic acid solution was applied prior to planting grain crops in our study, beginning in the 2nd year. In spite of these practices, weed infestations forced abandonment of both studies by the 6th year of organic continuous-NT. These results indicate that organic continuous-NT is not possible presently, even when using multiple weed control tools. However, numerous studies have demonstrated that rotational-NT can be used successively when growing field crops organically (Carr et al. 2013b, Delate et al. 2012; Halde et al. 2014; Halde and Entz 2014; Mischler et al. 2010; Mirsky et al. 2012; Nord et al.; Reberg-Horton et al. 2012). Adoption of rotational-NT is a viable strategy for organic farmers wishing to transition from conventional-tillage systems to conservation-tillage systems so that soil-water conservation and other ecosystem services can be realized.

Conservation-Tillage Impacts on the Soil Food Web

Soil organisms contribute to a wide range of ecosystem services associated with crop production including soil aggregate formation, nutrient cycling, immobilization of toxic compounds, nitrogen fixation, carbon sequestration, and pest suppression (Kibblewhite et al. 2008; Stirling 2014). The processes contributing to these ecosystem services are the result of different assemblages of fauna and flora comprising the soil biological community. The interaction of these organisms in the soil food web, in contrast to their functioning in isolation, is a fundamental concept that was first proposed by Hendrix et al. (1986) and later modified by Kibblewhite et al. (2008).

The sustainability of organic farming depends on the set of plant and animal production practices that emphasize reliance on renewable biological processes, including the cycling of nutrients through the decomposition of cover crops, animal manures, and/or other compounds (Moyniham 2010). Soil food webs in organic farming systems generally are more diverse in species richness and abundance than in systems where synthetic fertilizers and pesticides are used, and the incorporation of plant- and animal-derived organic amendments is aimed at soil food web enhancement. Soil food webs in organic farming systems also play a fundamental role in natural pest regulation or suppressiveness (Ferris et al. 2001; Mäder et al. 2002; Aude et al. 2004; Moyniham 2010).

Soil health is presumed to be the direct expression of the aggregate function of soil macro- and microcommunities which, in turn, are dependent on the physical and chemical conditions of the soil habitat. Any factor affecting a function performed by one group of organisms may affect the functions of other groups. For example, while bacteria and fungi are the primary decomposers in any agroecosystem, fungi dominate decomposition processes in undisturbed soils, while bacteria dominate these same processes in disturbed environments. Therefore, the adoption of conservation-tillage practices favors fungi taking the dominant role in decomposition processes with bacteria taking a secondary role. Similarly, macrofauna (such as earthworms) dominate higher trophic levels in NT systems, while smaller fauna like enchytraeid worms dominate in tilled systems.

Tillage-induced changes to physical and chemical soil properties impact biological activities directly (Zuber and Villamil 2016). Understanding the impacts of tillage practices on soil organisms enables one to select farming practices which protect and sustain biodiversity and maintain ecosystem processes and services (Bertrand et al. 2015; Roger-Estrade et al. 2010; Temme and Verburg 2011). There is a paucity of published information on conservation-tillage impacts on the soil food web in organic farming, so discussions of the potential benefits of tillage reductions on the soil food web health must occur irrespective of the farming system. Further, while current discussions on the soil community at micro-, meso-, and macroscales use biological metrics that are common in the literature, it should be acknowledged that the biological community is more complex and taxonomically diverse than might be inferred. Nevertheless, discussion on the impact of conservation tillage on the soil biological community should elucidate the likely impacts that conservation-tillage practices will have if adopted by organic farmers.

Effect of Conservation Tillage on the Soil Microbial Community

Conservation tillage generally increases soil microbial activity compared to conventional tillage. For example, Gonzalez-Chavez et al. (2010) observed a significant increase in microbial biomass following the adoption of NT, and several studies indicated that soil microbial activity was affected negatively by tillage (Hussain et al. 1999; Kladivko 2001; Sagar et al. 2001; Jinbo et al. 2007). A recent meta-analysis of 62 different studies indicated that microbial biomass and enzyme activities were higher following conversion to NT compared with tilled systems (Zuber and Villamil 2016). Likewise, reductions in tillage and not just complete elimination (as in continuous-NT) increased enzyme activity and microbial biomass. These studies provided compelling evidence that microbial activity and biomass will be enhanced following adoption of NT and other conservation-tillage practices on organic farming systems.

Applications of organic amendments enhance the soil microbial community (Gunapala and Scow 1998; Freckman 1988; Griffiths et al. 1994; Bulluck et al. 2002; Briar et al. 2011). Determining the impact of these amendments on the soil food web is difficult since they typically are incorporated by tillage which has deleterious impacts on the soil microbial community, as previously discussed. Arbuscular mycorrhizal fungi (AMF) are extremely sensitive to soil disturbance, with even moderate tillage completely disrupting the hyphal networks created by this fungal group. This impact on the AMF community has serious repercussions to organic farming since AMF provide ecosystems services related to phosphorus uptake and aggregate stability and are especially important in less intensive agricultural systems (Kabir 2005).

Numerous studies indicate that conservation tillage favors AMF species richness and diversity, spore density, and root infection compared to tilled systems (Jansa et al. 2002; Yang et al. 2012; Köhl et al. 2014; Wetzel et al. 2014). Therefore, negative effects of tillage on AMF are anticipated when used in organic farming systems. Little work has been conducted on the impact of tillage on AMF in environments managed organically. The impact of cultivation on AMF communities under reduced and conventional moldboard plow tillage in an organic farming system was compared in central Europe (Säle et al. 2015). Both AMF spore density and species richness were significantly higher in the top layer of the soils under reduced tillage compared to the cultivated plots.

Impact of Tillage on Nematodes

Nematodes comprise a large fraction of soil microfauna which, in turn, make up a significant portion of the total faunal biomass in agricultural soils (Bardgett and Griffiths 1997; Stirling 2014). Use of ecological indices based on the nematode community analysis for indicating soil food web dynamics has been documented by many researchers (Briar et al. 2007; Sánchez-Moreno et al. 2009; DuPont et al. 2009; Ferris et al. 2012). External organic inputs in the form of compost, animal manures, and cover crops increase energy availability for soil microbes, thereby enhancing microbial activity and biomass, including those of nematodes (Lundquist et al. 1999; Gunapala and Scow 1998; Alon and Steinberger 1999). Therefore, microbial grazers like bacterivorous and frugivorous nematodes respond positively to additions of organic matter to the soil (Ferris and Bongers 2006).

These nematodes make significant contributions to the soil nutrient pool as well as regulate nutrient release into the soil as they graze on soil microbes (Ingham et al. 1985).

Adding organic amendments to the soil enhances population densities of beneficial free-living nematodes in the soil (Wang and McSorley 2005; McSorley et al. 2009). Results of a long-term study in Ohio showed that applications of composted animal manures or hay crop incorporation led to an increase in beneficial free-living nematodes feeding on bacteria and fungi in environments managed organically compared to environments where synthetic fertilizers and pesticides are used (Briar et al. 2007, 2011). However, there was no corresponding increase in large-size predatory or omnivorous nematodes at higher trophic levels in the organic farming system. Consequently, higher trophic links in the soil food web were similar in both systems. Frequent tillage during preparation of the seedbed, mixing of organic manures and cover crops, and cultivation for weed control were likely detrimental to the higher trophic groups. Similar declines in population levels of tillage-sensitive nematode trophic groups occurred in other studies (Fiscus and Neher 2002; Freckman and Ettema 1993; López-Fando and Bello 1995).

The reliance of tillage in organic farming systems appears to be counterproductive to the beneficial effects resulting from additions of organic amendments and cover crops to the soil and the natural progression of the soil food web toward maturity. The higher abundance of beneficial nematodes feeding on bacteria and fungi decomposers is partially offset by the negative impact on the soil microbial community during and after incorporation by tillage. Adoption of conservation-tillage systems and particularly NT could further enhance soil food web nutrient mineralization and maturity (Ferris and Bongers 2006; McSorley et al. 2009; Sánchez-Moreno et al. 2009).

Impact of Tillage on Soil Meso- and Macrofauna

The predominant meso-fauna in the soil are enchytraeids and a variety of collembolans, mites, and small insects collectively known as micro-arthropods, while macrofauna include millipedes, centipedes, spiders, termites, ants, scorpions, and earthworms (Stirling 2014). In general, the higher abundance and diversity of soil biota under conservation-tillage systems can be attributed to the accumulation of crop residues on or near the soil surface, as well as their regulation of both soil temperature and water. The accumulation of crop residues and organic matter in surface layers creates a favorable feeding condition for topsoil-dwelling species (El Titi 2003; Henneron et al. 2015). Surface residues also provide physical protection to shallow surface dwelling micro-arthropods from predators, as well as slow down the rate of soil drying in spring and freezing in winter. This impact on lengthening soil drying rates and buffering soil temperature extends the active period of micro-arthropods, including mites.

Among the soil invertebrate animals, earthworms occupy an important role among soil biota by manipulating soil physical properties and redistributing organic matter throughout the soil matrix, and conservation-tillage practices tend to support higher densities of earthworms (Edwards and Bohlen 1996; Reeleder et al. 2006). Earthworm abundance and biomass were reported to be higher in NT soil, particularly when cover crops were grown, compared with tilled soil, regardless of the crop species grown (Birkas et al. 2004; Chan 2001; Eriksen-Hamela et al. 2009; Metzke et al. 2007). However, earthworm abundance was impacted by the magnitude of tillage, depth of residue burial, and timing of the tillage operations, as well as soil, crop, and climate factors which can sometimes override the impacts of tillage. For example, reduction in earthworm population and biomass due to tillage was higher in finer-textured soils than sandy soils (Joschko et al. 2009; Menalled et al. 2007).

Suggestions for Future Research

Research on the impact of adopting conservation-tillage practices and particular NT in organic farming on the soil food web is limited. Carr et al. (2013a) reviewed research focusing on the effect of conservation tillage in organic farming systems in the USA and Western Europe. Across these studies, there was higher abundance of earthworms under conservation than conventional tillage. Differences in earthworm biomass between tillage treatments were less pronounced and inconsistent across studies, with an average earthworm biomass higher under conservation than conventional tillage in some instances but greater earthworm biomass under conventional tillage in others.

Future research is needed which quantifies the impact of adopting organic rotational-NT on soil micro- and macrofaunal and floral communities, since recent research indicates that organic continuous-NT is not possible using present knowledge and technology. This is particularly true in the US Great Plains and similar semiarid regions, where organic rotational-NT has clear advantages to tilled systems in soil-water conservation and where research on the impacts of rotational-NT on the soil food web are nonexistent. The development of strategies that maximize the likelihood that organic rotational-NT can be adopted successfully, and the benefits this adoption confers to soil food web dynamics, will likely revolutionize organic farming in dry regions globally.

One of the major obstacles preventing widespread adoption of rotational-NT among organic farmers in the US Great Plains and similar regions is inconsistent weed control provided by the vegetative mulch produced by killed cover crops. Screening of species as potential cover crops should continue since cover crops will remain an important component of organic rotational-NT systems. Integrated weed management approaches must be refined so that a suite of biological, cultural, and physical tactics can be bundled which provide effective and consistent control of annual and particularly perennial weeds in organic NT systems. Work is needed to develop strategies which optimize production of aboveground biomass by cover crops, as well as refine the technologies and practices which optimize termination of cover crops and production of a weed-suppressive vegetative mulch.

In many ways, organic rotational-NT is still in the development stage, much like where NT systems were in the 1970s in environments where synthetic fertilizers and pesticides are used. Progress since then largely explains why NT now is the dominant tillage system used on farms in a large portion of the US Great Plains. We suggest that continued research will result in similar progress being made in refining organic rotational-NT strategies such that economic and environmental sustainability can be optimized by adopting rotational-NT systems on organic farms.

References

Alon, A., & Steinberger, Y. (1999). Effect of nitrogen amendments on microbial biomass, above-ground biomass and nematode population in the Negev desert soil. *Journal of Arid Environments, 41*, 429–441.

Aude, E., Tybirka, K., Michelsen, A., Ejrnæs, R., Hald, A. B., & Mark, S. (2004). Conservation value of the herbaceous vegetation in hedgerows-does organic farming make a difference? *Biological Conservation, 118*, 467–478.

Bardgett, R. D., & Griffiths, B. (1997). Ecology and biology of soil protozoa, nematodes and microarthropods. In J. D. van Elsas, E. Wellington, & J. T. Trevors (Eds.), *Modern soil microbiology* (pp. 129–163). New York: Marcel Dekker. Press.

Barroso, J., Miller, Z., Lehnhoff, E., Hatfield, P., & Menalled, F. (2015). Impacts of cropping system and management practices on the assembly of weed communities. *Weed Research, 55*, 426–435.

Bertrand, M., Barot, S., Blouin, M., Whalen, J., de Oliveira, T., & Roger-Estrade, J. (2015). Earthworm services for cropping systems. A review. *Agronomy for Sustainable Development, 35*, 553–567.

Birkas, M., Jolankai, M., Gyuricza, C., & Percze, A. (2004). Tillage effects on compaction, earthworms and other soil quality indicators in Hungary. *Soil and Tillage Research, 78*, 185–196.

Brainard, D. C., Haramoto, E., Williams, M. M., II, & Mirsky, S. (2013). Towards a no-till no-spray future? Introduction to a symposium on nonchemical weed management for reduced-tillage cropping systems. *Weed Technology, 27*, 190–192.

Briar, S. S., Grewal, P. S., Somasekhar, N., Stinner, D., & Miller, S. A. (2007). Soil nematode community, organic matter, microbial biomass and nitrogen dynamics in field plots transitioning from conventional to organic management. *Applied Soil Ecology, 37*, 256–266.

Briar, S. S., Miller, S. A., Stinner, D., Kleinhenz, M. D., & Grewal, P. S. (2011). Effect of different organic transition strategies for peri-urban vegetable production on soil properties, nematode community, and tomato yield. *Applied Soil Ecology, 47*, 84–91.

Bulluck, L. R., III, Brosius, M., Evanylo, G. K., & Ristaino, J. B. (2002). Organic and synthetic fertility amendments influence soil microbial, physical and chemical properties on organic and conventional farms. *Applied Soil Ecology, 19*, 147–160.

Carr, P. M., Martin, G. B., & Horsley, R. D. (2009). Impact of tillage on field pea following wheat. *Canadian Journal of Plant Science, 89*, 281–288.

Carr, P. M., Anderson, R. L., Lawley, Y. F., Miller, P. R., & Zwinger, S. F. (2012). Organic zero-till in the northern U.S. Great Plains region: Opportunities and obstacles. *Renewable Agriculture and Food Systems, 27*, 12–20.

Carr, P. M., Gramig, G. G., & Liebig, M. A. (2013a). Impacts of organic zero tillage systems on crops, weeds, and soil quality. Online. *Sustainability, 5*, 3172–3201.

Carr, P. M., Horsley, R. D., Gunderson, J. J., Winch, T. J., & Martin, G. B. (2013b). Weed growth and crop performance following hairy vetch, rye, and wheat cover crops in a cool semiarid region. *Organic Agriculture, 3*, 149–161.

Chan, K. Y. (2001). An overview of some tillage impacts on earthworm population abundance and diversity- implications for functioning in soils. *Soil and Tillage Research, 57*, 179–191.

Delate, K., Cwach, D., & Chase, C. (2012). Organic no-till system effects on organic soybean, corn, and tomato production and economic performance in Iowa. *Renewable Agriculture and Food Systems, 27*, 49–59.

DuPont, S. T., Ferris, H., & Van Horn, M. (2009). Cover crop quality and quantity affect soil food webs and nutrient cycling in soils. *Applied Soil Ecology, 41*, 157–167.

Edwards, C. A., & Bohlen, P. J. (1996). *Biology and ecology of earthworms*. London: Chapman and Hall. 426 p.

El Titi, A. 2003. Effects of tillage on invertebrates in soil ecosystems. El Titi, A., Soil tillage in agroecosystems. CRC Press, Boca Raton, 261–296.

Eriksen-Hamela, N. S., Sperattia, A. B., Whalena, J. K., Légèreb, A., & Madramootooc, C. A. (2009). Earthworm populations and growth rates related to long-term crop residue and tillage management. *Soil and Tillage Research, 104*, 311–316.

Ferris, H., & Bongers, T. (2006). Nematode indicators of organic enrichment. *Journal of Nematology, 38*, 3–12.

Ferris, H., Bongers, T., & de Geode, R. G. M. (2001). A framework for soil food web diagnostics: Extension of the nematode faunal analysis concept. *Applied Soil Ecology, 18*, 13–29.

Ferris, H., Sánchez-Moreno, S., & Brennan, E. B. (2012). Structure, functions and interguild relationships of the soil nematode assemblage in organic vegetable production. *Applied Soil Ecology, 61*, 16–25.

Fiscus, D. A., & Neher, D. A. (2002). Distinguishing sensitivity of free-living soil nematode genera to physical and chemical disturbances. *Ecological Applications, 12*, 565–575.

Freckman, D. W. (1988). Bacterivorous nematodes and organic matter decomposition. *Agriculture, Ecosystems and Environment, 24*, 195–217.

Freckman, D. W., & Ettema, C. H. (1993). Assessing nematode communities in agroecosystems of varying human intervention. *Agriculture, Ecosystems and Environment, 45*, 239–261.

Gonzalez-Chavez, M. D. A., Aitkenhead-Peterson, J. A., Gentry, T. J., Zuberer, D., Hons, F., & Loeppert, R. (2010). Soil microbial community, C, N, and P response to long term tillage and crop rotation. *Soil and Tillage Research, 106*, 285–293.

Griffiths, B. S., Ritz, K., & Wheatley, R. E. (1994). Nematodes as indicators of enhanced microbiological activity in a Scottish organic farming system. *Soil Use and Management, 10*, 20–24.

Gunapala, N., & Scow, K. M. (1998). Dynamics of soil microbial biomass and activity in conventional and organic farming systems. *Soil Biology and Biochemistry, 30*, 805–816.

Halde, C., & Entz, M. H. (2014). Flax (*Linum usitatissimum* L.) production system performance under organic no-till and two organic tilled systems in a cool subhumid continental climate. *Soil and Tillage Research, 143*, 145–154.

Halde, C., Gulden, R. H., & Entz, M. H. (2014). Selecting cover crop mulches for organic rotational no-till systems in Manitoba, Canada. *Agronomy Journal, 106*, 1193–1204.

Halde, C., Bamford, K. C., & Entz, M. H. (2015). Crop agronomic performance under a six-year continuous organic no-till system and other tilled and conventionally-managed systems in the northern Great Plains of Canada. *Agriculture, Ecosystems & Environment, 213*, 121–130.

Hansen, N. C., Allen, B. L., Baumhardt, R. L., & Lyon, D. J. (2012). Research achievements and adoption of no-till, dryland cropping in the semi-arid U.S. Great Plains. *Field Crops Research, 132*, 196–203.

Hatfield, P. G., Lenssen, A. W., Spezzano, T. M., Blodgett, S. L., Goosey, H. B., Kott, R. W., & Marlow, C. B. (2007). Incorporating sheep into dryland grain production systems II. Impact on changes in biomass and weed density. *Small Ruminant Research, 67*, 216–221.

Hendrix, P. H., Parmelee, R. W., Crossley, D. A., Coleman, D. C., Odum, E. P., & Groffman, P. M. (1986). Detritus food webs in conventional and no-tillage agroecosystems. *Bioscience, 36*, 374–380.

Henneron, L., Aubert, M., Bureau, F., Dumas, Y., Ningre, F., Perret, S., Richter, C., Balandier, P., & Chauvat, M. (2015). Forest management adaptation to climate change: A cornelian dilemma between drought resistance and soil macro-detritivore functional diversity. *Journal of Applied Ecology, 52*, 913–927.

Hill, P. R. (1998). Use of rotational tillage for corn and soybean production in the eastern Corn Belt. *Journal of Production Agriculture, 11*, 125–128.

Ingham, R. E., Trofymow, J. A., Ingham, E. R., & Coleman, D. C. (1985). Interactions of bacteria, fungi, and their nematode grazers: Effects on nutrient cycling and plant growth. *Ecological Monographs, 55*, 119–140.

Jansa, J., Mozafar, A., Anken, T., Ruh, R., Sanders, I. R., & Frossard, E. (2002). Diversity and structure of AMF communities as affected by tillage in a temperate soil. *Mycorrhiza, 12*, 225–234.

Jinbo, Z., Changchuna, S., & Wenyan, Y. (2007). Effects of cultivation on soil microbiological properties in a freshwater marsh soil in Northeast China. *Soil and Tillage Research, 93*, 231–235.

Joschko, M., Gebbers, R., Barkusky, D., Rogasik, J., Höhn, W., Hierold, W., Fox, C. A., & Timmer, J. (2009). Location-dependency of earthworm response to reduced tillage on sandy soil. *Soil and Tillage Research, 102*, 55–66.

Kabir, Z. (2005). Tillage or no-tillage: Impact on mycorrhizae. *Canadian Journal of Plant Science, 85*, 23–29.

Kibblewhite, M. G., Ritz, K., & Swift, M. J. (2008). Soil health in agricultural systems. *Philosophical Transactions of The Royal Society B, 363*, 685–701.

Kladivko, E. J. (2001). *Soil and Tillage Research, 61*, 61–76.

Köhl, L., Oehl, F., Van Der, H., & Marcel, G. A. (2014). Agricultural practices indirectly influence plant productivity and ecosystem. *Ecological Applications, 24*, 1842–1853.

López-Fando, C., & Bello, A. (1995). Variability in soil nematode populations due to tillage and crop rotation in semi-arid mediterranean agrosystems. *Soil and Tillage Research, 36*, 59–72.

Lundquist, E. J., Jackson, L. E., Scow, K. M., & Hsu, C. (1999). Changes in microbial biomass and community composition, and soil carbon and nitrogen pools after incorporation of rye into three California agricultural soils. *Soil Biology and Biochemistry, 31*, 221–236.

Mäder, P., Fliessbach, A., Dubois, D., Gunst, L., Fried, P., & Niggli, U. (2002). Soil fertility and biodiversity in organic farming. *Science, 296*, 1694–1697.

McKenzie, S., Goosey, H., O'Neill, K. M., & Menalled, F. (2016). Impact of integrated sheep grazing for cover crop termination on weed and ground beetle (Coleoptera:Carabidae) communities. *Agriculture, Ecosystems and Environment, 218*, 141–149.

McSorley, R., Seal, D. R., Klassen, W., Wang, K. H., & Hooks, C. R. R. (2009). Non-target effects of sunn hemp and marigold cover crops on the soil invertebrate community. *Nematropica, 39*, 235–245.

Melander, B., Munier-Jolain, N., Charles, R., Wirth, J., Schwarz, J., van der Weide, R., Bonin, L., Jensen, P., & Kudsk, P. (2013). European perspectives on the adoption of nonchemical weed management in reduced-tillage systems for arable crops. *Weed Technology, 27*, 231–240.

Menalled, F. D., Smith, R. G., Dauer, J. T., & Fox, T. B. (2007). Impact of agricultural management on carabid communities and weed seed Predation. *Agriculture, Ecosystems, and Environment, 118*, 49–54.

Metzke, M., Potthoff, M., Quintern, M., Heß, J., & Joergensen, R. G. (2007). Effect of reduced tillage systems on earthworm communities in a 6-year organic rotation. *European Journal of Soil Biology, 43*, 209–215.

Mirsky, S. B., Curran, W. S., Mortensen, D. A., Ryan, M. R., & Shumway, D. L. (2009). Control of cereal rye with a roller/crimper as influenced by cover crop phenology. *Agronomy Journal, 101*, 1589–1596.

Mirsky, S. B., Ryan, M. R., Curran, W. S., Teasdale, J. R., Maul, J., Spargo, J. T., Moyer, J., Grantham, A. M., Weber, D., & Way, T. R. (2012). Cover crop-based rotational no-till grain production in the mid-Atlantic region. *Renewable Agriculture and Food Systems, 27*, 31–40.

Mischler, R., Dulker, S. W., Curran, W. S., & Wilson, D. (2010). Hairy vetch management for no-till organic corn production. *Agronomy Journal, 102*, 355–362.

Moyer, J. (2011). *Organic no-till farming*. Austin: Acres USA.

Moyniham, M. (2010). Status of organic agriculture in Minnesota: A report to the Minnesota legislature 2010. Minnesota Department of Agriculture. Web/URL: http://www.mda.state.mn.us/~/media/Files/news/govrelations/organicstatusreport.ashx

Nord, E. A., Curran, W. S., Mortensen, D. A., Mirsky, S. B., & Jones, B. P. (2011). Integrating multiple tactics for managing weeds in high residue no-till soybean. *Agronomy Journal, 103*, 1542–1551.

Omonode, R. A., Gal, A., Stott, D. E., Abney, T. S., & Vyn, T. J. (2006). Short-term versus continuous chisel and no-till effects on soil carbon and nitrogen. *Soil Science Society of America Journal, 70*, 419–425.

Reberg-Horton, S. C., Grossman, J. M., Kornecki, T. S., Meijer, A. D., Price, A. J., Place, G. T., & Webster, T. M. (2012). Utilizing cover crop mulches to reduce tillage in organic systems in the southeastern USA. *Renewable Agriculture and Food Systems, 27*, 41–48.

Reeleder, R. D., Miller, J. J., Ball Coelho, B. R., & Roy, R. C. (2006). Impacts of tillage, cover crop, and nitrogen on populations of earthworms, microarthropods, and soil fungi in a cultivated fragile soil. *Applied Soil Ecology, 33*, 243–257.

Roger-Estrade, J., Anger, C., Bertrand, M., & Richard, G. (2010). Tillage and soil ecology: Partners for sustainable agriculture. *Soil and Tillage Research, 111*, 33–40.

Sagar, S., Yeates, G. W., & Shepherd, T. G. (2001). Cultivation effects on soil biological properties, micro fauna and organic matter dynamics in Eutric Gleysol and Gleyic Luvisol soils in New Zealand. *Soil and Tillage Research, 58*, 55–68.

Säle, V., Aguilera, P., Laczko, E., Mäder, P., Berner, A., Zihlmann, U., van der Heijden, M. G. A., & Oehl, F. (2015). Impact of conservation tillage and organic farming on the diversity of arbuscular mycorrhizal fungi. *Soil Biology and Biochemistry, 84*, 38–52.

Sánchez-Moreno, S., Ferris, H., Nicola, N. L., & Zalom, F. G. (2009). Effects of agricultural management on nematode – mite assemblages: Soil food web indices as predictors of mite community composition. *Applied Soil Ecology, 41*, 107–117.

Shirtliffe, S. J., & Johnson, E. N. (2012). Progress towards no-till organic weed control in western Canada. *Renewable Agriculture and Food Systems, 27*, 60–67.

Silva, E. M. (2014). Screening five fall-sown cover crops for use in organic no-till crop production in the Upper Midwest. *Agroecology and Sustainable Food Systems, 38*, 748–763.

Stirling, G. R. (Ed.). (2014). *Biological control of plant-parasitic nematodes*. Wallingford: CABI Publishing, CAB International.

Tanaka, D. L., Miller, P. R., Merrill, S. D., & McConkey, B. G. (2010). Soil and water conservation advances in the semiarid Northern Great Plains. In T. M. Zobeck & W. F. Schillinger (Eds.), *Soil and water conservation advances in the United States* (pp. 81–102). Madison: SSSA.

Teasdale, J. R. (1996). Contribution of cover crops to weed management in sustainable agriculture systems. *Journal of Production Agriculture, 9*, 475–479.

Temme, A. J. A. M., & Verburg, P. H. (2011). Mapping and modeling of changes in agricultural intensity in Europe. *Agriculture, Ecosystems and Environment, 140*, 46–56.

Vaisman, I., Entz, M. H., Flaten, D. N., & Gulden, R. H. (2011). Blade roller- green manure interactions on nitrogen dynamics, weeds, and organic wheat. *Agronomy Journal, 103*, 879–889.

Venterea, R. T., Baker, J. M., Dolan, M. S., & Spokas, K. A. (2006). Carbon and nitrogen storage are greater under biennial tillage in a Minnesota corn–soybean rotation. *Soil Science Society of America Journal, 70*, 1752–1762.

Wang, K., & McSorley, R. (2005). Effect of soil ecosystem management on nematode pests, nutrient cycling, and plant health. APSnet Feature Articles. https://doi.org/10.1094/APSnetFeatures/2005-0105.

Wetzel, K., Silvab, G., Matczinskia, U., Oehl, F., & Fester, T. (2014). Superior differentiation of arbuscular mycorrhizal fungal communities from till and no-till plots by morphological spore identification when compared to T-RFLP. *Soil Biology and Biochemistry, 72*, 88–96.

Wortmann, C. S., Quincke, A., Drijber, R. A., Mamo, M., & Franti, T. (2008). Soil microbial community change and recovery after one- time tillage of continuous no-till. *Agronomy Journal, 100*, 1681–1686. https://doi.org/10.2134/agronj2007.0317.

Yang, A. N., Hu, J. L., Lin, X. G., Zhu, A. N., Wang, J. H., Dai, J., & Wong, M. H. (2012). Arbuscular mycorrhizal fungal community structure and diversity in response to 3-year conservation tillage management in a sandy loam soil in North China. *Journal of Soils and Sediments, 12*, 835–843.

Zuber, S. M., & Villamil, M. B. (2016). Meta-analysis approach to assess effect of tillage on microbial biomass and enzyme activities. *Soil Biology and Biochemistry, 97*, 176–187.

Use of Biochar in Organic Farming

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Chapter Overview

There are currently relatively few studies on the use of biochar in organic farming systems, yet there is much that can be learned from historical use charcoal in agriculture and contemporary research in conventional agriculture. From the citrus fields of Japan to basket willow stands of north Great Britain to the famous *Terra Preta* soils of Amazon Basin, farmers have used biochar, the practice of burying charcoal in soil to improve fertility and tilth for centuries. Biochar has recently had a revival in modern agriculture with this carbon (C)-rich material being widely used as a means of improving soil tilth and promote a more sustainable agriculture. The purpose of this chapter is to briefly describe the nature and properties of biochar and its potential impact on the fertility and function of soils following incorporation with an emphasis on organic agriculture. We briefly review biochar generation and limitations associated with centralized production and distribution. We then discuss in detail the influence of biochar application on soil properties and crop production using organic examples where possible. Finally, we discuss the specific use of biochar in organic farming systems and highlight the San Juan Island experience wherein replicated studies were conducted on ten independent organic farms to assess the influence of locally produced wood biochar on soil properties and processes and crop productivity on the San Juan Islands, WA, USA.

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Introduction: Biochar History and Use in Agricultural Systems

Biochar is a carbon (C)-rich, stable solid material that is generated from the pyrolysis or thermochemical decomposition of organic material in an oxygen-limited environment under controlled condition, and it differs from charcoal generated during wildfires (DeLuca and Aplet 2008) or that produced for fuel as biochar is specifically generated for use as a soil amendment, while charcoal is commonly produced as an energy carrier (Lehmann and Joseph 2015). Biochar can be made from a variety of materials including forest or crop residues, municipal solid waste, or biosolids (Brown et al. 2015). The C-rich nature of biochar combined with its unique resistance to decomposition has resulted in it being discussed as a means of abating climate change by sequestering C when applied to soils (Lehmann et al. 2006). Besides, the morphological characteristics of biochar might also alter soil hydrological properties and subsequently affect soil nutrient transformations (DeLuca et al. 2015b). It has therefore become a topic of unique interest in soil science (Atkinson et al. 2010), and the numbers of papers published annually on the subject have increased exponentially over the last 20 years (Gao and DeLuca 2016).

Despite the fact that the term "biochar" was introduced only recently, the original idea for using charcoal in agriculture dates back thousands of years. The "Amazon Dark Earth" or *Terra Preta* soils found in the Amazon River Basin was reported to have been established by aboriginal cultures thousands of years ago yet remain some of the most fertile and high biodiverse soils in the Amazon today. The origin of *Terra Preta* remains unclear but was ascribed to the large proportion of char that remains in these soils makes it unlikely that it was a product of biomass burning (slash-and-burn farming), but it is not clear whether the "biochar application" was intentional (Glaser and Birk 2012) or a means of sanitary waste management in populated areas of the Amazon basin. Olarieta et al. (2011) indicated that an ancient method named "formiguer," the structure of which is somehow similar to a charcoal kiln, was largely used in the Mediterranean region to produce "soil-fertilizing material" with dried woody vegetation up to the 1960s. Pioneering work on the agricultural use of biochar in combination with composting techniques was shown to have been performed by farmers in Japan since early twentieth century (Ogawa and Okimori 2010). Farmers would use rice husks and other farming residues to produce charcoal using traditional earthen kilns and use them largely as soil improvers or odor absorbents (Nishio 1996). However, in-depth investigation of the beneficial effects of biochar on agricultural soils received little attention by Japanese scientists until the early 1980s (Saito 1990).

As noted above, the number of papers addressing the use of biochar in agricultural ecosystems have increased dramatically, with the focus largely being soil C storage and sequestration (Lehmann et al. 2006), management of greenhouse gas emissions (He et al. 2017), soil fertility and nutrient management (Nguyen et al.

2017), and crop productivity (Jones et al. 2012; Griffin et al. 2017). Given the broad interest in achieving more sustainable agricultural ecosystems while maintaining food security, there is increasing interest in understanding how biochar application fits into this framework, particularly for organic farming systems that rely on natural soil amendments and seek to minimize environmental impacts (Wezel et al. 2014; Reganold and Wachter 2016). Herein we describe the nature and properties of biochar, its potential impact on the fertility and function of soils following incorporation, and highlight recent research using biochar in on-farm organic field trials.

Biochar Generation and Properties

Biochar Generation

Charcoal production through wood carbonization has been practiced for thousands of years; however, the ancient method for producing *Terra Preta* by earthen-pit burning may have released a large amount of greenhouse gases and volatiles back into the atmosphere (Brown et al. 2015). Modern biochar production involves some form of pyrolysis, a thermal-chemical conversion process, of agricultural or forestry biomass residues. A variety of carbonization technologies associated with pyrolysis or gasification reactors have been developed to pyrolyze organic material and produce biochar, and this production can be done on either large or small scale (Boateng et al. 2015).

Large-scale centralized biochar generation typically involves reactors that can process 2000 metric tons of dry biomass per day, either through pyrolysis under relatively low heating rate (approximately 100 °C min^{-1}), namely, slow pyrolysis, or high heating rate (on the order of several hundred °C s^{-1}) such as fast pyrolysis or gasification (Wright et al. 2010; Verma et al. 2012). Slow pyrolysis reactors can be further classified as kilns or retorts where kilns are typically used in traditional charcoal making without recovering the subsequent liquid fractions, whereas retorts capture gaseous and liquid fractions during pyrolysis process (Boateng et al. 2015). Fast pyrolysis or gasification typically has lower percentage of biochar yield (15–20%) compared to slow pyrolysis (20–50%) where those reactors are intended to maximize the production of high-value energy product (bio-oil or syngas) with biochar as a by-product. Although large-scale centralized pyrolysis systems have higher efficiency in processing agricultural or forestry residues, long-haul distances can more than double the break-even price of biochar (Schackley et al. 2015) reducing attractiveness of biochar to agricultural operations. Further, monetizing the value of biochar applications to agricultural operations is challenging given the variable and perhaps long-term benefits of biochar to landowners or land managers.

Therefore, distributed biochar production by low-tech pyrolysis kilns or simple mobile units may increase the attractiveness of biochar to farms that generate small quantities of biochar using local resources.

Typically, small-scale systems for biochar production utilize slow pyrolysis which involves longer processing time yet higher yields of biochar (Odesola and Owoseni 2011). Such systems can process 0.5–1 metric ton of biomass per hour and can be distributed on small properties and operated on farms (Nsamba et al. 2015). Schmidt and Taylor (2014) described a "Kon-Tiki" method which follows the principle of pyrolyzing biomass layer after layer in an open, conically built metal kiln (Schmidt and Taylor 2014). Briefly, a fire is started in the kiln to burn the first layer of biomass into embers on the bottom of the kiln; a thin layer is then added on top of the embers and being heated quickly to be carbonized. When ash starts to appear and the fire becomes hot, the next layer of biomass is homogenously spread on top. Energy from both the flames above and the layer below will start to pyrolyze fresh biomass. The manual layering of biomass is repeated until the kiln is filled, and the reaction is stopped by quenching with water or a layer of soil on top. The generated biochar below the upper pyrolyzing layer is shielded from oxygen flow and thus oxidation. Syngas generated during the process will simultaneously react with combustion air entering from the top of the kiln, producing heat and partially self-sustaining the system. This fast, easy-to-operate biochar production method has been reported to be low in greenhouse gas emissions and can produce roughly 750–850 L of biochar within 4–5 h (Schmidt and Taylor 2014). It has been continuously improved and widely used in many small-scale farming operations (Cornelissen et al. 2016; Gao et al. 2016, 2017; Pandit et al. 2017; Hagemann et al. 2018).

Physical and Structural Properties of Biochar

Various feedstock types combined with a diverse range of pyrolysis conditions can strongly influence the structure and physical properties of a biochar (Zhao et al. 2013). Scanning electron microscope (SEM) images (Fig. 1) have revealed that the pore structure of a biochar will generally represent the cellular structure of its feedstock (Lee et al. 2013). On the other hand, as the highest treatment temperature (HTT) of biochar increases, the biochar exhibits a greater percentage of crystallinity, where the percentage of aromatic C is increased and the entire structure of the biochar becomes more graphitic (Chia et al. 2015).

Typically, with the increased ordering of turbostratic aromatic C sheets, the interplanar distances of aromatic C forms will decrease, creating high surface area per total volume of a biochar (Lehmann et al. 2011). Coarse sand typically has very low surface area (0.01 $m^2\ g^{-1}$), whereas clay can have exceptionally high surface areas (100–1000 $m^2\ g^{-1}$) (Heilman et al. 1965). Biochar has been widely reported to have similar or higher surface area than clays, for example, biochar produced from Douglas-fir wood by fast pyrolysis at 900–1000 °C was reported to have a surface

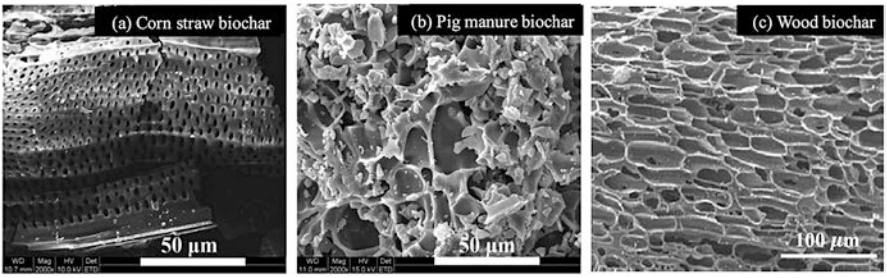

Fig. 1 Scanning electron microscopy images of biochar produced from different feedstocks: (**a**) corn straw, (**b**) pig manure, and (**c**) wood (Source of (**a**) and (**b**): Wang et al. 2017b, Article link (open access): https://www.nature.com/articles/s41598-017-12503-3. License: Creative Commons Attribution 4.0 International License https://creativecommons.org/licenses/by/4.0/. Reprinted with permission; source of (**c**): Jaafar et al. 2014, Article link: http://www.sciencedirect.com/science/article/pii/S2095311913607030?via%3Dihub. License: under Copyright's Clearance Center's Rightslink service. Reprinted with permission)

area of 745 $m^2\ g^{-1}$ by the N_2 BET method (Karunanayake et al. 2017). The micropore (diameter less than 2 nm) density of a biochar has contributed to this high surface area, leading to higher adsorptive capacities and hydrophobic effect potentials (Yang et al. 2018). Biochar can be used to remediate contaminated agricultural soils through the adsorption of heavy metals (Lu et al. 2017) and organic pollutants such as polycyclic aromatic hydrocarbons (PAHs) (Cao et al. 2016) or pesticides (Jones et al. 2011a). Biochar also has the potential to absorb some organic molecules that are involved in chelation, forming organo-mineral-biochar complexes which can potentially aid soil soluble P availability in organic farming systems (DeLuca et al. 2015b).

Macromolecular Properties of Biochar

Specific chemical changes occur in biomass when it is heated in an environment lacking electron acceptor such as oxygen (Kleber et al. 2015). Biochar generation starts with water loss at low heating temperatures, but as temperature increases, molecules such as lignin, cellulose, and hemicellulose are lost, and amorphous C begins to form. With further heating, turbostratic crystallites start to form as aromatic rings begin to condense and grow into sheets (Keiluweit et al. 2010). Eventually, feedstock biomass C is "compressed" into new solid phases with higher proportions of C, and some amount of its original C lost as volatiles during the heating process. It has been proposed that the nature of these C structures formed during the heating processes is a primary reason for biochar's high stability in soils (Nguyen et al. 2010; Lehmann et al. 2011). Although degradation of some labile components of biochar may occur in soils, soil microorganisms will generally be less likely to utilize these aromatic C compounds as an energy source, potentially contributing to the biochemical stability of biochar (Wang et al. 2016). Recent studies have also demonstrated the chemical stability and thermal stability of biochar (Chen et al. 2016a; Conti et al. 2016; Suárez-Abelenda et al. 2017).

Influence of Biochar on Soil Properties

Soil Physical Properties

The addition of biochar to agricultural soils can lead to unique interactions that influence soil physical properties including changes in soil porosity, water holding capacity (WHC), bulk density, aggregation, and drainage (Lehmann and Joseph 2015). As mentioned above, biochar is highly porous and possesses great surface area, thereby enhancing the total surface area, porosity, and water- or nutrient-holding capacities when added to soil. Głąb et al. (2016) demonstrated that the application of winter wheat straw biochar significantly improved the total porosity of a sandy agricultural soil, with the most volume increment increase being in small pores (less than 50 μm in diameter). The changes in soil porosity were also reflected in the water retention properties of the investigated soil with the finer biochar particles causing a greater increase in soil WHC. Similarly, Liu et al. (2017a) reported a 17% increase of soil porosity and a 28% increase in soil WHC of a silt loam agricultural soil following maize biochar application. Biochar was also reported to increase the retention of water at field capacity by 1.3% in an organically managed loamy soil (Ulyett et al. 2014).

Soil aggregation determines the soil pore network and thus contributes to root elongation, water infiltration, aeration, drainage, and diffusion of nutrients. Wang et al. (2017a) reported a significant improvement of wet aggregate stability in a silt loam agricultural soil following application of either walnut shell or softwood biochar with a 126% and 217% average increase of mean weight diameter observed for walnut shell and softwood biochar treatments, respectively. Du et al. (2017) also observed an increase in the stability of soil macroaggregates with increasing biochar doses. Biochar additions to soil generally lead to the creation of aggregate bridges and large void spaces, therefore potentially reducing soil bulk density, which describes the mass of soil per unit volume (Jones et al. 2011b; Agegnehu et al. 2016a). The reduced bulk density mediated by biochar could further alleviate soil compaction stress and possibly transition into promotion of crop growth (Liu et al. 2017a). Although there is some variation in the literature, soil physical properties are generally improved with the addition of biochar to agricultural soils.

Soil Biochemical Properties

In organic farming systems, soil fertility and plant production depend on the mineralization of nutrients from plant and animal residues, soil minerals, and resident soil organic matter involving a variety of soil biochemical processes (Mäder et al. 2002). It is therefore essential to understand how biochar applications influence soil biochemical properties and processes including C storage, soil nutrient capital and cycling, and microbial and associated enzyme activities. The use of biochar generated from local feedstocks in organic farming systems has been reported to either increase or have no significant impact on soil nutrient availability (Arif et al. 2016; Cavoski et al. 2016; Usman et al. 2016); and the mechanisms behind these shifts have been argued as both abiotic (such as adsorption or desorption of nutrients) or biotic factors associated with nutrient transformation processes, particularly N cycling (Nguyen et al. 2017). Gao et al. (2016) demonstrated that locally produced wood biochar had the ability to enhance the availability of soil NH_4^+-N in agricultural sandy soils of an organically managed system when applied alone or in combination with an organic fertilizer. The enhanced N availability was potentially due to increased adsorption capacity associated with the wood biochar as well as increased N mineralization rates following biochar application (Gao et al. 2016). With similar rates of biochar application in the following year, the authors subsequently detected a significant increase in both soil available inorganic P (citrate-extractable P) and potentially available organic P (enzyme-extractable P) pools five months after biochar amendment at six organic farms (Gao et al. 2017). Similarly, in a field study, Agegnehu et al. (2016b) reported that an increment of soil exchangeable cations including K, Na, Ca, and Mg following the addition of *Acacia* spp. produced biochar on an organic barley field, and they attributed these nutrient alterations to the direct effect of biochar on soil cation exchange capacity (CEC) due to its various surface charges and high surface area. By contrast, Sánchez-García et al. (2016) reported that biochar applied alone did not alter soil mineral N content in a two consecutive year of field study with organic olive crop growing in a calcareous arid land.

Nitrogen is considered as one of the most limiting nutrients in temperate agroecosystems; hence its transformation following biochar application to soils has been widely investigated for the last 10 years. Relatively thorough reviews of biochar influence on nutrient cycling can be found elsewhere (DeLuca et al. 2015b; Gao and DeLuca 2016; Gul and Whalen 2016; Nguyen et al. 2017). The influence of biochar or natural charcoal on N cycling and specifically nitrification appears to be more pronounced in forest soils than in N-amended agricultural soils. In forest soils, charcoal presence appears to stimulate net nitrification potentially as a result of charcoal adsorption of phenolics or terpenes that otherwise may interfere with this process (DeLuca et al. 2006). In organic agricultural soils, several recent studies also demonstrated increased nitrification following biochar addition which might be explained by a stimulated nitrifier activity due to an alteration in soil moisture and aeration (Ulyett et al. 2014; Pereira et al. 2015). For acidic agricultural soils, biochar-induced pH rise might also accelerate nitrification process (Teutscherova et al. 2017a). Nitrogen mineralization, the process by which organic N is converted to inorganic forms, was reported to increase in response to a ryegrass biochar application at the first week and decrease over time (Maestrini et al. 2014). It has been suggested that the short-term enhanced soil N mineralization rates with biochar addition to soil might be related to the H/C ratio of the biochar, where a higher ratio represents less recalcitrant biochar which is more likely to be decomposed and thereby release N trapped in the char into the mineral pool (Mukherjee and Zimmerman 2013; Pereira et al. 2015). Alternatively, the biochar additions may adsorb organic compounds associated with litter decomposition thereby enhancing net N mineralization (DeLuca et al. 2015b). Regardless of the mechanism, accelerated N mineralization with biochar addition would be particularly beneficial for organic farming systems as they tend to be challenged by a slower mineral-N release from the decomposition of organic material throughout the season when compared to conventional farming. On the other hand, biochar can affect soil N losses via denitrification process or direct leaching, both of which are commonly found to be reduced when biochar presents (Gao et al. 2016; Pereira et al. 2017). Biochar-mediated reductions in N_2O emissions can possibly be explained by changes in a variety of factors including soil pH, aeration, and substrate availability such as organic C or inorganic N (Gao and DeLuca 2016), while biochar could reduce N leaching by altering soil physical properties, or via altering total soil cation-exchange capacity and increasing NH_4^+ retention in surface soils (DeLuca et al. 2015b). Biochar additions to agricultural soils is often cited as means of increasing total C storage in soils (Lehmann et al. 2006). As mentioned above, a large proportion of biochar on a mass basis is aromatic C which tends to be resistant to microbial decomposition. When biochar is mixed into soil, this portion of C in biochar can immediately enhance soil total organic C content and, due to the resistance of biochar to decomposition, subsequently contribute to the long-term C storage and sequestration (Lehmann et al. 2011). Conventional agricultural systems tend to have reduced soil organic C content compared to forest soils as their topsoils have been constantly disturbed (van Wesemael et al. 2010); therefore, biochar amendment might provide a beneficial yet low-cost means of retaining more organic C into soil sink (Lehmann et al. 2006). While organic farming systems are having relatively higher organic C content than conventional farming (Gattinger et al. 2012), biochar addition was demonstrated to significantly contribute more to this C pool in a couple of studies associated with organic farming (Schulz et al. 2013; Sánchez-García et al. 2016).

Most soil nutrient transformations are enzyme-mediated reactions, and many of these have been found to be influenced by biochar additions to soil (Thies et al. 2015). Unfortunately, few of these studies have specifically been conducted in association with organic farming systems (Gao et al. 2017). Soil enzyme activity in response to biochar addition largely depends on the alterations in the interaction of substrate and enzyme through sorption and desorption, which subsequently is related to substrate availability. β-Glucosidase, an enzyme involved in cellulose degradation process, was shown to generally be nonresponsive or respond negatively with biochar addition on agricultural soils (Wu et al. 2013; Abujabhah et al. 2016), whereas peroxidase which is involved in the degradation of recalcitrant C forms in soil was positively responsive to char addition (Ng et al. 2014; García-Delgado et al. 2015). This trend potentially reflects or could be explained by the dominance of persistent forms of C in char-amended soils that would or would not be preferred substrates for specific enzymes (Chen et al. 2013). An opposite trend for β-glucosidase activity occurs in studies where the biochar used in the study temporarily contributed labile C (Al Marzooqi and Yousef 2017; Gao et al. 2017). Soil enzymes associated with N or P mineralization (urease, amidases, phosphatase, etc.) have been reported to generally respond neutrally or positively to biochar additions (Gao et al. 2017; Huang et al. 2017; Liu et al. 2017b; Teutscherova et al. 2017b). Enzyme response to biochar partly depends on how the enzyme active site or substrate interacts with biochar and its local chemical environment (Thies et al. 2015), yet it is important to note that enzyme activity does not always directly dictate microbial activity, and a considerable amount of activity detected in biochar amended soils may be from enzymes stabilized in soil matrix that are no longer associated with viable cells (Nannipieri et al. 2018). Overall, organic farming systems tend to have less readily available inorganic forms of nutrients that compared to that in conventional farming systems. Therefore, it is likely that biochar would play a potentially more important role in nutrient turnover and availability in organic farming systems.

Soil Microorganisms

Soil microorganisms play an integral role in virtually all soil processes, such that microbial abundance, activity, and composition will largely determine sustainable productivity of agricultural land (Paul 2014). Studies examining soil biota following biochar addition to agricultural soils are relatively abundant (Lehmann et al. 2011), yet little attention has been paid to this response within organic cropping systems (Gao et al. 2017; Gao and DeLuca 2018). Soil microbial communities can be influenced by biochar through several mechanisms: (1) the biochar itself could serve as a habitat or surface for soil microorganisms (Quilliam et al. 2013; Jiang et al. 2016); (2) biochar can serve as a substrate or loci of substrate accumulation for microbial consumption (Lehmann et al. 2011; Quilliam et al. 2013); (3) biochar can adsorb soil toxins and chemical signals that will otherwise inhibit microbial growth (Kasozi et al. 2010); and (4) biochar can alter the abundance of soil microorganisms through changing abiotic factors such as moisture, pH, or the concentration of specific elements or compounds possibly via adsorption (DeLuca et al. 2015b; Pingree and DeLuca 2017; Yu et al. 2018). For instance, Dumontet et al. (2017) observed evaluated biochemical and microbial activity in biochar-amended soils with or without organic fertilizer additions, and their results showed that both treatments had higher C oxidizing potential and greater diversity of cellulose-degrading bacteria than the control, suggesting a positive biochar effect in microbial heterotrophic metabolism possibly through inputs of C substrate. Similarly, Teutscherova et al. (2017a) recorded higher microbial activity and subsequent enhanced N mineralization rates following biochar addition to a degraded acidic soil in a microcosm experiment. The authors attributed this finding to the biochar alteration of the soil microenvironment, where biochar addition resulted in a significant increase in soil pH throughout the incubation period.

A number of studies in recent years have investigated the abundance and diversity of soil microbial populations in biochar-amended soils with respect to soil bacteria and archaea, fungi, and fauna (Abujabhah et al. 2017; Lucheta et al. 2017; Teutscherova et al. 2017b). Results of these studies vary widely, and the differences in these responses are likely related to interactions between biochar and microenvironmental factors including soil pH and soil moisture content. Most studies have reported no significant change or slight decrease in microbial abundance in biochar-treated soils (Quilliam et al. 2013; Gao et al. 2016). Recently, Teutscherova et al. (2017b) reported a decrease of microbial biomass in biochar-treated soils in a short-term incubation study using the substrate-induced respiration (SIR) method and attributed this decrease to the biochar-induced shift in soil pH which altered the balance between fungal and bacterial biomass. A similar argument was forwarded by Yao et al. (2017) where the authors detected higher soil fungal abundance (compared to bacteria or archaea) following 3 years of biochar addition by using quantitative PCR. Lucheta et al. (2017) used high-throughput DNA sequencing to observe elevated fungal abundance and richness in Amazon Dark Earth compared to unamended surrounding soils. These Amazonian dark earth soils are characterized by high levels of charred black carbon (Lucheta et al. 2017). As noted above, the porous physical structure of biochar and its high surface area can potentially contribute to water retention and the sorption of soil organic molecules, making it suitable for fungal colonization both internally and externally (Thies et al. 2015). However, an opposite trend has been observed where bacterial abundance was significantly increased by 28% with the application of 20 t biochar ha^{-1}, while fungal abundance decreased by 35% in a rice paddy soil (Chen et al. 2013). It was speculated that the neutral soil pH was unresponsive to biochar addition, therefore favoring a diverse bacterial community compared to acid soils that would likely be preferred by fungi (Fierer and Jackson 2006; Rousk et al. 2009).

Given that biochar may induce changes in microbial biomass (Gao et al. 2019), such overall changes in abundance will likely to cause some microbial groups to become more dominant and thus lead shifts in community structure of microorganisms (Lehmann et al. 2011). Studies associated with the influence of biochar on soil bacterial, fungal, or faunal diversity have also demonstrated varied results. Soil bacterial diversity was generally found to decrease or have no change in short-term studies (Imparato et al. 2016; Song et al. 2017) but generally increase in long-term studies and in the Terra Preta soils (O'Neill et al. 2009; Zheng et al. 2016; Abujabhah et al. 2017). The labile substances in biochar may stimulate activity (Jones et al. 2012) and induce shifts in microbial communities (Lehmann et al. 2011); however these resources are quickly mineralized in and present a transient effect, whereas long-term effect of biochar on soil microbial communities are likely achieved by multiple direct and indirect mechanisms and related to physicochemical and biochemical properties (Gul et al. 2015). In a long-term study examining microbial community structure following corncob biochar additions to a soybean-cultivated agricultural soil, researchers detected greater activity and diversity of bacteria in biochar-treated soils compared to the control, where the bacterial communities shifted from preferring metabolizing carbohydrates to xenobiotics (Sun et al. 2016). On the phylum level, the relative abundance of *Proteobacteria* and *Actinobacteria* increases with biochar amendment, while that of *Acidobacteria* decreased (Ahmad et al. 2016; Xu et al. 2016), and the overall shift was attributed to the high dissolved organic C present in biochar (Ahmad et al. 2016; Sun et al. 2016; Xu et al. 2016). On the other hand, fungal diversity exhibited very different responses to biochar application across various functional types and study conditions (Chen et al. 2016b; Lucheta et al. 2017; Yao et al. 2017). Using the phospholipid fatty acid (PLFA) technique, Luo et al. (2017) found that the proportion of arbuscular mycorrhizal fungi and the ratio of arbuscular mycorrhizal fungi/saprotrophic fungi were both enhanced by biochar addition and were correlated with biochar application rates (Luo et al. 2017). On a phylum level, biochar has been reported to increase the relative abundance of the *Basidiomycota* with high fungal diversity index observed in biochar-amended soils (Awasthi et al. 2017). More commonly fungal diversity observed in long-term studies was found to be unchanged although fungal community structure found to be significantly correlated with soil total C, N, or K (Dai et al. 2016; Lucheta et al. 2016; Yao et al. 2017).

The addition of biochar to soils also appears to influence the relative abundance of soil fauna, with a focus on earthworms (Bamminger et al. 2014; Kamau et al. 2017; Pingree et al. 2017). In fact, nearly all biochar-mediated changes in soil properties could directly or indirectly influence the soil faunal community (Sauvadet et al. 2016). Biochar generally directly affects soil faunal communities by improving habitat or indirectly through the biochar-mediated alterations at the lower trophic levels within the soil food web, such as shifts in the abundance of fungi and bacteria (Paz-Ferreiro et al. 2015). A recent study demonstrated that the abundance of earthworms in soil was not only related to soil charcoal content but to the nature of the biochar feedstock (Kamau et al. 2017). And in a short-term microcosm study, Pingree et al. (2017) reported a significantly greater biologically available P pool in both biochar-treated and biochar- and earthworm-treated soils, suggesting an interactive effect of biochar and earthworms in mediating soil P cycling. Earthworms have also been demonstrated to directly ingest biochar particles and thus could contribute to the stability or decomposition of biochar in soil (Lehmann et al. 2011).

Influence of Biochar on Crop Productivity in Organic Agriculture

Organic farming aims at creating a closed nutrient cycle on the farm to produce food with no soluble mineral or synthetic pesticide inputs and minimal harm to ecosystems (Mäder et al. 2002). However, critics argue that agriculture based on these principles typically result in relatively lower yields compared to conventional farming systems (Seufert et al. 2012). Therefore, while the goal of organic operations also includes building soil fertility over time, one must explore effective crop and nutrient management practice including initiating biochar amendments to surface soils.

Although a large number of studies in recent years have examined the influence of biochar on crop nutrient uptake and yield (see Lehmann and Joseph 2015), few have focused on its use in organic farming systems and especially associated with field studies (Table 1). Broadly speaking, aboveground production and yield have been widely reported to increase in biochar-treated agricultural soils (Biederman and Harpole 2013), and the response of crop to biochar addition primarily depends

Table 1 Recent biochar studies associated with organic farming systems

Study	Study type	Study period	Study focus and details
Dumontet et al. (2017)	Field (1 farm)	Two months	Metabolic and genetic patterns of soil microbial communities following olive mill waste biochar (commercial) and compost amendments on an organic farm
Gao et al. (2016)	Field (10 farms)	One growing season	Wood biochar (80% Douglas fir, locally produced on-site) amendment on soil nutrient availability (particularly N, P), retention, and dry beans nutrient uptake
Gao et al. (2017)	Field (6 farms)	One growing season	Wood biochar (80% Douglas fir locally produced on-site) amendment on soil nutrient availability (particularly N, P), and winter squash yield and nutrient uptake
Pereira et al. (2015)	Greenhouse mesocosm	42 days	Effect of different types of biochar (Douglas fir, pine, or hog waste wood produced) on soil N transformations (with molecular and stable isotope techniques) and lettuce growth performance
Pereira et al. (2016)	Field (1 farm)	One growing season	Walnut shell biochar (locally produced on-site) amendment on CO_2 abatements and emissions on an organic walnut farm
Pereira et al. (2017)	Greenhouse mesocosm	Two growing seasons	Pine chip and walnut shell biochar (commercial) with organic N fertilizer on soil N leachate, N_2O emission, and plant N uptake
Sánchez-García et al. (2016)	Field (1 farm)	Two years	Oak biochar (commercial) and compost amendments on soil C buildup, N dynamics, and plant nutritional status in a drip-irrigated organic olive crop
Ulyett et al. (2014)	Field (2 farms)	Two months	Deciduous mixed wood biochar (commercial) amendment on water retention and nitrification processes in sandy loam soils under organic and conventional management
Ye et al. (2016)	Pot trial at experimental station	1.5 months	Biochar-mineral complexes (commercial) and compost amendments on soil physicochemical properties, bacterial abundance, and Pakchoi nutritional status and yield

on biochar's effect on soil physical and biochemical properties that is later transformed to soil-plant interaction (Gao and DeLuca 2016). The overall responses were found to vary with crop types, soil types, biochar types, residence time of biochar in soil, and a combination of these factors (Jeffery et al. 2011). The black color of biochar will enhance surface albedo and subsequently influence thermal dynamics that are associated with soil physical conditions, and this may possibly influence the germination process (Genesio et al. 2012). Generally, biochar additions improve soil physical properties including WHC thereby reducing nutrient leaching and possibly promoting soil nutrient availability and biomass gain (Gao et al. 2017). However, crop productivity increase was shown to be less responsive under wood- and crop-derived biochar additions than that under manure biochar; and crops growing on acidic soil with a coarse texture tend to respond more rapidly and efficiently to biochar additions in their productivity (Liu et al. 2013).

In a short-term field study (see San Juan case study below) examining nutrient uptake by dry bean on organic farming systems, Gao et al. (2016) found higher P, iron (Fe), magnesium (Mg), and zinc (Zn) concentrations in whole dry bean plant following biochar application over one growing season, and the responses were aligned with reduced resin-sorbed accumulations of these nutrients below dry beans rooting zone, suggesting an alteration of biochar-soil-plant interaction through its effect on soil nutrient leaching. A greenhouse experiment involving biochar amendments to an organically managed soil was also found to significantly reduce cadmium (Cd) availability in soil solution as well as Cd accumulation in all parts of the wheat plant (root, shoot, grain, or husk) due to the sorption of Cd onto biochar surface (Yousaf et al. 2016). The potential of biochar to remove heavy metal and associated pollutants is of importance to organic farming systems since there is potential for introducing contaminants from municipal and industrial organic wastes which would need to be managed without the use of synthetic chemicals (Alloway 2013). In addition, a significant synergistic effect of biochar and organic fertilizer or compost has been found to improve soil nutrient availability and organic C content, subsequently promoting crop nutrient uptake and yield in biochar-treated soils (Ye et al. 2016; Gao et al. 2017). This indicates a biochar-induced priming effect could potentially provide an additive effect in promoting organic fertilizer use efficiency in organic farming systems (Plaza et al. 2016). Another agricultural benefit of biochar in agriculture that has been commonly explored is the influence of biochar on biological N_2 fixation, root nodulation, and legume crop growth (DeLuca et al. 2015b) which are uniquely important in organic farming systems. This effect has been widely proposed to be closely related to the greater boron (B) and molybdenum (Mo) availability by biochar additions (Rondon et al. 2007; Güereña et al. 2015). Although organic farming systems have been reported to generate 5–34% lower yields than conventional farming (Seufert et al. 2012), the incorporation of biochar into an organic management system might help reduce nutrients loss and aid reducing the yield gap between the two farming systems while aiding in the buildup of soil C and fertility (Jeffery et al. 2011; Liu et al. 2013; Gao et al. 2017; Gao et al. 2019).

Biochar in Organic Agriculture: The San Juan Experience

As we mentioned above, a great number of studies have examined the role of biochar in agricultural soils in general, but few have focused on its use in organic farming systems, particularly associated with biochar generation using on-site feedstock. To our knowledge, the following case study is the first and only published field trial that has investigated the effect of locally produced wood biochar on soil fertility and crop performance in association with well-replicated established plots on multiple small-scale organic farming systems to date (Gao et al. 2016, 2017). Aiming at creating a closed-loop system that recaptures the value of local logging biomass that would otherwise be pile burned and generate net loss of nutrients, our study leveraged the existing resources and community readiness to create sustainable forest restoration and agriculture practices.

Background and Biochar Generation

Fire is a major form of disturbance in forests ecosystems of the western US (Heyerdahl et al. 1995). Active fire suppression and a shift in forest management objectives over the last few decades have led to an increased occurrence of heavily stocked second-growth forests that potentially change wildfire behavior (Naficy et al. 2010). Forest restoration and fuel reduction treatments, such as selection harvest combined with prescribed fire, are being practiced in the western USA to rebuild a more resilient forest structure (Agee and Skinner 2005). Forest residues from timber harvests are normally piled and burned resulting in emissions of gaseous air pollutants and volatiles, net loss of nutrients, and no net environmental benefit. Therefore, generating a value-added approach to managing timber harvest residues might help catalyze restoration activities on private and public forest lands.

We conducted an extensive study at six to ten organic farms located on the nearshore islands of San Juan County, WA, USA. Since the region is largely covered by heavily stocked, second-growth forests, thinning treatments have become a common practice for foresters and landowners on the islands. However, the dominant small-diameter timber in these forests has relatively low value and high transportation costs to get the timber to the market resulting in the timber mostly being piled and burned. At the same time, a critical part of San Juan County's economy rests on small-scale organic farming on sandy loam soils formed in glacial till and outwash across the islands. Creation of a system that simultaneously generates less pollution from forest thinning while contributing to the soil fertility of local organic farms food production would be highly desirable. Biochar generation from local timber harvest residues in this region may offer a sustainable means of reducing wildfire hazard fuel loading while improving soil health on neighboring organic farms.

With the formation of local nonprofit organization (http://restorechar.org/team/), environmental consulting (http://www.rainshadowconsulting.com/), forest service company (http://www.nnrg.org/), and county conservation district (https://www.sanjuanislandscd.org/), biochar was produced on-site by "cylinder burn" method tested by a group of local farmers and foresters and proved to be a highly efficient technique on the island (http://restorechar.org/make-charcoal/). The production cylinder was set up in close proximity to farm sites using logging residues which on average consisted of a mixture of 80% Douglas-fir (*Pseudotsuga menziesii*), 15% white fir (*Abies concolor*), and 5% western red cedar (*Thuja plicata*). The kiln was 1.5 m in height by 1.5 m diameter, and the production method operated in a similar manner to the traditional method called the "Kon-Tiki" kiln. Briefly, the cylinder burn operated with an open lid and relied on regular additions of feedstock to fill the cylinder (Gao et al. 2016). As the flame wall climbing up and feedstock being added throughout the burning, the material below was kept in a low-oxygen environment. Pyrolysis took approximately 7 h with temperature being kept at 450–550 °C. Approximately 55 L of water was later used to douse the flame once the fire reached the top of the cylinder. A floating metal lid was then placed on top and sealed with mineral earth. After 48 h, the char was removed, allowed to dry, ground by crushing under a polyvinyl tarp, and then sieved to 2 cm diameter.

Study Design and Results

The study region has a large percentage of forest land cover, consisting mostly of Douglas fir, western hemlock, and western red cedar. Most of the remaining land in the county is used for organic agriculture. The climate of the region is influenced by the Olympic Mountains and Vancouver Island, Canada, creating a "rain shadow" effect producing less rainfall and experiencing significantly drier and brighter weather than the surrounding locations. The soils of this region are predominately sandy loam soils formed in glacial till and outwash with a naturally high leaching capacity. Organic farms involved in our field study are dominated by Xerepts and Xeralfs as soil suborders (USDA soil survey: https://websoilsurvey.sc.egov.usda.gov/).

This field study was started in summer 2015, biochar amendment practice and associated examination of soil and crop performances have been conducted for three continuous growing seasons, and the sites are currently still under management by local farmers. The four treatments used in this study included (1) control with no additional amendment, (2) poultry litter applied at 70 kg N ha^{-1}, (3) wood biochar applied at 20 t ha^{-1}, and (4) a mix of poultry litter and biochar (70 kg N ha^{-1} + 20 t ha^{-1}). Local pond water was used to create a slurry of dry poultry litter and biochar in treatment (4), resulting in a moist "charged biochar," while the same volume of pond water was also applied with the poultry litter in treatment (2) (see Gao et al. 2016 for more details). In May 2015, the study was conducted on ten organic farms located on three islands in the region with cover crops being dry beans (*Phaseolus vulgaris L.*); three to five replicated blocks were established on each farm, and four treatments were randomly applied within each block with treatment plot size of 1 ×

1 m and 30 cm buffer in between. The following growing season (May 2016), six organic farms on Waldron Island were set up semipermanently for this study, a larger size of treatment plot (2 × 2 m) and buffer (1.5 m) was used, and four treatments were replicated three times and applied randomly at each farm with cover crops being Kobocha squash (*Cucurbita maxima*). The same layout and design were continuously applied on those six farms that all grew dry beans in summer 2017. Biochar were produced in the same manner for 2015 and 2016, and all treatments were applied before any plantation of crops in May 2015 and 2016.

Composite soil samples were collected from each treatment plot both at the mid-growing season (3 months after biochar application) and the end-growing season (6 months after biochar application). Soil samples were analyzed for a series of physical and biochemical variables including pH, bulk density, WHC, total C and N content, NH_4^+-N, NO_3^- -N, biologically based P status (DeLuca et al. 2015a), other soil macro- and micronutrient concentrations, potentially mineralizable N (PMN), microbial biomass C or N, basal respiration, and enzyme activities associated with C, N, and P cycling. Other soil analyses are described in details in Gao et al. (2017). Whole plant samples were taken when harvested for nutrient concentration determination. Given the fact that the plots were incorporated into the normal farming operations by farmers at individual farms, we were only able to get plot-size crop yield data at the second growing season (summer 2016). Ionic resin capsules were installed below crop rooting zone during each growing season to capture those accumulated nutrients that were leaching down or lost, and the resins were retracted at the end-growing season and extracted for nutrient concentrations.

Here we only present the data from the first two growing seasons (summer 2015 and 2016) that have been published. Biochar addition to soils significantly enhanced soil WHC in both growing seasons, implying an improved hydrological function of sandy soils by biochar. A significant increase in soil total C content following biochar additions was observed both growing seasons across all farms (30% on the ten farms in 2015 and 45% across the six farms in 2016) thereby enhancing soil C sequestration. The practice of biochar amendment was also found to alter soil N dynamics in both growing seasons, where soil PMN and NH_4^+-N were found to largely increase in biochar-treated plots at both midseason sampling points, but no differences were observed for soil NO_3^- -N pools. This finding implied a stimulated N mineralization process and associated NH_4^+-N pool being built up by biochar amendment, possibly through its adsorption of resident organic N compounds (such as amino acids, small proteins, and peptides) that added to the total mineralizable N pool or through its effect on soil moisture retention which may have improved conditions for mineralization process of regional sandy soils. The lack of change in NO_3^- -N pool with biochar addition was likely due to an already active nitrifier community that does not benefit from biochar additions (DeLuca et al. 2006, 2015b). Synergistic effects of poultry litter and biochar were found in both seasons. In organic farming systems, N is added in organic forms requiring net mineralization into plant available forms compared to conventional farms where N is applied in soluble (e.g., NH_4NO_3) or easily mineralizable (urea) forms. Our finding that biochar imparts a short-term increase in mineralization of applied organic N in these organic farming systems is of significance. However, it is also important to note that the observed effect of biochar on soil N appears to be transient given that no significant differences were observed among treatment plots at harvesting time in both seasons.

Soil available P status was also shown to be altered by biochar additions in both seasons. Citrate-extractable P (which represents a chelation-based acquisition strategy) was observed enhanced by charcoal at the first growing season (29% increase); and both citrate- and enzyme-extractable P (which represents an enzyme hydrolysis-based acquisition strategy) was found to be higher in biochar-treated plots at the second growing season (by 25% and 54%, respectively). Hydrophobic or charged biochar was demonstrated to be able to surface adsorb organic molecules involved in the chelation of specific ions forming organo-biochar or organo-mineral-biochar complexes (Joseph et al. 2013; DeLuca et al. 2015b), thereby they can modify soil P solubility and the pool of bioavailable P. Further, regarding the observed P status shifts in the second growing season, we proposed that wood-based biochar added to regional sandy soils were able to increase the phytoavailability of both organic and inorganic P pools through stimulating the P-solubilizing bacterial communities (PSB) and plant or microbial phosphatase activity, given the fact that an enhanced microbial biomass, bulk soil phosphatase activity, and abundance of PSB were observed with char addition. These biochemical variables were also found to share a significant percentage of variance with soil physicochemical properties, potentially suggesting that these changes in soil nutrient status were largely mediated by biochar-stimulated soil microbial communities. Again, similar to soil N, P inputs to organic farming systems are largely as manures or other organic P sources; thus the enhanced enzyme activity may potentially play a key role in supplementing the bioavailable P through mineralization process.

Significantly lower levels of NO_3^- -N, NH_4^+-N, P, Ca, and Fe were detected in ionic resins buried below the rooting zone in biochar plots compared to controls during both growing seasons, suggestion that biochar reduced leaching potentials in these sandy soils. Among those nutrients, Fe and P were reflected in cover crops where higher concentrations were observed in plants growing in biochar-treated plots, both dry beans of the first year and winter squash of the second year. An approximately 20% increment of squash fresh fruit yield was reported for the second growing season, posing a rather promising view of biochar use in these farming systems.

Linking Sustainable Agroforestry to Organic Farming

Our on-farm biochar study over the past two growing seasons has demonstrated the beneficial role of biochar in nutrient cycling and uptake by cover crops in these active organic farming systems associated with sandy soil of a glacial till origin. Biochar effect on soils that were observed in our study was primarily the significant increase in soil total C storage, alterations of N dynamics, biologically based P status, and significant less accumulated nutrients below crop rooting zone. These benefits on local soils were later reflected in cover crops across multiple organic farms on the islands. Concomitantly, the study region has an urgent need for forest health management or fuel reduction treatments to reduce fire risk on the isolated dry-forest ecosystem, but dealing with those on-site logging residues remains a problem for resident landowners. Therefore, linking the utilization of local woody residues to the creation of a closed-loop organic farming system with the need of improving soil fertility, our study has served as a unique example of sustainable agriculture practice and a community cooperative effort that represented operational, on-farm research trials that are of value to the broader research community as well as the regional farming community.

With small-scale regional biochar producers charging approximately $30 per cubic foot of biochar, selling almost exclusively to high-end gardeners and garden stores, biochar is currently not an economically feasible option for many small-scale organic farmers. In regions where forests and agricultural activities are close together, there is a great potential to create partnerships between the local forest industry, forest landowners, and farmers to create and utilize lower-cost production methods for biochar while driving forward forest restoration simultaneously. In addition, organic farming aims at emphasizing fewer negative environmental impacts, higher system resilience and ecological services provisions, soil sustainability, and quality food production while reducing external inputs cost and enhancing social capacity (Jouzi et al. 2017). By using local feedstock, relatively low-tech biochar production methodology, with minimal transportation costs, and decentralized yet less human labor in applying biochar by farmers on neighboring lands, this practice potentially minimized the net system nutrient loss and catalyzed local agricultural industry. It is possible that this type of biochar-associated sustainable agroforestry strategy could be exported to other agroecosystems that are in locales where forest biomass residues are abundant in and distributed across a landscape with small-scale farming operations that would benefit from biochar additions to surface soils.

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References

Abujabhah, I. S., Bound, S. A., Doyle, R., & Bowman, J. P. (2016). Effects of biochar and compost amendments on soil physico-chemical properties and the total community within a temperate agricultural soil. *Applied Soil Ecology, 98*, 243–253.

Abujabhah, I. S., Doyle, R. B., Bound, S. A., & Bowman, J. P. (2017). Assessment of bacterial community composition, methanotrophic and nitrogen-cycling bacteria in three soils with different biochar application rates. *Journal of Soils and Sediments, 18*, 1–11.

Agee, J. K., & Skinner, C. N. (2005). Basic principles of forest fuel reduction treatments. *Forest Ecology and Management, 211*, 83–96.

Agegnehu, G., Bass, A. M., Nelson, P. N., & Bird, M. I. (2016a). Benefits of biochar, compost and biochar–compost for soil quality, maize yield and greenhouse gas emissions in a tropical agricultural soil. *Science of the Total Environment, 543*, 295–306.

Agegnehu, G., Nelson, P. N., & Bird, M. I. (2016b). Crop yield, plant nutrient uptake and soil physicochemical properties under organic soil amendments and nitrogen fertilization on Nitisols. *Soil and Tillage Research, 160*, 1–13.

Ahmad, M., Ok, Y. S., Kim, B. Y., Ahn, J. H., Lee, Y. H., Zhang, M., et al. (2016). Impact of soybean stover- and pine needle-derived biochars on Pb and As mobility, microbial community, and carbon stability in a contaminated agricultural soil. *Journal of Environmental Management, 166*, 131–139.

Al Marzooqi, F., & Yousef, L. F. (2017). Biological response of a sandy soil treated with biochar derived from a halophyte (*Salicornia bigelovii*). *Applied Soil Ecology, 114*, 9–15.

Alloway, B. J. (2013). *Sources of heavy metals and metalloids in soils* (pp. 11–50). Dordrecht: Springer.

Arif, M., Ali, K., Jan, M. T., Shah, Z., Jones, D. L., & Quilliam, R. S. (2016). Integration of biochar with animal manure and nitrogen for improving maize yields and soil properties in calcareous semi-arid agroecosystems. *Field Crops Research, 195*, 28–35.

Atkinson, C. J., Fitzgerald, J. D., & Hipps, N. A. (2010). Potential mechanisms for achieving agricultural benefits from biochar application to temperate soils: A review. *Plant and Soil, 337*, 1–18.

Awasthi, M. K., Li, J., Kumar, S., Awasthi, S. K., Wang, Q., Chen, H., et al. (2017). Effects of biochar amendment on bacterial and fungal diversity for co-composting of gelatin industry sludge mixed with organic fraction of municipal solid waste. *Bioresource Technology, 246*, 214–223.

Bamminger, C., Zaiser, N., Zinsser, P., Lamers, M., Kammann, C., & Marhan, S. (2014). Effects of biochar, earthworms, and litter addition on soil microbial activity and abundance in a temperate agricultural soil. *Biology and Fertility of Soils, 50*, 1189–1200.

Biederman, L. A., & Harpole, W. S. (2013). Biochar and its effects on plant productivity and nutrient cycling: A meta-analysis. *GCB Bioenergy, 5*, 202–214.

Boateng, A. A., Garcia-Perez, M., Masek, O., Brown, R., & del Campo, B. (2015). Biochar production technology. In J. Lehmann & S. Joseph (Eds.), *Biochar for environmental management: Science, technology and implementation* (pp. 53–87). London: Routledge.

Brown, R. C., del Campo, B., Boateng, A. A., Garcia-perez, M., & Mašek, O. (2015). Fundamentals of biochar production. In J. Lehmann & S. Joseph (Eds.), *Biochar for environmental management: Science, technology and implementation* (pp. 39–61). London: Routledge.

Cao, Y., Yang, B., Song, Z., Wang, H., He, F., & Han, X. (2016). Wheat straw biochar amendments on the removal of polycyclic aromatic hydrocarbons (PAHs) in contaminated soil. *Ecotoxicology and Environmental Safety, 130*, 248–255.

Cavoski, I., Al Chami, Z., Jarrar, M., & Mondelli, D. (2016). Solutions for soil fertility management to overcome the challenges of the Mediterranean organic agriculture: Tomato plant case study. *Soil Research, 54*, 125–133.

Chen, J., Liu, X., Zheng, J. J. J. J., Zhang, B., Lu, H., Chi, Z., et al. (2013). Biochar soil amendment increased bacterial but decreased fungal gene abundance with shifts in community structure in a slightly acid rice paddy from Southwest China. *Applied Soil Ecology, 71*, 33–44.

Chen, D., Yu, X., Song, C., Pang, X., Huang, J., & Li, Y. (2016a). Effect of pyrolysis temperature on the chemical oxidation stability of bamboo biochar. *Bioresource Technology, 218*, 1303–1306.

Chen, J., Sun, X., Li, L., Liu, X., Zhang, B., Zheng, J., et al. (2016b). Change in active microbial community structure, abundance and carbon cycling in an acid rice paddy soil with the addition of biochar. *European Journal of Soil Science, 67*, 857–867.

Chia, C. H., Downie, A., & Munroe, P. (2015). Characteristics of biochar: Physical and structural properties. In J. Lehmann & S. Joseph (Eds.), *Biochar for environmental management: Science, technology and implementation* (pp. 89–109). London: Routledge.

Conti, R., Fabbri, D., Vassura, I., & Ferroni, L. (2016). Comparison of chemical and physical indices of thermal stability of biochars from different biomass by analytical pyrolysis and thermogravimetry. *Journal of Analytical and Applied Pyrolysis, 122*, 160–168.

Cornelissen, G., Pandit, N. R., Taylor, P., Pandit, B. H., Sparrevik, M., & Schmidt, H. P. (2016). Emissions and char quality of flame-curtain “Kon Tiki” kilns for farmer-scale charcoal/biochar production. *PLoS One, 11*, 1–16.

Dai, Z., Hu, J., Xu, X., Zhang, L., Brookes, P. C., He, Y., et al. (2016). Sensitive responders among bacterial and fungal microbiome to pyrogenic organic matter (biochar) addition differed greatly between rhizosphere and bulk soils. *Scientific Reports, 6*, 36101.

DeLuca, T. H., & Aplet, G. H. (2008). Charcoal and carbon storage in forest soils of the Rocky Mountain West. *Frontiers in Ecology and the Environment, 6*, 18–24.

DeLuca, T. H., MacKenzie, M. D., Gundale, M. J., & Holben, W. E. (2006). Wildfire-produced charcoal directly influences nitrogen cycling in Ponderosa pine forests. *Soil Science Society of America Journal, 70*, 448.

DeLuca, T. H., Glanville, H. C., Harris, M., Emmett, B. A., Pingree, M. R. A. A., de Sosa, L. L., et al. (2015a). A novel biologically-based approach to evaluating soil phosphorus availability across complex landscapes. *Soil Biology and Biochemistry, 88*, 110–119.

DeLuca, T. H., Gundale, M. J., MacKenzie, M. D., & Jones, D. L. (2015b). Biochar effects on soil nutrient transformations. In J. Lehmann & S. Joseph (Eds.), *Biochar for environmental management: Science, technology and implementation* (pp. 421–454). London: Routledge.

Du, Z. L., Zhao, J. K., Wang, Y. D., & Zhang, Q. Z. (2017). Biochar addition drives soil aggregation and carbon sequestration in aggregate fractions from an intensive agricultural system. *Journal of Soils and Sediments, 17*, 581–589.

Dumontet, S., Cavoski, I., Ricciuti, P., Mondelli, D., Jarrar, M., Pasquale, V., et al. (2017). Metabolic and genetic patterns of soil microbial communities in response to different amendments under organic farming system. *Geoderma, 296*, 79–85.

Fierer, N., & Jackson, R. B. (2006). The diversity and biogeography of soil bacterial communities. *Proceedings of the National Academy of Sciences of the United States of America, 103*, 626–631.

Gao, S., & DeLuca, T. H. (2016). Influence of biochar on soil nutrient transformations, nutrient leaching, and crop yield. *Advances in Plants & Agriculture Research, 4*, 150.

Gao, S., Hoffman-Krull, K., Bidwell, A. L., & DeLuca, T. H. (2016). Locally produced wood biochar increases nutrient retention and availability in agricultural soils of the San Juan Islands, USA. *Agriculture, Ecosystems and Environment, 233*, 43–54.

Gao, S., Hoffman-Krull, K., & DeLuca, T. H. (2017). Soil biochemical properties and crop productivity following application of locally produced biochar at organic farms on Waldron Island, WA. *Biogeochemistry, 136*, 31–46.

Gao, S., & DeLuca, T. H. (2018). Wood biochar impacts soil phosphorus dynamics and microbial communities in organically-managed croplands. *Soil Biology and Biochemistry, 126*, 144–150.

Gao, S., DeLuca, T. H., & Cleveland, C. C. (2019). Biochar additions alter phosphorus and nitrogen availability in agricultural ecosystems: A meta-analysis. *Science of The Total Environment, 654*, 463–472.

García-Delgado, C., Alfaro-Barta, I., & Eymar, E. (2015). Combination of biochar amendment and mycoremediation for polycyclic aromatic hydrocarbons immobilization and biodegradation in creosote-contaminated soil. *Journal of Hazardous Materials, 285*, 259–266.

Gattinger, A., Muller, A., Haeni, M., Skinner, C., Fliessbach, A., Buchmann, N., et al. (2012). Enhanced top soil carbon stocks under organic farming. *Proceedings of the National Academy of Sciences, 109*, 18226–18231.

Genesio, L., Miglietta, F., Lugato, E., Baronti, S., Pieri, M., & Vaccari, F. P. (2012). Surface albedo following biochar application in durum wheat. *Environmental Research Letters, 7*, 14025.

Głąb, T., Palmowska, J., Zaleski, T., & Gondek, K. (2016). Effect of biochar application on soil hydrological properties and physical quality of sandy soil. *Geoderma, 281*, 11–20.

Glaser, B., & Birk, J. J. (2012). State of the scientific knowledge on properties and genesis of Anthropogenic Dark Earths in Central Amazonia (terra preta de Índio). *Geochimica et Cosmochimica Acta, 82*, 39–51.

Griffin, D. E., Wang, D., Parikh, S. J., & Scow, K. M. (2017). Short-lived effects of walnut shell biochar on soils and crop yields in a long-term field experiment. *Agriculture, Ecosystems and Environment, 236*, 21–29.

Güereña, D. T., Lehmann, J., Thies, J. E., Enders, A., Karanja, N., & Neufeldt, H. (2015). Partitioning the contributions of biochar properties to enhanced biological nitrogen fixation in common bean (*Phaseolus vulgaris*). *Biology and Fertility of Soils, 51*, 479–491.

Gul, S., & Whalen, J. K. (2016). Biochemical cycling of nitrogen and phosphorus in biochar-amended soils. *Soil Biology and Biochemistry, 103*, 1–15.

Gul, S., Whalen, J. K., Thomas, B. W., Sachdeva, V., & Deng, H. (2015). Physico-chemical properties and microbial responses in biochar-amended soils: Mechanisms and future directions. *Agriculture, Ecosystems and Environment, 206*, 46–59.

Hagemann, N., Subdiaga, E., Orsetti, S., de la Rosa, J. M., Knicker, H., Schmidt, H.-P., et al. (2018). Effect of biochar amendment on compost organic matter composition following aerobic composting of manure. *Science of the Total Environment, 613–614*, 20–29.

He, Y., Zhou, X., Jiang, L., Li, M., Du, Z., Zhou, G., et al. (2017). Effects of biochar application on soil greenhouse gas fluxes: A meta-analysis. *GCB Bioenergy, 9*, 743–755.

Heilman, M. D., Carter, D. L., & Gonzalez, C. L. (1965). The ethylene glycol monoethyl ether technique for determining soil surface area. *Soil Science, 100*, 409–413.

Heyerdahl, E. K., Berry, D., & Agee, J. K. (1995). *Fire history database of the western United States*. Seattle: US Forest Service.

Huang, D., Liu, L., Zeng, G., Xu, P., Huang, C., Deng, L., et al. (2017). The effects of rice straw biochar on indigenous microbial community and enzymes activity in heavy metal-contaminated sediment. *Chemosphere, 174*, 545–553.

Imparato, V., Hansen, V., Santos, S. S., Nielsen, T. K., Giagnoni, L., Hauggaard-Nielsen, H., et al. (2016). Gasification biochar has limited effects on functional and structural diversity of soil microbial communities in a temperate agroecosystem. *Soil Biology and Biochemistry, 99*, 128–136.

Jaafar, N. M., Clode, P. L., & Abbott, L. K. (2014). Microscopy observations of habitable space in biochar for colonization by fungal hyphae from soil. *Journal of Integrative Agriculture, 13*, 483–490.

Jeffery, S., Verheijen, F. G. A., van der Velde, M., & Bastos, A. C. (2011). A quantitative review of the effects of biochar application to soils on crop productivity using meta-analysis. *Agriculture, Ecosystems and Environment, 144*, 175–187.

Jiang, X., Denef, K., Stewart, C. E., & Cotrufo, M. F. (2016). Controls and dynamics of biochar decomposition and soil microbial abundance, composition, and carbon use efficiency during long-term biochar-amended soil incubations. *Biology and Fertility of Soils, 52*, 1–14.

Jones, D. L., Edwards-Jones, G., & Murphy, D. V. (2011a). Biochar mediated alterations in herbicide breakdown and leaching in soil. *Soil Biology and Biochemistry, 43*, 804–813.

Jones, D. L. L., Murphy, D. V. V., Khalid, M., Ahmad, W., Edwards-Jones, G., & DeLuca, T. H. H. (2011b). Short-term biochar-induced increase in soil CO2 release is both biotically and abiotically mediated. *Soil Biology and Biochemistry, 43*, 1723–1731.

Jones, D. L., Rousk, J., Edwards-Jones, G., DeLuca, T. H., & Murphy, D. V. (2012). Biochar-mediated changes in soil quality and plant growth in a three year field trial. *Soil Biology and Biochemistry, 45*, 113–124.

Joseph, S., Graber, E. R., Chia, C., Munroe, P., Donne, S., Thomas, T., et al. (2013). Shifting paradigms: Development of high-efficiency biochar fertilizers based on nano-structures and soluble components. *Carbon Management, 4*, 323–343.

Jouzi, Z., Azadi, H., Taheri, F., Zarafshani, K., Gebrehiwot, K., Van Passel, S., et al. (2017). Organic farming and small-scale farmers: Main opportunities and challenges. *Ecological Economics, 132*, 144–154.

Kamau, S., Barrios, E., Karanja, N. K., Ayuke, F. O., & Lehmann, J. (2017). Spatial variation of soil macrofauna and nutrients in tropical agricultural systems influenced by historical charcoal production in South Nandi, Kenya. *Applied Soil Ecology, 119*, 286–293.

Karunanayake, A. G., Todd, O. A., Crowley, M., Ricchetti, L., Pittman, C. U., Anderson, R., et al. (2017). Lead and cadmium remediation using magnetized and nonmagnetized biochar from Douglas fir. *Chemical Engineering Journal, 331*, 480–491.

Kasozi, G. N., Zimmerman, A. R., Nkedi-Kizza, P., & Gao, B. (2010). Catechol and humic acid sorption onto a range of laboratory-produced black carbons (biochars). *Environmental Science & Technology, 44*, 6189–6195.

Keiluweit, M., Nico, P. S., Johnson, M. G., & Kleber, M. (2010). Dynamic molecular structure of plant biomass-derived black carbon (biochar). *Environmental Science & Technology, 44*, 1247–1253.

Kleber, M., Hockaday, W., & Nico, P. S. (2015). Characteristics of biochar: Macro-molecular properties. In J. Lehmann & S. Joseph (Eds.), *Biochar for environmental management: Science, technology and implementation* (pp. 111–137). London: Routledge.

Lee, Y., Park, J., Gang, K. S., Ryu, C., & Yang, W. (2013). Production and characterization of biochar from various biomass materials by slow pyrolysis. *Food Fertility Technology Center, 197*, 1–11.

Lehmann, J., & Joseph, S. (2015). *Biochar for environmental management: Science, technology and implementation*. New York: Routledge.

Lehmann, J., Gaunt, J., & Rondon, M. (2006). Bio-char sequestration in terrestrial ecosystems–a review. *Mitigation and Adaptation Strategies for Global Change, 11*, 395–419.

Lehmann, J., Rillig, M. C., Thies, J., Masiello, C. A., Hockaday, W. C., & Crowley, D. (2011). Biochar effects on soil biota–a review. *Soil Biology and Biochemistry, 43*, 1812–1836.

Liu, X., Zhang, A., Ji, C., Joseph, S., Bian, R., Li, L., et al. (2013). Biochar's effect on crop productivity and the dependence on experimental conditions-a meta-analysis of literature data. *Plant and Soil, 373*, 583–594.

Liu, Q., Liu, B., Zhang, Y., Lin, Z., Zhu, T., Sun, R., et al. (2017a). Can biochar alleviate soil compaction stress on wheat growth and mitigate soil N_2O emissions? *Soil Biology and Biochemistry, 104*, 8–17.

Liu, S., Meng, J., Jiang, L., Yang, X., Lan, Y., Cheng, X., et al. (2017b). Rice husk biochar impacts soil phosphorous availability, phosphatase activities and bacterial community characteristics in three different soil types. *Applied Soil Ecology, 116*, 12–22.

Lu, K., Yang, X., Shen, J., Robinson, B., Huang, H., Liu, D., et al. (2017). Effect of bamboo and rice straw biochars on the mobility and redistribution of heavy metals (Cd, Cu, Pb, and Zn) in contaminated soil. *Journal of Environmental Management, 186*, 285–292.

Lucheta, A. R., de Souza Cannavan, F., Roesch, L. F. W., Tsai, S. M., & Kuramae, E. E. (2016). Fungal community assembly in the Amazonian Dark Earth. *Microbial Ecology, 71*, 962–973.

Lucheta, A. R., Cannavan, F. d. S., Tsai, S. M., & Kuramae, E. E. (2017). Amazonian Dark Earth and its black carbon particles harbor different fungal abundance and diversity. *Pedosphere, 27*, 832–845.

Luo, S., Wang, S., Tian, L., Li, S., Li, X., Shen, Y., et al. (2017). Long-term biochar application influences soil microbial community and its potential roles in semiarid farmland. *Applied Soil Ecology, 117–118*, 10–15.

Mäder, P., Fliessbach, A., Dubois, D., Gunst, L., Fried, P., & Niggli, U. (2002). Soil fertility and biodiversity in organic farming. *Science, 296*, 1694–1697.

Maestrini, B., Herrmann, A. M., Nannipieri, P., Schmidt, M. W. I., & Abiven, S. (2014). Ryegrass-derived pyrogenic organic matter changes organic carbon and nitrogen mineralization in a temperate forest soil. *Soil Biology and Biochemistry, 69*, 291–301.

Mukherjee, A., & Zimmerman, A. R. (2013). Organic carbon and nutrient release from a range of laboratory-produced biochars and biochar–soil mixtures. *Geoderma, 193*, 122–130.

Naficy, C., Sala, A., Keeling, E., Graham, J., & DeLuca, T. (2010). Interactive effects of historical logging and fire exclusion on ponderosa pine forest structure in the northern Rockies. *Ecological Applications, 20*, 1851–1864.

Nannipieri, P., Trasar-Cepeda, C., & Dick, R. P. (2018). Soil enzyme activity: a brief history and biochemistry as a basis for appropriate interpretations and meta-analysis. *Biology and Fertility of Soils, 54*(1), 11–19.

Ng, E. L., Patti, A. F., Rose, M. T., Schefe, C. R., Wilkinson, K., & Cavagnaro, T. R. (2014). Functional stoichiometry of soil microbial communities after amendment with stabilised organic matter. *Soil Biology and Biochemistry, 76*, 170–178.

Nguyen, B. T., Lehmann, J., Hockaday, W. C., Joseph, S., & Masiello, C. A. (2010). Temperature sensitivity of black carbon decomposition and oxidation. *Environmental Science & Technology, 44*, 3324–3331.
Nguyen, T. T. N., Xu, C.-Y., Tahmasbian, I., Che, R., Xu, Z., Zhou, X., et al. (2017). Effects of biochar on soil available inorganic nitrogen: A review and meta-analysis. *Geoderma, 288*, 79–96.
Nishio, M. (1996). *Microbial fertilizers in Japan*. Kannondai 3-1-1, Tsukuba, Ibaraki 305 Japan.
Nsamba, H. K., Hale, S. E., Cornelissen, G., & Bachmann, R. T. (2015). Sustainable technologies for small-scale biochar production: A review. *Journal of Sustainable Bioenergy Systems, 5*, 10–31.
O'Neill, B., Grossman, J., Tsai, M. T., Gomes, J. E., Lehmann, J., Peterson, J., et al. (2009). Bacterial community composition in Brazilian Anthrosols and adjacent soils characterized using culturing and molecular identification. *Microbial Ecology, 58*, 23–35.
Odesola, I. F., & Owoseni, T. A. (2011). Small scale biochar production technologies: A review. *Journal of Emerging Trends in Engineeringa and Applied Sciences, 1*, 151–156.
Ogawa, M., & Okimori, Y. (2010). Pioneering works in biochar research, Japan. *Australian Journal of Soil Research, 48*, 489.
Olarieta, J. R., Padrò, R., Masip, G., Rodríguez-Ochoa, R., & Tello, E. (2011). "Formiguers", a historical system of soil fertilization (and biochar production?). *Agriculture, Ecosystems and Environment, 140*, 27–33.
Pandit, N. R., Mulder, J., Hale, S. E., Schmidt, H. P., Cornelissen, G., & Cowie, A. (2017). Biochar from "Kon Tiki" flame curtain and other kilns: Effects of nutrient enrichment and kiln type on crop yield and soil chemistry. *PLoS One, 12*, e0176378.
Paul, E. A. (2014). *Soil microbiology, ecology, and biochemistry*. New York: Academic Press.
Paz-Ferreiro, J., Liang, C., Fu, S., Mendez, A., & Gasco, G. (2015). The effect of biochar and its interaction with the earthworm *pontoscolex corethrurus* on soil microbial community structure in tropical soils. *PLoS One, 10*, e0124891.
Pereira, E. I. P., Suddick, E. C., Mansour, I., Mukome, F. N. D. D., Parikh, S. J., Scow, K., et al. (2015). Biochar alters nitrogen transformations but has minimal effects on nitrous oxide emissions in an organically managed lettuce mesocosm. *Biology and Fertility of Soils, 51*, 573–582.
Pereira, E. I. P., Suddick, E. C., & Six, J. (2016). Carbon abatement and emissions associated with the gasification of walnut shells for bioenergy and biochar production. *PLoS One, 11*, 1–16.
Pereira, E. I. P., Conz, R. F., & Six, J. (2017). Nitrogen utilization and environmental losses in organic greenhouse lettuce amended with two distinct biochars. *Science of the Total Environment, 598*, 1169–1176.
Pingree, M. R. A., & DeLuca, T. H. (2017). Function of wildfire-deposited pyrogenic carbon in terrestrial ecosystems. *Frontiers in Environmental Science, 5*, 53.
Pingree, M. R. A., Makoto, K., & DeLuca, T. H. (2017). Interactive effects of charcoal and earthworm activity increase bioavailable phosphorus in sub-boreal forest soils. *Biology and Fertility of Soils, 53*, 1–12.
Plaza, C., Giannetta, B., Fernández, J. M., López-de-Sá, E. G., Polo, A., Gascó, G., et al. (2016). Response of different soil organic matter pools to biochar and organic fertilizers. *Agriculture, Ecosystems and Environment, 225*, 150–159.
Quilliam, R. S., Glanville, H. C., Wade, S. C., & Jones, D. L. (2013). Life in the "charosphere" – Does biochar in agricultural soil provide a significant habitat for microorganisms? *Soil Biology and Biochemistry, 65*, 287–293.
Reganold, J. P., & Wachter, J. M. (2016). Organic agriculture in the twenty-first century. *Nature Plants, 2*, 15221.
Rondon, M. A., Lehmann, J., Ramírez, J., & Hurtado, M. (2007). Biological nitrogen fixation by common beans (*Phaseolus vulgaris L.*) increases with bio-char additions. *Biology and Fertility of Soils, 43*, 699–708.

Rousk, J., Brookes, P. C., & Bååth, E. (2009). Contrasting soil pH effects on fungal and bacterial growth suggest functional redundancy in carbon mineralization. *Applied and Environmental Microbiology, 75*, 1589–1596.

Saito, M. (1990). Charcoal as a micro-habitat for VA mycorrhizal fungi, and its practical implication. *Agriculture, Ecosystems and Environment, 29*, 341–344.

Sánchez-García, M., Sánchez-Monedero, M. A., Roig, A., López-Cano, I., Moreno, B., Benitez, E., et al. (2016). Compost vs biochar amendment: A two-year field study evaluating soil C build-up and N dynamics in an organically managed olive crop. *Plant and Soil, 408*, 1–14.

Sauvadet, M., Chauvat, M., Cluzeau, D., Maron, P. A., Villenave, C., & Bertrand, I. (2016). The dynamics of soil micro-food web structure and functions vary according to litter quality. *Soil Biology and Biochemistry, 95*, 262–274.

Schackley, S., et al. (2015). Economic evaluation of biochar systems: Current evidence and challenges. In J. Lehmann & S. Joeseph (Eds.), *Biochar for environmental management* (pp. 813–851). New York: Routledge.

Schmidt, H., & Taylor, P. (2014). Kon-Tiki flame curtain pyrolysis for the democratization of biochar production. *Biochar Journal, Arbaz, Switzerland, ISSN 1663-0521*, 14–24.

Schulz, H., Dunst, G., & Glaser, B. (2013). Positive effects of composted biochar on plant growth and soil fertility. *Agronomy for Sustainable Development, 33*, 817–827.

Seufert, V., Ramankutty, N., & Foley, J. A. (2012). Comparing the yields of organic and conventional agriculture. *Nature, 485*, 229–232.

Song, Y., Bian, Y., Wang, F., Herzberger, A., Yang, X., Gu, C., et al. (2017). Effects of biochar on dechlorination of hexachlorobenzene and the bacterial community in paddy soil. *Chemosphere, 186*, 116–123.

Suárez-Abelenda, M., Kaal, J., & McBeath, A. V. (2017). Translating analytical pyrolysis fingerprints to Thermal Stability Indices (TSI) to improve biochar characterization by pyrolysis-GC-MS. *Biomass and Bioenergy, 98*, 306–320.

Sun, D., Meng, J., Xu, E. G., & Chen, W. (2016). Microbial community structure and predicted bacterial metabolic functions in biochar pellets aged in soil after 34 months. *Applied Soil Ecology, 100*, 135–143.

Teutscherova, N., Vazquez, E., Masaguer, A., Navas, M., Scow, K. M., Schmidt, R., et al. (2017a). Comparison of lime- and biochar-mediated pH changes in nitrification and ammonia oxidizers in degraded acid soil. *Biology and Fertility of Soils, 53*, 1–11.

Teutscherova, N., Vazquez, E., Santana, D., Navas, M., Masaguer, A., & Benito, M. (2017b). Influence of pruning waste compost maturity and biochar on carbon dynamics in acid soil: Incubation study. *European Journal of Soil Biology, 78*, 66–74.

Thies, J. E., Rillig, M. C., & Graber, E. R. (2015). Biochar effects on the abundance, activity and diversity of the soil biota. In J. Lehmann & S. Joseph (Eds.), *Biochar for environmental management: Science, technology and implementation* (pp. 327–389). London: Routledge.

Ulyett, J., Sakrabani, R., Kibblewhite, M., & Hann, M. (2014). Impact of biochar addition on water retention, nitrification and carbon dioxide evolution from two sandy loam soils. *European Journal of Soil Science, 65*, 96–104.

Usman, A. R. A., Al-Wabel, M. I., Ok, Y. S., Al-Harbi, A., Wahb-Allah, M., El-Naggar, A. H., et al. (2016). Conocarpus biochar induces changes in soil nutrient availability and tomato growth under saline irrigation. *Pedosphere, 26*, 27–38.

Verma, M., Godbout, S., Brar, S. K., Solomatnikova, O., Lemay, S. P., & Larouche, J. P. (2012). Biofuels production from biomass by thermochemical conversion technologies. *International Journal of Chemical Engineering, 2012*, 1–18.

Wang, J., Xiong, Z., & Kuzyakov, Y. (2016). Biochar stability in soil: Meta-analysis of decomposition and priming effects. *GCB Bioenergy, 8*, 512–523.

Wang, D., Fonte, S. J., Parikh, S. J., Six, J., & Scow, K. M. (2017a). Biochar additions can enhance soil structure and the physical stabilization of C in aggregates. *Geoderma, 303*, 110–117.

Wang, T., Sun, H., Ren, X., Li, B., & Mao, H. (2017b). Evaluation of biochars from different stock materials as carriers of bacterial strain for remediation of heavy metal-contaminated soil. *Scientific Reports, 7*, 12114.

van Wesemael, B., Paustian, K., Meersmans, J., Goidts, E., Barancikova, G., & Easter, M. (2010). Agricultural management explains historic changes in regional soil carbon stocks. *Proceedings of the National Academy of Sciences, 107*, 14926–14930.

Wezel, A., Casagrande, M., Celette, F., Vian, J. F., Ferrer, A., & Peigné, J. (2014). Agroecological practices for sustainable agriculture. A review. *Agronomy for Sustainable Development, 34*, 1–20.

Wright, M. M., Daugaard, D. E., Satrio, J. A., & Brown, R. C. (2010). Techno-economic analysis of biomass fast pyrolysis to transportation fuels. *Fuel, 89*, 2–10.

Wu, F., Jia, Z., Wang, S., Chang, S. X., & Startsev, A. (2013). Contrasting effects of wheat straw and its biochar on greenhouse gas emissions and enzyme activities in a Chernozemic soil. *Biology and Fertility of Soils, 49*, 555–565.

Xu, N., Tan, G., Wang, H., & Gai, X. (2016). Effect of biochar additions to soil on nitrogen leaching, microbial biomass and bacterial community structure. *European Journal of Soil Biology, 74*, 1–8.

Yang, K., Jiang, Y., Yang, J., & Lin, D. (2018). Correlations and adsorption mechanisms of aromatic compounds on biochars produced from various biomass at 700 °C. *Environmental Pollution, 233*, 64–70.

Yao, Q., Liu, J., Yu, Z., Li, Y., Jin, J., Liu, X., et al. (2017). Three years of biochar amendment alters soil physiochemical properties and fungal community composition in a black soil of Northeast China. *Soil Biology and Biochemistry, 110*, 56–67.

Ye, J., Zhang, R., Nielsen, S., Joseph, S. D., Huang, D., & Thomas, T. (2016). A combination of biochar-mineral complexes and compost improves soil bacterial processes, soil quality, and plant properties. *Frontiers in Microbiology, 7*, 1–13.

Yousaf, B., Liu, G., Wang, R., Zia-ur-Rehman, M., Rizwan, M. S., Imtiaz, M., et al. (2016). Investigating the potential influence of biochar and traditional organic amendments on the bioavailability and transfer of Cd in the soil–plant system. *Environment and Earth Science, 75*, 1–10.

Yu, L., Duan, L., Naidu, R., & Semple, K. T. (2018). Abiotic factors controlling bioavailability and bioaccessibility of polycyclic aromatic hydrocarbons in soil: Putting together a bigger picture. *Science of the Total Environment, 613–614*, 1140–1153.

Zhao, L., Cao, X., Mašek, O., & Zimmerman, A. (2013). Heterogeneity of biochar properties as a function of feedstock sources and production temperatures. *Journal of Hazardous Materials, 256–257*, 1–9.

Zheng, J., Chen, J., Pan, G., Liu, X., Zhang, X., Li, L., et al. (2016). Biochar decreased microbial metabolic quotient and shifted community composition four years after a single incorporation in a slightly acid rice paddy from Southwest China. *Science of the Total Environment, 571*, 206–217.

Pest and Disease Control Strategies in Organic Fruit Production

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Pests and diseases cause huge economic losses to fruit growers by directly reducing 30–100% of fruit production. Additionally they deteriorate the physical appearance, market value and quality and nutritive value of fruits by sucking, chewing or boring into different reproductive parts causing spots, cracks and holes and rotting of fruits. Chemical pesticides have been in use for a long time to control insect pests and fungal diseases (Aktar et al. 2009). Pesticides used in fruit crops accumulate toxic residues in fruits used for human consumption causing health hazards to consumers. Their continuous use is adversely affecting environment by inducing development of resistance in many pests, resurgence and outbreak of new pests and health hazards to production workers and farm labourers due to incorrect or lack of knowledge of handling and use and pesticide poisoning (Groner 1990). Many synthetic pesticides like organochlorines, organophosphates, carbamates and organophthalides have been banned or restricted from use due to their harmful effect on the environment and their high toxicity in nature to the nontarget organisms like beneficial insects, amphibians, fishes and birds as well as to humans. However, attempts are now being made to replace the chemical pesticides with eco-friendly compounds which are safe to human and environment for the control of insect pests and diseases (Balandrin 1996; Adel et al. 2000; Beattie et al. 2002; Basta and Spooner-Hart 2003; Burgel et al. 2005; Cheok et al. 2014).

Organic fruit farming is a production system that sustains the health of soils, ecosystems and people. It relies on ecological processes, biodiversity and cycles adapted to local conditions, rather than the use of inputs with adverse effects. It is an ecologically sustainable fruit production system which protects biodiversity, physico-chemical and biological health of our soils since it is based on minimal use of chemical inputs for sustaining crop health and protection against biotic threats. In

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India, organic fruit production was practised only by individual NGOs and entrepreneurs in isolated areas and is now slowly gaining popularity due to increased organic agribusiness trade, demand for safe food by the consumers, support from the government to organic fruit producers and income security to growers.

Among other production problems, the challenge in organic fruit production is timely control of several pests like hoppers, mealy bugs, stem bores and fruit flies and diseases like powdery mildew, anthracnose, sooty mould, mango malformation, etc. (Campbell 1992; Tiwari et al. 2006) that drastically reduce fruit yields and quality. For successful organic fruit production an integrated pest management (IPM) approach which involves underlying preventative approaches is recommended to minimize the occurrence and extent of problems. Those practising organic fruit cultivation in complementation with the adoption of IPM strategies observe greater yields and profits than organic farm cultivators without IPM. It may require some change in chemicals used for the control of specific pests and diseases. Efforts to secure the existing biodiversity of the organic farms, to attract and harbour beneficial predators, can better the efficiency of the employed IPM methods (Zehnder et al. 2007).

Success of organic farming, in general, encompasses use of crop varieties with high to moderate resistance to biotic challenges. However, use of varieties with partial resistance is preferred to high-level resistance, since the former shall support and maintain low-level pest densities that facilitate natural enemy populations. Growing resistant varieties are thus the best option available with the farm holders practising organic farming. However, any chosen variety cannot be resistant to all the pest problems; hence an alternate strategy to successfully control pests in organic fruit production is desirable. Some of these are discussed in the following sections.

Soil Management Practices to Reduce Pest Incidence

A critical review of the available literature indicates that pest and disease resistance in plants is related to realization of optimum physico-chemical and biological characteristics of cultivable soil. Researches reveal a lower resurgence of insect pests in the organic than the conventional practices of farm management. In the organically managed farms, a higher availability of organic matter and the associated biological activity ensures sufficient buffering capacity to facilitate optimal nutrient availability and nutrient balance in soil-plant continuum, which in turn determines the performance of phytophagous insects. Interventions like incorporation of organic mulches are useful organic farming practices to supplement not only the soil organic matter but also to reduce soil temperature and improve water holding capacity of the soil. A reduced aphid infestation and incidence of viral infection with the application of straw mulch have been reported across crops and may be attributed to a reduction in host finding ability and an increase in predation from the natural enemies. However, application of organic mulch does favour growth of some other pests such as the squash bug, *Anasa tristis*, and the American palm *cixiid*, *Myndus crudus*.

Another important recent farm intervention is conservation tillage, which along with cover cropping practice and mechanical cultivation helps to control weeds under organic cultivation. The above practice which helps in conservation of water and maintenance of soil health can significantly alter the population and diversity of arthropod pests and natural enemies. It also triggers development of rich soil biota which is important to improve soil-nutrient cycling and crop health. In addition to conservation tillage, other farm management practices like mechanical removal of weeds and grasses may further reduce the number of arthropod predators, particularly the spiders and the staphylinid beetles.

Field Management Practices to Reduce Pest Incidence

Pest and disease management in organic fruit production involves a wide range of long-term activities practised in complementation to support each other's cause of effective prevention against pests and disease attack by ensuring reduced pest population. On the other hand, an effective control strategy is a short-term activity and would involve killing of pests and pathogens. Management of pests and diseases rather than their control is preferred. The routine pest and disease control methods attempt to rout the cause of the problem rather than correcting the disease symptoms and that its management over the control becomes the priority.

A simple management strategy could involve selection of crop/production site where the persisting environment suits crop production and the development of natural enemy of the pest but not the development of the pest. This ensures that the area and the crop shall remain free of the crop pest and the related diseases for a long time and even if the pest starts to show up the presence of natural enemies of the pest will act to stall the development and resurgence of the pest population not allowing it to stabilize to a level that is detrimental to the economic production. The above characteristics can be exemplified by the fact that organic fruit farming in the USA is majorly executed in regions that are free and/or do not support the growth of insect pests such as the plum curculio, *Conotrachelus nenuphar*. Further control of pests can be achieved by isolating the susceptible crops from the target host crops which has been effective in preventing the spread of aphid-borne viral diseases.

To employ apt farm management practices, it is important to decode the extent, season and quantum of specific pest or disease problem at any given location as it can help manage production costs and ensure the production targets. Identified risks can be minimized by adopting robust organic management. For example, southern growing regions need to consider orchard varieties, farm plan, density, canopy structure and extent of pruning to avoid fungal attack. In organic fruit productions in overly wet condition during fruiting, neglected orchards are constant source for new outbreaks of pest or disease (or weeds) and reduce yields drastically. Intermittent placement of organic and conventional farms may alter the pest and disease dynamics; thus cooperation with conventional growers is desired. Constant monitoring of farm pest and diseases can help reduce costs of unnecessary sprays besides improving resistance. However, resistant planting materials should always be used wherever possible. Use of local varieties that exhibit tolerance to local environmental variation and pest and diseases will ensure healthy growth. Since, a healthy tree requires soil to be healthy; improving the biological activity of soils by supplying them with adequate organic matter and providing conditions that enhance nutrient cycling to facilitate balanced physico-chemical and biological activities of the soil must be achieved. Pruning of tree canopy to enable opening of the structure that allows efficiency aeration in the canopy and adequate internal lighting can minimize disease risk and help in development of quality fruits of desired coloration. Practices like removal of infected wood, dead branches and fruits, leaves and other plant tissue can help reduce the infestation and resurgence of pests and diseases. Besides these, a regular monitoring and timely intervention are important for effective pest and disease management. Maintaining soil nutritional health also enables in reducing disease incidence. Diseases like mildew, anthracnose and leaf spot diseases can be regulated with sulphur or copper preparations, which are permitted and must be adhered to in organic cultivation.

Physical Methods to Control Flying Pests

Strategies like light traps, fruit bagging, pheromone traps and sticky traps are effective physical methods available to control insect populations. Use of fruit bags prevents fruit flies from laying insects on fruits and helps in controlling pest damage to the fruits and effectively checks latex burns and fungal spots, thereby improving their marketability. Bagging also helps minimize physical injuries like scratching and scaring and improves quality and productivity of fruits from an organic farm. Insect traps, which use attractants (colours, lights, etc.) and traps (chemical scents) for achieving mass trapping, using glue to immobilize insects, and mating disruption are equally important for monitoring insect populations to decide on the control measure. Water traps are also useful for trapping thrips, leaf miners and aphids. These insect traps help in monitoring insect population besides helping in delaying the build-up of pests and in reducing existing insect populations. However, once water or sticky pad is covered with insects, it should be changed to continue harness benefits of the technology. Colour traps like yellow traps, however, also attract many beneficial insects. These traps should be checked regularly to monitor the population of insect pests. Use of light traps to attract and trap insects is another important pest management strategy. Light traps effectively and efficiently trap different moth species such as armyworms, cutworms, stem borers and other night flying insects particularly when these are planted not later than the emergence of the adult moth but before the egg laying stage. Use of solar energy to kindle light traps in the orchards can reduce cost and enable the grower to use in orchards where electricity is not available. Embedded sensors automatically protect from rain, control light, relative humidity and can automatically switch on the lights in the evening and turn off in the morning.

Sex pheromones are of great help in controlling the population of insect pests in the orchards and the vineyards as they effectively disrupt the mating behaviour of various lepidopteran pests (Vail et al. 1993). Majority of research on effectiveness of sex pheromones and other techniques of controlling lepidopteran pests focus on monitoring the population of damage-causing insect pests such as the pea moth, *Cydia nigricana*, the olive fruit fly *Bactrocera oleae* and the cutworm, *Agrotis* spp. Hanging pheromone traps containing methyl eugenol in fruit orchards help in catching fruit flies and other pests. A successful example has been reported from Australia which involved commercial rearing of the Australian endemic egg parasitoid *Trichogramma carverae* for their mass release in vineyards for regulating the population of the light brown apple moth, *Epiphyas postvittana*. Since the life of the parasitoids is short, it is important to ensure accurate monitoring so that the release of predator coincides with maximum host egg density in order to achieve unrestricted impact on the target. Further, the longevity and fecundity of this natural enemy can be bettered by making them feed on nectar-producing plants such as alyssum, *Lobularia maritima*, in organic vineyards. Wrapping a slippery plastic band around each fruit tree especially in mango trees in the lower trunk region will restrict the movement of the emerging mealy bugs from soil up the trunk to branches, floral parts and growing fruits. Migration of weevils to branches for egg laying can be reduced by tying sticky band.

Another effective insect repellant which has shown promise as a potential alternative to insecticide treatment in different crops is kaolin clay (Glenn et al. 1999; Puterka et al. 2000; Cottrell et al. 2002; Glenn et al. 2002; Pasqualini et al. 2002; Mazor and Erez 2004; Melgarejo et al. 2004; Burgel et al. 2005). Kaolin film makes a physical restriction and a hostile environment for insects to develop and to infest and also impedes their movement, feeding and egg laying capacity and thus ensures an effective control of aphids and other sucking pests and diseases of fruit crops.

Botanicals in Pest and Disease Control

Fruit crops have developed many ways to fight against pests and pathogens by using secondary metabolites or plant-derived compounds which are valuable biopesticides for sustainable and healthy fruit cultivation. Mineral oils extracted from several wild and medicinal plants can be used for pest and disease control. Plant-based insecticides such as pyrethrum, neem and plant oils are most common, while those from ryania, nicotine and sabadilla are used less frequently in organic farming (Taylor et al. 2004; Ntalli and Menkissoglu-Spiroudi 2011). In fruit orchards, mineral oils are commonly used in winters to eliminate the overwintering developmental stages of pests. Several of the plant oils and their constituents (neem oil and essential oils) exhibit remarkable toxicity (both as contact and fumigant) to a large number of economically important pathogenic fungi, insect pests and mites. Triterpenoid steroid saponins present in different parts like leaves, stems, roots, bark and flowers of many plants are non-volatile, surface-active compounds, well tested against several insect pests like aphids, beetles, weevils, leafhoppers, worms, moths and several pathogens for their antimicrobial, antioxidant, and insecticidal, nematicidal and molluscicidal activities (Vincken et al. 2007). Steroid saponins are present in eggplant, peppers, tomato, potato, oats, garlic, onion, leek, alfalfa, alliums, fenugreek, yam, yucca, ginseng, soybean, chickpea and asparagus (De Geyter et al. 2007; Da Silva et al. 2012; Faizal and Geelen 2013; Cheok et al. 2014). Triterpenoid saponins are common in legumes, chenopods, spinach, sugar beet, liquorice, sunflower, horse chestnut, soapbark tree, sarsaparilla, quinoa and tea. Saponins stored in the roots act as phytoprotectant against invading soilborne microbes that attack fruit trees. Use of these botanicals as soil applicant or foliar spray is environment-friendly and nontoxic to humans and animal health and constitutes an effective, economically viable and sustainable approach to control several pests and diseases in fruit crops (Moses et al. 2014).

Foliar spray with pyrethrum solution; plant extracts like neem, garlic, chilli and tephrosia; spraying with 1% soap solution in 1% alcohol; and application of paraffin oil (white oil) as a 3% water emulsion can reduce the pest incidence. Spraying of 0.2% nimbicidin or azadirachtin 3000 ppm@2 m/l at initial stage of hopper population can control hopper attack. In our study, strong antifungal activity and significant inhibition of floral malformation were observed when mango trees were sprayed with a concoction brewed from *Datura stramonium*, *Calotropis gigantea*, *Azadirachta indica* and cow manure at bud break stage and again at fruit set stage when compared with the control. All malformed panicles completely dried and dropped 2 days after foliar spray and did not require any manual deblossoming, a regular recommended practice which is not only tedious but is also labour intensive. Whereas in the control, the malformed panicles remained green and competed with the growing fruits for plant nutrients. All mealy buds either dropped from mango trees or died immediately after spraying with brewed tea. Soil application of neem cake or datura, calotropis and neem plant extracts helps in killing eggs and larval stages of soilborne pests, termites, nematodes and pathogens.

Microbial Bioagents in Pest Control

Biological control of plant diseases through the use of antagonistic microorganisms has been considered as a viable alternate method to chemical control. Several entomopathogens (viruses, bacteria, fungi and nematodes) are safe for the environment, beneficial insects, applicators and food supply, and they can be applied just prior to harvest (Shapiro-Ilan et al. 2002a, b). Various spore-forming and non-spore-forming bacteria are pathogens of insects. Bioinsecticides dominated by *Bacillus thuringiensis*-based products command little more than 1% of the global insecticide market (Silimela and Korsten 2006). It is now well known that a crystal protein toxins present in the parasporal inclusions that are produced during sporulation contributes towards insecticidal tendencies of *B. thuringiensis*. These toxic proteins are basically the stomach poisons that potentially kill the insect by disrupting the osmotic balance in the midgut epithelium. Biopesticides such as *Pseudomonas fluorescens*, *Verticillium lecanii* and *Beauveria bassiana* as foliar sprays help in controlling several fungal diseases. The granulovirus (CpGV) is safe to nontarget organisms, and its use is effective for control of codling moth and some closely related species and contributes to the conservation of other natural enemies in orchard agroecosystems (Tanada 1964; Falcon et al. 1968). Due to airborne nature of dissemination and infection of buds, foliar spray once before flowering and again at the time of flower bud initiation with *B. subtilis* reduced the extent of mango malformation. Protection of buds from infection when inoculums prevail is necessary to control the disease. Fungus *Verticillium lecanii* controls hopper population, while *fungi Aspergillus* sp. and *Beauveria bassiana* were found effective in mango weevil control. Biopesticides such as *Pseudomonas fluorescens*, *Verticillium lecanii* and *Beauveria bassiana* as foliar sprays on the infected parts will knock off many pests and diseases. Soil application of bioagents like *Trichoderma viride*, *Trichoderma harzianum* and *Bacillus subtilis* ensnares and consumes other fungi as well as nematodes that live in the soil. In other words the laboratory virulence may not necessarily and always translate into ability to achieve effective suppression in the field. For example, *S. feltiae* and *S. riobrave* showed equally high potency *of* virulence to *C. nenuphar* larvae under the *laboratory* conditions, but in the field only *S. riobrave* could successfully and effectively control the insect pests. Nonchemical means of pest control are successful in organic farming; however, regardless of their efficacy, cost competitiveness is a major hurdle in their popularization and limits their exploitation as the mainstream pest management extension recommendation. The use of nematodes for control of *D. abbreviatus* is a success story; however the relative high cost of nematodes has prevented their implementation in some cropping systems. On the other hand, the ease of handling and greater cost competitiveness in *B. thuringiensis* products has facilitated their success. Use of EPNs for *D. abbreviatus* is cost competitive because the applications are made only under the canopy, which harbours the insects, and not over the tree canopy and not between rows. Such targeted application of the pest control technology over much reduced orchard area enhances the economic feasibility of the pest management strategies in the organic fruit orchards. Soil application of bioagents like *B. subtilis*, *Trichoderma viride* and *Trichoderma harzianum* is an effective, economically viable approach to control several soilborne pests, diseases, nematodes, etc. A list of promising biocontrol agents for pest control in organic farming is presented as Table 1.

Fruit growers also use fermented teas using different ingredients for pest control. For example, cow urine, dung, milk and milk products, i.e. curd, and ghee are the chief ingredients of panchagavya; however, coconut water, bananas, toddy juice and sugarcane juice are added to improve its nutrient quality and efficacy and to reduce odour (Devi and Arumugam 2005). Panchagavya is a good source of macro- and micronutrients and beneficial fungi and bacteria, which induce growth and also repel risky pests. Similarly other organic formulations like dasagavya, Amrut Jal 10% solution can be applied to soil and foliar spray once in 15–30 days, which act

Table 1 Biocontrol agents used in fruit crops for pest control

Biocontrol agent	Against fruit crop pests	References
Bacillus thuringiensis	Lepidopteran pests Oriental fruit moths, chrysomelid pests, leafrollers, bud moths, fruitworms	Boscheri et al. (1992), Beegle and Yamamoto (1992), Pari et al. (1993), Crickmore et al. (1998), Lacey and Siegel (2000), Lacey et al. (2005), Garczynski and Siegel (2007), Delate et al. (2005), Blommers (1994), and De Reede et al. (1985)
Granulosis viruses	Codling moth, *Cydia pomonella* summer fruit tortrix	Falcon et al. (1968), Balazs et al. (1997) and Altieri (1992)
Baculoviruses	Species of Lepidoptera	Huber (1986), Groner (1990) and Miller (1997)
Entomopathogenic fungi (e.g. *Neozygites fresenii*, *Entomophaga maimaiga*) and *Hypocreales* (e.g. *Lecanicillium* spp., *Aschersonia* spp., *Hirsutella* spp.; *Beauveria bassiana*, *Metarhizium anisopliae*, *Paecilomyces fumosoroseus*)	Weevils, lepidopteran and dipteran pests, crickets, *C. caryae*	Tedders et al. (1973), Harrison and Gardner (1991), Lezama-Gutierrez et al. (2000) Zimmermann (2005), Shapiro-Ilan et al. (2003, 2004), Goettel et al. (2005), Wraight et al. (2007), Steinkraus (2007), Barnett et al. (1993), and Grewal et al. (2005)
Entomoparasitic nematodes, e.g. *Heterorhabditis bacteriophora*; *S. carpocapsae*	Weevils, lepidopteran and dipteran fruit flies, crickets; borers; navel orange worm	Cossentine et al. (1990), Yee and Lacey (2003), Kuske et al. (2005), Grewal et al. (2005), Agudelo-Silva et al. (1995), Lindegren et al. (1987)
Insect parasitoids, e.g. wasps	Aphids, leafhoppers, lepidopteran pests, whiteflies	Daane et al. (2005), Begum et al. (2004), and Wyss et al. (1999)
Insect predators, e.g. mites, coccinellid and lacewing	Aphids, psyllids, leafhoppers, spider mites	Peng and Christian (2005) and Kehrli and Wyss (2001)

as protective cover for beneficial insects and pathogens. Handi khata controls all pests and diseases when sprayed @20 ml/litre of water. Foliar spray with organic formulations like handi khata, panchagavya and dasagavya and bioagents like *Trichoderma harzianum*, *T. viride, Pseudomonas fluorescens*, *B. subtilis*, *Beauveria bassiana* and *Verticillium lecanii* is environment-friendly and nontoxic to humans and animal health and constitutes sustainable approach to control pests and diseases in organic orchards. Biofertilizers with special focus on vesicular arbuscular mycorrhiza and plant growth-promoting rhizobia when used in the nurseries and field help to control soilborne diseases.

Natural Enemies for Pest Management

Natural enemies such as lady beetle larva, wasps, spiders and parasitic fungi attack the maggots of fruit flies. Predators such as rove beetles, weaver ants, spiders, birds and bats are very efficient in protecting fruit trees from several pests, including fruit flies. Their presence and foraging activity hinder the fruit flies from laying eggs, resulting in reduced fruit fly damage. This technique demands utmost caution and thorough study, as it could go all wrong, if not managed properly.

A successful example has been reported from Australia which involved commercial rearing of the Australian endemic egg parasitoid *Trichogramma carverae* for their mass release in vineyards for regulating the population of the light brown apple moth, *Epiphyas postvittana*. Since the life of the parasitoids is short, it is important to ensure accurate monitoring so that the release of predator coincides with maximum host egg density in order to achieve unrestricted impact on the target pest. Further, the longevity and fecundity of this natural enemy can be bettered by making them feed on nectar-producing plants such as alyssum, *Lobularia maritima* in organic vineyards. The natural enemies, viz. a mite (*Rhizoglyphus* sp.), ants (*Camponotus* sp., *Monomorium* sp. and *Oecophylla smaragdina*), and fungus, *Aspergillus* sp. and *Beauveria bassiana*, were found effective in mango weevil control (De and Pande 1987). Female weevil lays eggs 55 days after flowering when fruits are about 29 g in weight. Bioagents must be released at this stage to control weevil population (Shapiro-Ilan 2003).

Sterile insect technique (SIT) is an important eco-friendly approach for the control of insect pests. This involves mass rearing of target insect and inducing sexual sterility with radiation in adults (especially males) without altering their mating vigour and competitiveness. Release of such sterile adults in overwhelming number in natural population would limit the reproductive ability of natural population and can bring down the insect population to a manageable level or even can eradicate completely. The first success story of SIT was eradication of screwworm fly (*Cochliomyia hominivorax*) from North America. The successful implementation of SIT against different fruit fly species has demonstrated the usefulness of radiation in the management of insect pests in fruit culture. At BARC, attempts have been initiated for the management of red palm weevil, a major insect pest in coconuts under a multilocation collaborative programme with Agricultural Universities in Maharashtra, Karnataka and Kerala.

Ecological Engineering Approaches

Scientists also advocate the strategy of conservation biological control which involves altering the environmental conditions and existing practices for better management of pest populations through enhanced efficacy and site-level abundance of the existing natural enemies at the community level. The conservation biological control approach is most suited for organic farming since it involves minimal application of broad-spectrum pesticides that are capable of disrupting the community structure and restrict the action of natural enemies. An increased activity of the natural processes also helps in limiting the necessity and use of synthetic inputs. It also enhances the ecosystem service potential of biological pest control provided by predators and parasitoids. Plant diversification is another strategy which can help realize the potential of resource-limited natural enemies by satisfying their requirements for food and shelter. Natural enemies get benefitted from the increased plant diversity in terms of achieving a favourable microclimate (shelter), the plants as food (nectar or pollen) and/or the source of alternative hosts or prey. One such recorded example involves raising of a semi-permanent strip of vegetation in the centre of the field (beetle bank) to harbour carabid and staphylinid beetles and spiders, as well as for birds and small mammals. These beetle banks in winter months can harbour more than 1000 predatory invertebrates per square metre and can help control orchard insect population as natural enemies. Another similar approach involves cultivation of flowering insectary strips to provide pollen and nectar, which can enhance natural enemy fitness to fight pests and diseases in organic fruit orchards. A fit natural enemy of predators and parasitoids possesses a better longevity and fecundity, which in the long run skews the sex ratio of the parasitoid offspring towards the females. Conservation biological control approach involving the use of flower strips can also alter the spatial distribution of natural enemies in and around crops, and strips that have grass and flower vegetation are most effective for increasing the rate of predation. Management of weed strips is thus an important concept for managing pest and diseases in organically grown fruit crops.

Biodiversity with Flowering Plants

It is important to engage in effective orchard management particularly that the floor management which should be done in a manner to better and/or maintain beneficial predators. Biodiversity should be enhanced by making windbreaks and shelterbelts as it helps in increasing parasitoids and predators' number due to availability of nectar, pollen and insects. One of the challenges that organic mango production faces is the need for space to increase fruit production and at the same time control pests and diseases organically. Cowpea, carrot, buckwheat, French bean, cluster bean, dandelion, maize, mustard, anise, tansy, caraway, dill, yarrow, zinnia, clover, alfalfa, parsley, cosmos, sunflower, chrysanthemum and marigold are flowering crops that attract the native wasp populations and provide good habitats for them. Growing these crops as border crops or trap crops can help in reducing the pest incidence on mango crop. One such recorded example involves raising of a semi-permanent strip of vegetation in the centre of the field (beetle bank) to harbour carabid and staphylinid beetles and spiders, as well as for birds and small mammals. These beetle banks in winter months can harbour more than 1000 predatory invertebrates per square metre and can help control farm insect population as natural enemies. Rows of flowering buckwheat planted as understories throughout the vineyard as a food reward for parasitoid wasps improves the control of *E. postvittana.* Raise flowering plants/compatible cash crops along the field border by arranging shorter plants towards main crop and taller plants towards the border to attract natural enemies as well as to avoid immigrating pest population. Grow selected flowering plants in fruit orchards as intercrops, on bunds, and wherever space is constraint, vertical gardens offer solutions. Growing different flowering, vegetables and herbs on vertical structures in organic orchards not only act attracting plants providing nectar and pollen for predators and parasitoids, but will also bring in additional income from sale of produce. Vertical gardening or farming deserves a place in twenty-first century inorganic farming techniques and practices. Clean cultivation by removing all weeds is often practised by growers in mango orchards. But do not uproot weed plants such as *Tridax procumbens*, *Ageratum* sp., *Alternanthera* sp., etc. growing naturally as they act as nectar source for natural enemies. The flowering plants attract natural enemies of the selected pests. Actual selection of flowering plants should be based on availability, agroclimatic conditions and soil types. An increase in population of predatory insects, particularly carabid beetles, but a decline in pest population was recorded under organic farm conditions. In a bid to achieve better control of *E. postvittana*, rows of flowering buckwheat were planted throughout the vineyard as a food reward for parasitoid wasps.

Intercrops to Check Pest Incidence

Intercropping of main crop with weeds or other subsidiary crop which interferes with the pest development is another practical approach for managing pests. The approved strategy operates on the well-known fact that availability of resources determines colonization of pest population and in crop-weed intercropping strategy, which is in line with the resource concentration hypothesis, that proposes that highly populated regions of host plants can easily be identified and colonized by herbivores. However, use of plants that are distinctly different from the favoured crop may interfere with the identification and colonization capacity of the specialized herbivores owing to visual and chemical level changes in the habitat. However, use of non-crop plants or weeds has no negative effect on the generalized herbivores as they can survive on either of the crop or non-crop plants. Establishing cover crops with Brassicaceae, which are known to possess large quantities of glucosinolates, a sulphur compound, is reported to help inhibit the development of soilborne pests and diseases through biofumigation.

Among the various diseases that attack fruit crop, gummosis is of great economic importance since the trees die within a very short time. Planting crops like turmeric, garlic and marigold as intercrops can help to reduce disease incidence. In our experiment conducted at village Murar in Bihar, using turmeric as intercrop showed promise in checking mango decline, soilborne diseases, nematodes, termites, etc. Fungal infection is also common in mango and is distributed throughout the tropics and subtropics, with affected trees showing symptoms of wilt and dieback (Korsten et al. 1992). More than 150 mango trees in village Murar in Bihar showed abundant gum secretion from branches and main trunk right from the tree base to tree top, wilting, dieback, vascular browning and death of several trees. The observed gummosis in mango trees was often accompanied by damage caused by a new species of trunk borer. The grubs caused severe damage by feeding on the bark inside the trunk, boring upward, making tunnels, thus hindering the transport of water and nutrients from the root to the shoot, resulting in wilting and drying of the shoot. Acting as a wounding agent and vector, the trunk borers probably assist in rapid spread of the disease in the orchard. Several chemicals tried to control mango decline showed little or no success. Turmeric plantation as intercrop in this severely declining mango orchard at village Murar in Bihar was helpful in suppressing the population of trunk borers, termites and gummosis causing pathogens in the soil and also provided additional income from the harvest of the rhizomes, 9 months after planting. Turmeric root exudates or curcumin in rhizomes present in soil probably assisted in disease suppression by reducing the activity and population of trunk borer larvae and soilborne fungus. The orchard also became free from termite attack after turmeric planting as intercrop in mango. This study indicates that turmeric plantation can be used as intercrop in organic farming systems to control various soilborne pests and diseases in several fruit orchards.

Trap Cropping

In general, conventionally the trap cropping is practised in complementation with use of pesticides. It, however, has tremendous scope and potential even in organic system of crop cultivation. However, for the success of the trap cropping strategy in pest management, it is important to ensure that the trap crop attracts the pest more than the main crop and pests prefer it as food or as the oviposition site. Thus, for successful adoption of the trap cropping strategy, both the relative attractiveness and size of the trap crop in a landscape are important and determine the relative pest control efficiency. Apart from the above-mentioned attributes, trap cropping also depends on various other factors such as plant type, justification for deployment and whether it is being used in isolation or in combination with other strategies of pest management. A successful example of controlling pest population in organic production system through the use of trap crop has surfaced from New Zealand. The density of the southern green stink bug was lowered, the timing of their colonization was delayed, and damage to crop was reduced when black mustard was grown around the perimeter of fields. Okra, marigold, sesamum, gingelly, sorghum, chrysanthemum, castor, sunflower and cucumber are commonly used as trap crops to attract pests like fruit borers and leaf minor. Marigold is used against nematodes. Crops like maize, sorghum or millet reduce white fly and aphid population in papaya crop.

Physical Methods to Control Postharvest Pests and Diseases

Merely enhancing fruit production is not enough. We must ensure its safety, reduce postharvest losses and facilitate fair distribution. The postharvest losses due to microbial spoilage, insect infestation, etc. add up to 30–50% depending on the commodity. Although India is a very large producer of fruits, the per capita production is only about 100 gm per person per day. Because of these losses, the per capita availability of fruits is only of the order of 75 gm per person per day, which is just half of the requirements of a balanced diet. A significant portion of this requirement can be met by cutting down the postharvest losses. A large number of physical methods such as gamma irradiation of insect pests, hot water treatment and vapour heat treatment are known; of these gamma irradiation can be practised under the organic farming condition as well as on postharvest produce, while other protocols are effective for postharvest control of insect pests and disease infestation alone. HACCP (Hazard Analysis Critical Control Points)-based quality assurance systems are suitable for establishing protocols and monitoring systems that meet organic requirements. Operations with existing HACCP-based quality assurance systems observe that only minor changes are required to be made in the existing system of organic cultivation to comply with the organic standards. Both pre- and postharvest disease controls are important under organic farming (Jones and Prusky 2001). It can be said that for better postharvest disease management while it is important to store the produce at optimum temperature and RH, it is also important to ensure a disease-free preharvest crop growth and orchard hygiene in the organic field. Use of proper equipment for cleaning of fruits and separating the rejected fruits from the better ones can reduce the transfer of fungal spores onto the new fruits. It is also important to differentiate and understand the need for pest control strategy depending on the markets and duration of storage required. For example, fruits to be sold in the domestic market are normally stored for short durations and hence may not require any pest control management, while fruits destined for export are stored for longer duration till they reach the ultimate consumer and thus require postharvest treatments for fungal control to restrict the incidence of fruit breakdown from the anthracnose and stem-end rot diseases.

For over 30 years, scientists at BARC have carried out studies on radiation processing of various fruits and fruit products. It involves controlled application of the energy of radiation such as gamma rays, X-rays and accelerated electrons. This ensures killing of pathogens and storage pests. Radiation at medium-dose levels can effectively destroy fruit-borne parasites and microorganisms responsible for human illness and thereby hygiene fruits. It can also reduce microbial load and extend shelf life of perishable fruits at their recommended temperature of storage (Kaya and Lacey 2007). The process is also referred to as cold pasteurization. Radiation processing is also effective in delaying ripening of fruits. Non-destructive X-ray imaging system is now available which can detect the seed weevils in mango varieties like alphonso, neelam and totapuri and spongy tissue in alphonso mangoes. The X-ray scanned mangoes are safe for consumption and there is no health hazard.

With the establishment of WTO, the globalization of trade in fruit and fruit commodities has been on the rise. Ensuring quarantine or bio-security in international trade would become mandatory for the exporting countries.

Hot water treatment, vapour heat treatment (VHT) and irradiation are physical methods of quarantine for export. After harvest, anthracnose and fruit fly damage can be controlled if the mango fruits are dipped in hot water at 55 °C for 3–5 min. In VHT, fruits are heated in a chamber with vapour saturated air until pulp reaches a temperature of 46 °C. This temperature is maintained for 10 min after which, the chamber is ventilated. This method is used to disinfest fruits from fruit flies. As per norms, it is mandatory to irradiate the king of fruits before being shipped to the USA. Around seven metric tonnes of mangoes are irradiated in 8-h shifts daily at the Lasalgaon facility.

Plant Products to Control Postharvest Pests and Diseases in Fruits

Fruits, due to their low pH, higher moisture content and nutrient composition are very susceptible to attack by more than 100 species of pathogenic fungi. Considerable postharvest damages caused by fungal plant pathogens include rots, decay and production of mycotoxins which make fruits unfit for consumption. Natural compounds like essential oils, acetaldehyde, benzaldehyde, hexanal, jasmonates, acetic acid, glucosinolates, propolis, fusapyrone and deoxyfusapyrone, chitosan, etc. can be used to prevent fruit decay caused by fungi (Knight et al. 2000; Murray 2000; Kharkwal et al. 2012; Moghimipour and Handali 2015). Thymol and other essential oils from leaves of *Melaleuca leucadendron*, *Ocimum canum* and *Citrus medica*, *Mentha arvensis*, *O. canum* and *Zingiber officinale* are effective in controlling grey mould, blue mould and brown rots on oranges, sweet cherries, apricots and plums and greatly reduced postharvest decay without causing any phytotoxicity. Many flavour compounds and volatiles express their effects at very low concentration as potential fungicides and their natural occurrence as part of the human diet; their ephemeral nature and their biodegradability suggest low toxic residue problems. Acetaldehyde, benzaldehyde, cinnamaldehyde, ethanol, benzyl alcohol, nerolidol and 2-nonanone produced by ripening fruits have antifungal activity against microorganisms such as *Erwinia carotovora*, *Pseudomonas fluorescens*, *Monilinia fructicola*, *Penicillium* spp. and yeast commonly found on fruits. (*E*)-2-Hexenal, an efficient fumigant, is strongly antifungal in nature to control moulds and other fruit diseases. Aldehydes are compounds released after tissue damage and have a use as antifungal agents in fruits such as pears, strawberries, bananas, pineapples and melons against growth of *Alternaria alternata* and *B. cinerea*. Use of these aldehydes in packaging of highly processed products of these commodities is a possible future option. Effective fumigation or surface sterilization by acetic acid that occurs naturally in many fruits can sterilize the fruit surface, killing surface-borne spores.

Fumigation with low concentrations of acetic acid protected grapes from spoilage for up to 2 months in modified atmosphere packaging at 0 °C and extended shelf life of wide range of fruits like apricots, plums, grapes and sweet cherries and for control of *B. cinerea* conidia on apple fruits without phytotoxic effect. Acetic acid vapour is inexpensive and can be used in relatively low concentrations to control decay in stored table grapes and to treat produce in airtight storage rooms or containers. The use of vinegar is even safer and still effective. A naturally occurring compound 7-geranoxy coumarin isolated from the flavedo tissue of 'Star Ruby' grapefruit (*Citrus paradisi*) or aqueous extract of *Acacia nilotica* exhibited showed pronounced antifungal activity against *P. italicum* and enhanced the shelf life of oranges for 6 days (Kerns and Wright 2001).

Postharvest application of jasmonates suppressed grey mould rot caused by *B. cinerea* in strawberry and *P. digitatum* of 'Marsh Seedless' grapefruit and reduced decay in several fruits. Methyl jasmonate has a pleasant aroma and is suitable for storage rooms or fumigation chambers, while jasmonic acid, which is more soluble in water, is suitable for use in solution as a drench or dip. The antifungal activity of glucosinolates, produced by the Cruciferae, has been tested against *Monilinia laxa* and several other postharvest pathogens. Exposure of pear fruit to an allyl isothiocyanate (AITC) a naturally occurring flavour compound in mustard and horseradish has a well-documented antimicrobial activity. AITC-enriched atmosphere resulted in good control of blue mould and can successfully be employed in modified atmosphere packaging or as a gaseous treatment before storage of pears with moderately low impact on the environment. Propolis, a natural resinous substance obtained from leaf and bark of poplar and conifer trees, and fusapyrone, an antifungal metabolite, chitosan and its derivatives have antifungal properties and can be used in solution, powder form, or as wettable coatings of fruits against blue mould especially in grapes and 'Red Delicious' apple fruits. Microbial antagonists have also been reported to protect a variety of harvested perishable commodities against a number of postharvest pathogens.

Conclusion

The challenge in organic fruit production is timely control of several pests like hoppers, mealy bugs, stem bores, fruit flies, bugs, caterpillars, mites and moth and diseases like powdery mildew, anthracnose, sooty mould, stem rot, gummosis, panama, moko disease, mango malformation, etc. that drastically reduce fruit yields and quality. Knowledge of what method to use, when to use and how much to use to reduce pest and disease incidence without compromising the fruit yield and quality are most essential. Successful organic production requires an integrated approach to managing pests and diseases. A range of preventative measures is important to minimize susceptibility to pest and disease pressures. Weekly orchard monitoring or a visual inspection of mango trees is important to notice the presence of pests and beneficial insects in order to consider when to make pest management decisions.

A large number of parasites, predator and pathogens are very active against pests of fruits crop in the fields. Their presence and foraging activity hinder the fruit flies from laying eggs, resulting in reduced pest damage. These natural enemies should be conserved in the field. Strategies like crop diversification and ecological engineering by selecting flowering plants that are available and suitable to the agroclimate region, along with management practices adopting physical and biological control methods, can reduce pests and disease incidence without need to use any chemicals. There is an urgent need to increase search for new technologies and create awareness among fruit growers on the available technologies to adopt organic fruit production in India on large scale.

References

Adel, M. M., Sehnal, F., & Jurzysta, M. (2000). Effects of alfalfa saponins on the moth Spodoptera littoralis. *Journal of Chemical Ecology, 26*, 1065–1078.

Agudelo-Silva, F., Zalom, F. G., Hom, A., & Hendricks, L. (1995). Dormant season application of *Steinernema carpocapsae* (Rhabditida: Steinernematidae) and *Heterorhabditis* sp. (Rhabditida: Heterorhabditidae) on almond for control of overwintering *Amyelois transitella* and *Anarsia lineatella* (Lepidoptera: Gelechidiidae). *Florida Entomologist, 78*, 516–523.

Aktar, M. W., Sengupta, D., & Chowdhury, A. (2009). Impact of pesticides use inagriculture: Their benefits and hazards. *Interdisciplinary Toxicology, 2*(1), 1–12.

Altieri, M. A. (1992). *Biodiversity and Pest Management in Agroecosystems* (p. 185). New York: Haworth Press.

Balandrin, M. F. (1996). Commercial utilization of plant-derived saponins: An overview of medicinal, pharmaceutical, and industrial applications. In G. R. Waller & K. Yamasaki (Eds.), *Saponins used in traditional medicine* (pp. 1–14). New York: Plenum Press.

Balazs, K. (1997). The importance of the parasitoids in apple orchards. *Biological Agric Hortic 15*, 123–129.

Barnett, W. W., Edstrom, J. P., Coviello, R. L., & Zalom, F. G. (1993). Insect pathogen "Bt" controls peach twig borer on fruits and almonds. *California Agriculture, 47*, 4–6.

Basta, A., & Spooner-Hart, R. (2003). Efficacy of an extract of Dorrigo pepper (Tasmannia stipitata) against two-spotted mite and greenhouse thrips. In G. A. C. Beattie & D. M. Watson (Eds.), *Spray oils beyond 2000: Sustainable pest and disease management*. Canberra: ACIAR.

Beattie, A., et al. (2002). Evaluation of rapeseed-based plant oils for control of citrus leafminer and their phytotoxicity to lemon. In *Spray oils beyond 2000*. University of Western Sydney.

Beegle, C. C., & Yamamoto, T. (1992). History of *Bacillus thuringiensis* Berliner research and development. *Canadian Entomologist, 124*, 587–616.

Begum, M., Gurr, G. M., Wratten, S. D., & Nicol, N. I. (2004). Flower colour affects tri-trophic biocontrolinteractions. *Biological Control, 30*, 584–590.

Blommers, L. H. M. (1994). Integrated pest management in European apple orchards. *Annual Review of Entomology, 39*, 213–241.

Boscheri, S., Rizzoli, W., & Paoli, N. (1992). Experience with mating disruption for control of the codling moth and leafrollers at the Laimburg Experiment Station (South Tirol-Bolzano). *Int Org Biol Control West Palearct Reg Sect Bull, 15*(5), 81–87.

Burgel, K., Daniel, C., & Wyss, E. (2005). Effects of autumn kaolin treatments on the rosy apple aphid, Dysaphis plantaginea (Pass.) and possible modes of action. *Journal of Applied Entomology, 129*, 311–314.

Campbell, R. J. (Ed.). (1992). *A guide to mangoes in Florida*. Miami: Fairchild Tropical Garden.

Cheok, C. Y., Salman, H. A. K., & Sulaiman, R. (2014). Extraction and quantification of saponins: A review. *Food Research International, 59*, 16–40.

Cossentine, J. E., Banham, F. L., & Jensen, L. B. (1990). Efficacy of the nematode *Heterorhabditis heliothidis* (Rhabditida: Heterorhabditidae) against peachtree borer, *Synanthedon exitiosa* (Lepidoptera: Sesiidae) in peach trees. *Journal of the Entomological Society of British Columbia, 87*, 82–84.

Cottrell, T. E., Wood, B. W., & Reilly, C. C. (2002). Particle film affects black pecan aphid (Homoptera: Aphididae) on pecan. *Journal of Economic Entomology, 95*, 782–788.

Crickmore, N., Zeigler, D. R., Feitelson, J., Schnepf, E., Van Rie, J., et al. (1998). Revision of the nomenclature for the *Bacillus thuringiensis* pesticidal crystal proteins. *Microbiology and Molecular Biology Reviews, 62*, 807–813.

Daane, K. M., Sime, K. R., & Dahlsten, D. L. (2005). The biology of Psyllaephagus bliteus Riek (Hymenoptera: Encyrtidae), a parasitoid of the red gum lerp psyllid (Hemiptera: Psylloidea). *Biological Control, 32*, 228–235.

Da Silva, P., Eyraud, V., Carre-Pierrat, M., Sivignon, C., Rahioui, I., Royer, C., et al. (2012). High toxicity and specificity of the saponin 3-GlcA- 28-AraRhaxylmedicagenate, from *Medicago truncatula* seeds, for *Sitophilus oryzae*. *BMC Chemical Biology, 12*, 3.

De Geyter, E. D., Lambert, E., Geelen, D., & Smagghe, G. (2007). Novel advances with plant saponins as natural insecticides to control pest insects. *Pest Technology, 1*(2), 96–105.

De, K., & Pande, Y. D. (1987). Evaluation of certain non-insecticidal methods of reducing infestation of the mango nut weevil, *Sternochetus gravis* (F.) in India. *Tropical Pest Management, 33*, 27–28.

Delate, K., McKern, A., & Turnbull, R. (2005). Integrated approaches to organic pest management in the Midwestern U.S.A.: Case studies of three crops. *Organic Research* May: 8N–15N.

De Reede, R. H., Gruys, P., & Vaal, F. (1985). Leafrollers in apple IPM under regimes based on *Bacillus thuringiensis*, on diflubenzuron, or on epofenonane. *Entomologia Experimentalis et Applicata, 37*, 263–274.

Devi, A. N., & Arumugam, T. (2005). Studies on the shelf life and quality of Rasthali banana as affected by postharvest treatments. *Orissa Journal of Horticutlture, 33*(2), 3–6.

Faizal, A., & Geelen, D. (2013). Saponins and their role in biological processes in plants. *Phytochemistry Reviews, 12*, 877–893.

Falcon, L. A., Kane, W. R. & Bethel, R. S. (1968). Preliminary evaluation of a granulosis virus for control of the codling moth. *Journal of Economic Entomology, 61*, 1208–1213.

Garczynski, S. F., & Siegel, J. P. (2007). Bacteria. See Ref. 95, 175–97.

Glenn, D. M., & Puterka, G. J. (2005). Particle films: A new technology for agriculture. *Horticultural Reviews, 31*, 1–44.

Glenn, D. M., Puterka, G., Venderzwet, T., Byers, R. E., & Feldhake, C. (1999). Hydrophobic particle films: A new paradigm for suppression of arthropod pests and plant diseases. *Journal of Economic Entomology, 92*, 759–771.

Glenn, D. M., Prado, E., Erez, A., & Puterka, G. J. (2002). A reflective, processed-kaolin particle film affects fruit temperature, radiation reflection and solar injury in apple. *Journal of the American Society for Horticultural Science, 127*, 188–193.

Goettel, M. S., Eilenberg, J., & Glare, T. R. (2005). Entomopathogenic fungi and their role in regulation of insect populations. In L. I. Gilbert, K. Iatrou, & S. Gill (Eds.), *Comprehensive molecular insect science* (Control) (Vol. 6, pp. 361–406). Oxford: Elsevier/Pergamon. 470 pp.

Grewal, P. S., Ehlers, R.-U., & Shapiro-Ilan, D. I. (Eds.). (2005). *Nematodes as biocontrol agents*. Cambridge, MA: CABI. 505 pp.

Groner, A. (1990). Safety to nontarget invertebrates of baculoviruses. In M. Laird, L. A. Lacey, & E. W. Davidson (Eds.), *Safety of microbial insecticides* (pp. 135–147). Boca Raton: CRC Press.

Harrison, R. D., & Gardner, W. A. (1991). Occurrence of entomogenous fungus *Beauveria bassiana* in pecan orchard soils in Georgia. *Journal of Entomological Science, 26*, 360–366.

Huber, J. (1986). Use of baculoviruses in pest management programs. In R. R. Granados, & B. A. Federici (Eds.), *The biology of baculoviruses.* Vol. II: *Practical Application for Insect Control* (pp. 181–202). CRC Press, Boca Raton.

Jones, R. W., & Prusky, D. (2001). Expression of an antifungal peptide in *Saccharomyces*: A new approach for biocontrol of the postharvest disease caused by *Colletotrichum coccodes*. *Phytopathology, 92*, 33–37.

Kaya, H. K., & Lacey, L. A. (2007). Introduction to microbial control. See Ref. 95, 3–7.

Kehrli, P., & Wyss, E. (2001). Effects of augmentative releases of the coccinellid, Adalia bipunctata, and of insecticide treatments in autumn on the spring population of aphids of the genus Dysaphis in apple orchards. *Entomol Exp Appl, 99*, 245–252.

Kerns, D. L., & Wright, G. C. (2001). *Citrus and deciduous fruit and nut research report*. Tucson: College of Agriculture and Life Sciences, University of Arizona.

Kharkwal, H., Panthari, P., Pant, M. K., Kharkwal, H., Kharkwal, A. C., & Joshi, D. D. (2012). Foaming glycosides: A review. *IOSR Journal of Pharmacy, 2*(5), 23–28.

Knight, A. L., Unruh, T. R., Christianson, B. A., Puterka, G. J., & Glenn, D. M. (2000). Effects of a kaolin-based particle film on the obliquebanded leafroller (Lepidoptera: Tortricidae). *Journal of Economic Entomology, 93*, 744–749.

Korsten, L., Lonsdale, J. H., De Villiers, E. E., & De Jager, E. S. (1992). Pre-harvest control of mango diseases. *South African Mango Growers' Association Yearbook, 12*, 72–78.

Kuske, S., Daniel, C., Wyss, E., Sarraquigne, J. P., Jermini, M., Conedera, M., & Grunder, J. M. (2005). Biocontrol potential of entomopathogenic nematodes against nut and orchard pests. *Insect Pathogens and Insect Parasitic Nematodes: Melolontha, 28*(2), 163–167.

Lacey, L. A., & Siegel, J. P. (2000). Safety and ecotoxicology of entomopathogenic bacteria. In J. F. Charles, A. Delecluse, & C. Nielsen-LeRoux (Eds.), *Entomopathogenic bacteria: From laboratory to field application* (pp. 253–273). Dordrecht: Kluwer Academic Publishers.

Lacey, L. A., Arthurs, S. P., & Headrick, H. (2005). Comparative activity of the codling moth granulovirus against *Grapholita molesta* and *Cydia pomonella* (Lepidoptera: Tortricidae). *Journal Entomological Society of British Columbia, 102*, 79–80.

Lacey, L. A., Arthurs, S. P., Knight, A., & Huber, J. (2007). Microbial control of lepidopteran pests of apple orchards. See Ref. 95, 527–46.

Lapointe, S. L. (2000). Particle film deters oviposition by *Diaprepes abbreviatus* (Coleoptera: Curculionidae). *Journal of Economic Entomology, 93*, 1459–1463.

Lezama-Gutierrez, R., Trujillo, A., Molina-Ochoa, J., Rebolledo-Dominguez, O., Pescador, A., Lopez-Edwards, M., & Aluja, M. (2000). Virulence of *Metarrizium anisopliae* (Deuteromycotina: Hypomycetes) on *Anastrepha ludens* (Diptera: Tephritidae): Laboratory and field trials. *Journal of Economic Entomology, 93*, 1080–1084.

Lindegren, J. E., Agudelo-Silva, F., Valero, K. A., & Curtis, C. E. (1987). Comparative small-scale field application of *Steinernema feltiae* for navel orangeworm control. *Journal of Nematology, 19*, 503–504.

Lacey LA, Siegel JP, Charles J-F, Delecluse A, Nielsen-LeRoux C (2000) Entomopathogenic Bacteria: From Laboratory to Field Application. Kluwer Academic Publishers, Dordrecht, The Netherlands

Mazor, M., & Erez, A. (2004). Processed kaolin protects fruits from Mediterranean fruit fly infestations. *Crop Protection, 23*, 47–51.

Melgarejo, P., Martinez, J. T., Hernandez, F. C. A., Martinez-Font, R., Barrows, P., & Erez, A. (2004). Kaolin treatment to reduce pomegranate sunburn. *Scientia Horticulturae-Amsterdam, 100*, 349–353.

Miller, L. K. (1997). Introduction to the baculoviruses. In L. K. Miller (Ed.), *The baculoviruses* (pp. 1–6). New York: Plenum Press.

Moghimipour, E., & Handali, S. (2015). Saponin: Properties, methods of evaluation and applications. *Annual Review & Research in Biology, 5*(3), 207–220.

Moses, T., Papadopoulou, K. K., & Osbourn, A. (2014). Metabolic and functional diversity of saponins, biosynthetic intermediates and semi-synthetic derivatives. *Critical Reviews in Biochemistry and Molecular Biology, 49*(6), 439–462.

Murray, B. I. (2000). Plant essential oils for pest and disease management. *Crop Protection, 19*, 603–608.

Ntalli, N. G., & Menkissoglu-Spiroudi, U. (2011). Pesticides of botanical origin: A promising tool in plant protection. pp. 3–24. In M. Stoytcheva (Ed.), *Pesticides – formulations, effects, fate*, Prof. Margarita Stoytcheva (Ed.), (p. 808). ISBN: 978-953-307-532-7, InTech, Available from: http://www.intechopen.com/books/pesticides-formulations-effectsfate/pesticides-ofbotanical-origin-a-promising-tool-in-plant-protection

Pari, P., Carli, G., Molinari, F., & Cravedi, P. (1993). Evaluations de l'efficacit'e de *Bacillus thuringiensis* Berliner contre *Cydia molesta* (Busck). *Bulletin OILB/SROP, 16*, 38–41.

Pasqualini, E., Civolani, S., & Corelli Grappadelli, L. (2002). Particle film technology: Approach for a biorational control of Cacopsylla pyri (Rynchota: Psyllidae) in northern Italy. *Bulletin Insect, 55*, 39–42.

Peng, R. K., & Christian, K. (2005). Integrated pest management in mango orchards in the Northern Territory Australia, using the weaver ant, Oecophyllasmaragdina, (Hymenoptera: Formicidae) as a key element. *International Journal of Pest Management, 51*(2), 149–155. https://doi.org/10.1080/09670870500131749

Puterka, G., Glenn, D. M., Sekutowski, D. G., Unruh, T. R., & Jones, S. K. (2000). Progress toward liquid formulations of particle films for insect and disease control in pear. *Environmental Entomology, 29*, 329–339.

Saour, G., & Makee, H. (2004). A kaolin-based particle film for suppression of the olive fruit fly *Bactrocera oleae* Gmelin (Dip., Tephritidae) in olive groves. *Journal of Applied Entomology, 128*, 28–31.

Shapiro-Ilan, D. I. (2003). Microbial control of the pecan weevil, *Curculio caryae*. In J. D. Dutcher, M. K. Harris, & D. A. Dean (Eds.), *Integration of chemical and biological insect control in native, seedling, and improved pecan production*, (pp. 100–14). *Southwest. Entomol. Suppl.* No. 27.

Shapiro-Ilan, D. I., Gouge, D. H., & Koppenhofer, A. M. (2002a). Factors affecting commercial success: Case studies in cotton, turf and citrus. See Ref. 58, 333–55.

Shapiro-Ilan, D. I., Mizell, R. F. I. I. I., & Campbell, J. F. (2002b). Susceptibility of the plum curculio, *Conotrachelus nenuphar,* to entomopathogenic nematodes. *Journal of Nematology, 34*, 246–249.

Shapiro-Ilan, D. I., Gardner, W. A., Fuxa, J. R., Wood, B. W., Nguyen, K. B., et al. (2003). Survey of entomopathogenic nematodes and fungi endemic to pecan orchards of the southeastern US and their virulence to the pecan weevil (Coleoptera: Curculionidae). *Environmental Entomology, 32*, 187–195.

Shapiro-Ilan, D. I., Cottrell, T., & Gardner, W. A. (2004). Trunk perimeter applications of *Beauveria bassiana* to suppress adult *Curculio caryae* (Coleoptera: Curculionidae). *Journal of Entomological Science, 39*, 337–349.

Showler, A. T. (2002). Effects of kaolin-based particle film application on boll weevil (Coleoptera: Curculionidae) injury in cotton. *Journal of Economic Entomology, 95*, 754–762.

Silimela, M., & Korsten, L. (2006). Evaluation of pre-harvest *Bacillus licheniformis* sprays to control mango fruit diseases. *Crop Protection, 26*, 1471–1481.

Steinkraus, D. C. (2007). Documentation of naturally-occurring pathogens and their impact in agroecosystems. See Ref. 95, 267–81.

Tanada, Y. (1964). A granulosis virus of the codling moth, *Carpocapsae pomonella* (Linnaeus) (Olethreutidae, Lepidoptera). *Journal og Insect Pathology, 6*, 378–380.

Taylor, W. G., Fields, P. G., & Sutherland, D. H. (2004). Insecticidal components from field pea extracts: Soyasaponins and lysolecithins. *Journal of Agricultural and Food Chemistry, 52*, 7484–7490.

Tedders, W. L., Weaver, D. J., & Wehunt, E. J. (1973). Pecan weevil: Suppression of larvae with the fungi *Metarhizium anisopliae* and *Beauveria bassiana* and the nematode *Neoaplectana dutkyi*. *Journal of Economic Entomology, 66*, 723–725.

Tiwari, R. K. S., Ashok, S., Rajput, M. L., & Bisen, R. K. (2006). Relative susceptibility of mango varieties to powdery mildew caused by *Oidium mangiferae*. *Advances in Plant Sciences, 19*, 181–183.

Vail, P. V., Hoffmann, D. F., Streett, D. A., Manning, J. S., & Tebbets, J. S. (1993). Infectivity of a nuclear polyhedrosis virus isolated from *Anagrapha falcifera* (Lepidoptera: Noctuidae) against production and postharvest pests and homologous lines. *Environmental Entomology, 22*, 1140–1145.

Vincken, J. P., Heng, L., de Groot, A., & Gruppen, H. (2007). Saponins, classification and occurrence in the plant kingdom. *Phytochemistry, 68*, 275–297.

Wraight, S. P., Inglis, G. D., & Goettel, M. S. (2007). Fungi. See Ref. 95, 223–48.

Wyss, E., & Daniel, C. (2004). Effects of autumn kaolin and pyrethrin treatments on the spring population of Dysaphis plantaginea in apple orchards. *Journal of Applied Entomology, 128*, 147–149.

Wyss, E., Villiger, M., Hemptinne, J-L., & Müller-Schärer, H. (1999). Effects of augmentative releases of eggs and larvae of the two-spot ladybird beetle, Adalia bipunctata, on the abundance of the rosy apple aphid, Dysaphis plantaginea, in organic apple orchards. *Entomol Exp Appl, 90*, 167–173.

Yee, W. L., & Lacey, L. A. (2003). Stage-specific mortality of *Rhagoletis indifferens* (Diptera: Tephritidae) exposed to three species of *Steinernema* nematodes. *Biological Control, 27*, 349–356.

Zehnder, G., Gurr, G. M., Kuhne, S., Wade, M. R., Wratten, S. D., & Wyss, E. (2007). Arthropod pest management in organic crops. *Annual Review of Entomology, 52*, 57–80.

Zimmermann, G. (2005). Pilzpräparate. In H. Schmutterer & J. Huber (Eds.), *Natürliche Schädlings bekämpfungsmittel* (pp. 87–109). Stuttgart: Ulmer-verlag.

Pesticides: Classification, Detection, and Degradation

Sarath Chandran C., Sabu Thomas, and M. R. Unni

Introduction

Human population has always followed a geometrical progression, whereas food production shows an arithmetic progression. The huge pressure of providing food at low costs has forced farmers to use pesticides. According to the Federal Insecticide, Fungicide and Rodenticide Act, a pesticide is defined as any substance or mixture of substances intended for preventing, destroying, repelling, or mitigating any insects, rodents, nematodes, fungi, weeds, or any other form of life declared to be pests; it is any substance or mixture of substances intended for use as a plant regulator, defoliant, or desiccant (Benson 1969; What are Pesticides|Definition|Types|Uses and Effects 2016). According to the Food and Agriculture Organization, a pesticide is any substance or mixture of substances intended for preventing, destroying, or controlling any pest, including vectors of human or animal disease, or unwanted species of plants or animals causing harm during or otherwise interfering with the production, processing, and storage or marketing of food agriculture commodities, wood or wood products, or animal feed stuffs, or which may be administered to animals to control insects arachnids or other pests in or on their bodies (Zacharia and Tano 2011). These chemicals may be growth regulators, defoliants, desiccants, fruit-thinning agents, or agents for preventing the premature fall of fruits that are applied in the field or on food during storage and transport. The evolution of pesticide use is represented in Fig. 1.

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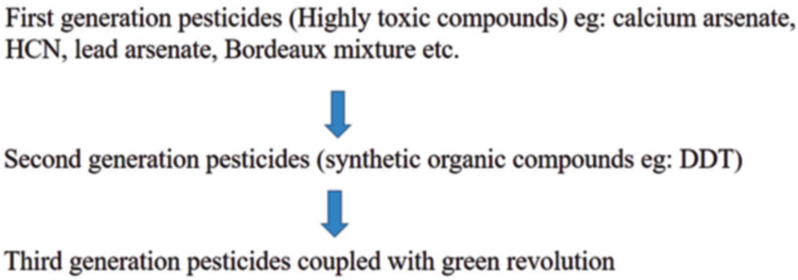


Fig. 1 Schematic representation of the evolution of pesticides (Zacharia and Tano 2011; Compelling Evidence of Human Health Effects of Pesticides n.d.)

The green revolution brought an excessive use of pesticides to enhance productivity and reduce crop loss (Singh 2000; Conway and Barbier 2013). The widespread use of pesticides, environmental persistence, and potential hazards to wildlife initiated research on the impact of pesticides on the ecosystem (Conway and Barbier 2013). Thereby, studies revealed that the entire population is exposed to a mixture of pesticides through food, water, and air. The effect of pesticides on different classes of people is summarized in Table 1.

Pesticide formulations usually contain active and inert ingredients. The active component kills the pest, whereas the role of inert components is to improve the efficiency of the active ingredient. These inert ingredients are not tested thoroughly and are seldom disclosed on the product labels, with most of them being toxic when inhaled or absorbed by the skin. The health effects of different classes of pesticides can be categorized as shown in Table 2.

Pesticide available in the market can be classified as shown in Table 3.

Figure 2 shows the cycle of pesticide exposure and represents the course of a pesticide's journey after application on farmland.

In most cases, the degradation products of pesticides are far more toxic than the original pesticides; for example, photodieldrin is several times toxic than dieldrin. The degradation of common pesticides was investigated in detail by Benson et al., who confirmed that the degradation products of most pesticides are far more toxic than the parent pesticides. Photodegradation and other modes of degradation for common pesticides are shown in Fig. 3.

Eugina et al. investigated the amount of heavy metals in pesticides, fertilizers, and soil. Soil samples from rice farming areas in Albufera Natural Park were selected for the study (Gimeno-García et al. 1996). Significant amounts of heavy metals are found in pesticides due to insufficient purification for reducing the cost of production. Fertilizers such as superphosphate contain high concentrations of Cd, Co, and Zn, whereas $CuSO_4$ and $FeSO_4$ showed a high content of Pb and Ni. Similarly, pesticides showed the presence of high concentrations of Cd, Fe, Mn, Zn, and Ni.

Table 1 Effects of pesticides on different classes of people (What are Pesticides|Definition|Types|Uses and Effects 2016)

Infants and exposure in womb	Pregnant women	Adults and farmers
Premature birth, low birth weight, cancer, brain tumors, neuroblastoma, leukemia, underdeveloped brain, paralysis, birth defects, developmental disabilities, fetal death	Pregnancy complications, miscarriage; children with birth defects, oral clefts, neural tube defects, heart defects, limb defects, and leukemia	Memory loss, loss of coordination, reduced speed of response to stimuli, reduced visual ability, asthma, allergies, cancer, hormone disruption, paralysis, stroke, etc.

Table 2 Different categories of pesticides and their effects on humans

Organochlorine (Longnecker et al. 1997; Alavanja et al. 2004; Schade and Heinzow 1998)	Organophosphates and carbamates (Alavanja et al. 2004; Eskenazi et al. 1999; Senanayake and Karalliedde 1987; Karalliedde et al. 2000; Wesseling et al. 2002; Karami-Mohajeri and Abdollahi 2011)	Pyrethroids (Vijverberg and vanden Bercken 1990; Saillenfait et al. 2015; Shafer et al. 2005; Bradberry et al. 2012)	Herbicides (Bertazzi et al. 2001; Sterling and Arundel 1986; Kligerman et al. 2000; Wolfe et al. 1990)
Loss of sensation, hypersensitivity to light and sound, dizziness, tremors, nausea, vomiting, nervousness, neurological diseases, decrease in sperm count and mobility	Increased salivation, perspiration, narrowing of pupils, nausea, diarrhea, decreased blood pressure, muscle weakness and fatigue, paralysis Human toxicity caused a decline in their use and spurred search for new alternatives	Hyperexcitation, aggressiveness, lack of coordination, whole body tremors, skin allergies, cancers, reproductive or developmental effects, endocrine system effects	Birth defects, cancers, liver disease and other related illnesses; also affect wildlife and aquatic organisms; contaminate surface water and ground water

Detection of Pesticides

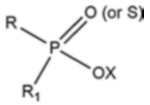
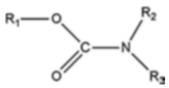
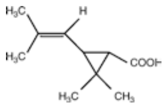
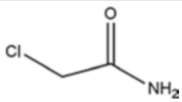
Chromatographic Techniques

Pesticide detection usually involves the steps shown in Fig. 4 (Omeroglu et al. 2012).

The major drawbacks of the chromatographic technique include the following (Wan and Wong 1996):

1. Large amounts of organic solvents are required.
2. Special purification techniques are required for these solvents, making them very costly.
3. The recovery of solvents along with their disposal are difficult.
4. The solvents are hazardous to the environment.

Table 3 Different classes of pesticides available in the market along with their general structure

Common pesticides	Comments
1. Organochlorine pesticides (OCPs)	Introduced in 1950s and banned due to extreme toxicity. They are stable, thereby persistent in environment. OCP contaminants can be found in soil, river sediments, and costal marine sediments
	For example, CCl4, DDT, DDE, heptachlor, β-HCH, dieldrin
2. Organophosphate pesticides (OPPs)	Generalized during the Second World War , toxi to non-target species also
	For example, acephate, parathion, malathion, phosmet
	Most of them are banned in the United States of America
3. Carbamates	Neurotoxin and acetylcholinesterase inhibitors, adverse effect on human development
	For example, aldicarb, carbaryl, methiocarb, pirimicarb, maneb
4. Pyrethroids	Interfere with cell signaling, adverse effect on male reproductive health suspected endochrine disrupters
	For example, cyhalothrin, cypermethrin, deltamethrin
5. Neonicotinoids	Neuroactive insecticide with a structure similar to nicotine. It was first introduced in 1985. They are more toxic to insects than mammals. They have suspected toxicity to bees
	For example, clothianidin, imidacloprid, thiamethoxam
6. Chloroacetamides	Suspected to cause developmental abnormalities, reproductive toxicity, teratogenecity.
	For example, alachlor, metolachlor
7. Glyphosate	Usually and aqueous mixture of isopropylamine salt of glyphosate, a surfactant, antifoaming and coloring agents, biocides, and inorganic ions
	Glyphosate is an example of a compound where toxicity is due to the "inert" ingredient

To reduce the impact of these effects, several strategies have been reported. Bushway et al. reported the use of miniaturization of scale, where a small portion of the extract is cleaned for analysis (Bushway et al. 1995). This reduces the solvent consumption and decreases the analysis time. Simplification of the analysis procedure is another accepted methodology, which can broadly be divided into two methods:

1. The thorough removal of analyte from the sample matrix, followed by washing the remainder with large amounts of solvent. They are then combined.
2. The sample is extracted only once. Small amounts of this extract are then used for subsequent clean-up as required.

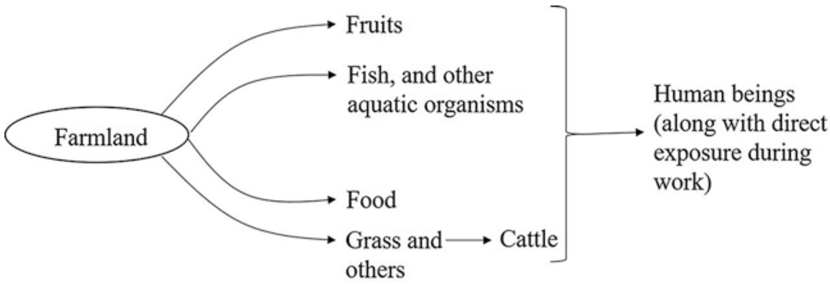


Fig. 2 Cycle of pesticide transfer after application (Alternative and Biological Pest Controls|Commons Abundance Network n.d.)

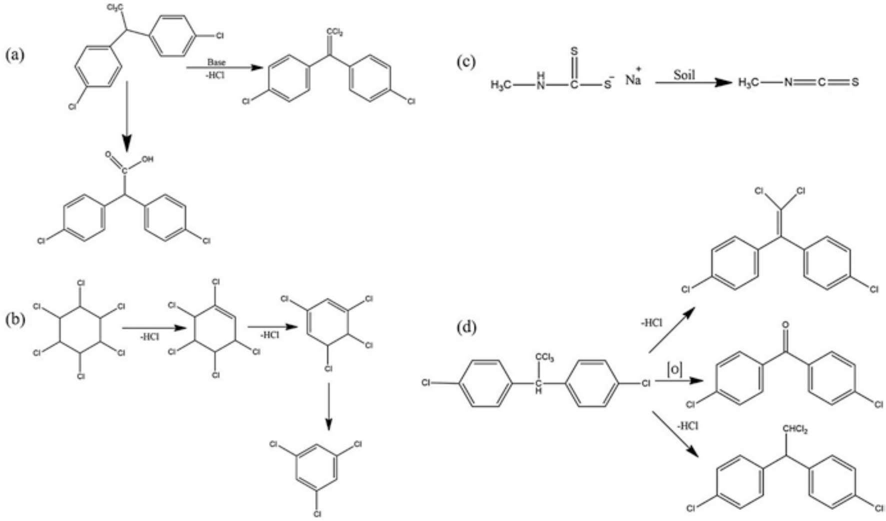


Fig. 3 Different modes of degradation and the products formed for different pesticides: (**a**) 1,1′-(2,2,2-trichloroethane-1,1-diyl)bis(4-chlorobenzene) (DDT), (**b**) benzene hexachloride (BHC), (**c**) methyl isocyanate, (**d**) p,p′-dichlorodiphenyldichloroethene (P, P′-DDE)

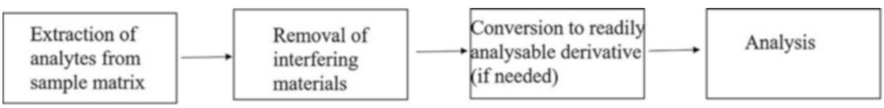


Fig. 4 Different steps involved in the chromatographic detection of pesticides

Liao et al. (1991) and Miyahara et al. (1994) reported the direct analysis of samples (where a clean-up step is omitted); however, this is not recommended due to the possibility of negative effects from complex matrices. Kadenczki et al. reported a multi-residue method in which extraction and column clean-up occurred in a single step (Kadenczki et al. 1992). In the early 1990s, researchers developed new extraction techniques, such as solid-phase extraction (which is mainly used for the trace enrichment of water samples before testing). Belardi and Pawliszyn developed a solid-phase microextraction technique in which sorbent-coated silica fibers are used for the extraction of analytes from aqueous and gaseous samples and then used for analysis (Application of chemically modified fused silica fibers in the extraction of organics from water matrix samples and their rapid transfer to capillary columns n.d.). Later, a solid-phase microextraction (SPE) method was used for the detection of phenols and metal ions in water samples (Rosenfeld 1999; Huang et al. 1997). The major drawback of the SPE technique is the fact that the sorbents can be used only once and are quite expensive (Barker 2007). Matrix solid-phase extraction is a new member of the family of SPE family; it is commonly performed in supercritical fluid extraction (SFE) and pressurized liquid extraction (PLE) to retain water/unwanted matrix compounds (Barker 2007; Oniszczuk et al. 2013).

Supercritical Fluid Extraction

Carbon dioxide (CO_2) is safe, unreactive, readily available, relatively inexpensive, and has low critical pressure and temperature; thus, it is the most commonly used solvent in SFE (McHugh and Krukonis 2013). Important advantages of SFE include the following (McHugh and Krukonis 2013):

1. SFE is a viable approach for the extraction of individual and multiple pesticides from food, soil, and plants.
2. It reduces operation costs, time, labor, space, glassware, and laboratory space, among others.
3. Fatty foods require clean-up after SFE, whereas non-fatty foods do not require any clean-up.
4. SFE results in minimal pesticide loss.
5. Water and salts can have strong effects in the SFE process.
6. Satisfactory extraction efficiency can be achieved for pesticides with low polarity; for pesticides with high polarity, modifier addition is necessary. Kane et al. (1993) discussed in detail the relationship between the structure of an analyte and the mode of extraction.

Pressurized Liquid Extraction

PLE was introduced as a competitor for SFE by Dionex scientists (Hawthorne et al. 2000; Carabias-Martínez et al. 2005; Mustafa and Turner 2011). Figure 5 shows a schematic representation of the instrumentation of PLE.

PLE is very similar to Soxhlet extraction and has been described as a "green" technology for the extraction of nutraceuticals from food and herbal plants (Hawthorne et al. 2000; Mustafa and Turner 2011). Suchen et al. compared the

Fig. 5 Schematic representation of the instrumentation of PLE (Hawthorne et al. 2000)

efficiency of PLE with Soxhlet extraction; the authors concluded that PLE showed better efficiency than Soxhlet extraction for indicator polychlorinated biphenyls, some organochlorine pesticides, more volatile hexachlorobenzenes, as well as semi-volatile compounds. However, the major limitation of PLE is the high cost of the instrument (Suchan et al. 2004).

Gel Permeation Chromatography

Gel permeation chromatography (GPC), also known as size exclusion chromatography, involves the separation of molecules on the basis of their size (López-Mesas et al. 2000). GPC is commonly used for the determination of molecular weight.

Analysis of Pesticides

Durand et al. (1989) discussed the accuracy of various analytical techniques, such as gas chromatography (GC), mass spectroscopy (MS), GC-MS, and liquid chromatography (LC)-MS, for chlorotriazines and organophosphorus pesticides. It was concluded that GC methods offer better detection of 1–2.5 orders of magnitude, whereas an LC-LC-diode array (DA) is more easily applicable for soil samples (Durand et al. 1989). Balinova and Balinov (1991) reported the use of GC coupled with an electron capture detector for the analysis, detection, and estimation of nine soil applied herbicides with different chemical structures (Balinova and Balinov 1991). A specially packed column was used for the study; Fig. 6 shows the recovery of herbicides using various extraction solvents (Balinova and Balinov 1991).

A specially packed column was prepared by combining 3% OV-225 and 5% SE-52 in a ratio of 1:4:0.9, coupled with consecutive filling; it was reported to be simple, reliable, rapid, and effective for the detection of pesticides, with OV 225 at the side of injector and SE-52 at the side of the detector. Raju and Gupta (1991) first reported the use of spectroscopic methods for the determination of endosulfan in soil and water (Raju and Gupta 1991). Sulfer dioxide (SO_2) from endosulfan was liberated using p-toluene sulfonic acid, which was then absorbed in malonyldihydrazide followed by estimation using p-aminoazobenzene and formaldehyde in HCl medium. This method provided 98–99% recovery from soil samples and approximately 99% recovery from water samples, which was reported to be superior to other methods for recovery (Raju and Gupta 1991). Figure 7 shows the ultraviolet-visible (UV-vis) spectra of endosulfan (Raju and Gupta 1991).

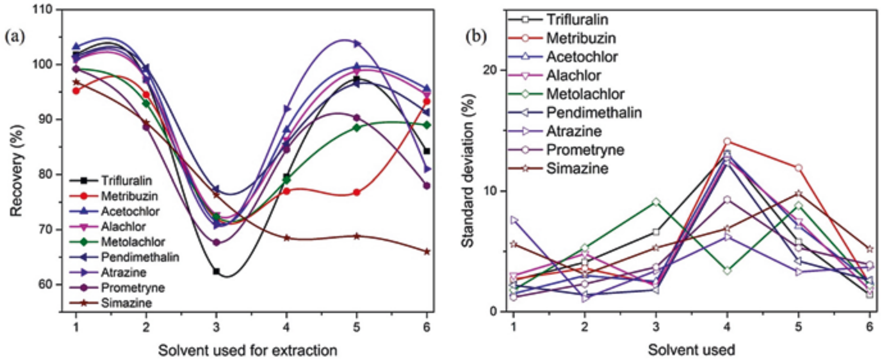


Fig. 6 (**a**) Recovery of various herbicides using various solvents: (1) acetone, (2) acetonitrile, (3) methanol, (4) acetone-water, (5) acetonitrile-water (9:1), (6) hexane-water (9:1) and (**b**) the corresponding standard deviations (Balinova and Balinov 1991)

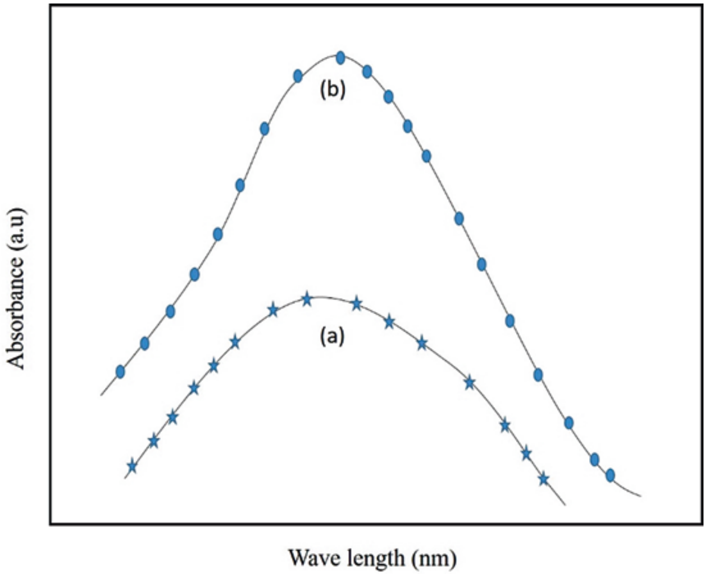


Fig. 7 Ultraviolet-visible spectra of the dye: (**a**) the blank reagent and (**b**) amount of endosulfan (Raju and Gupta 1991)

de Bertrand et al. (1991) reported the use of liquid chromatographic diode array determination (LC-DAD) for the estimation of carbamate pesticides in soil. LC-DAD provides a way to improve selectivity, with detection limits of approximately 25 ng/g corresponding to an absolute injected amount of 5 ng; it was reported to be effective for the detection of different carbamate pesticides at low levels of 0.1–1 $\mu g \cdot g^{-1}$ (de Bertrand et al. 1991). The significance of this work is evident by the fact that carbamates are unstable compounds, thermolabile, and quickly decomposed by alkali, which make their analysis extremely complicated.

An advantage of using LC coupled with a UV-vis variable detector is to enhance the selectivity by working at different wavelengths. The use of LC-DAD is simple, less time consuming, and allows simultaneous determination of 1-naphthol (de Bertrand et al. 1991).

Durand et al. (1991) reported the use of thermospray LC-MS for the determination of pesticides (Durand et al. 1991). The effect of four different mobile-phase compositions with reversed-phase methanol-water (50:50) + 0.05 M ammonium nitrate, methanol-water (50:50) + 0.05 M ammonium formate, acetonitrile-water (50:50) + 0.05 M ammonium formate were compared for the determination of carbamate and chlorotriazine pesticides (Durand et al. 1991). The results showed 3–3.5 orders of improvement in PI mode for carbamates, with the exception of pirimicarb, carbaryl, and α-naphthol (Durand et al. 1991).

Taylor (1991) developed a method using GC and LC for the general pesticide screening of soil samples from mixer/loader sites (Taylor 1991). Samples were extracted in methanol-acetone mixture, concentrated, and then analyzed using capillary GC with flame ionization detection and an LC-diode array (Taylor 1991).

Organophosphate derivatives of O-nitrophenol have been used quite extensively as herbicides, insecticides, and fungicides (Taylor 1991). Wong et al. used enzyme-linked immunosorbent assay (ELISA) and GC for the detection of organophosphate pesticides (Wong et al. 1991). ELISA is less time consuming, low cost, and has the advantage of running the analysis without an extensive sample work-up (Wong et al. 1991). Figure 8 shows a comparison of the results obtained for ELISA, GC-electron capture detector, and GC-nitrogen phosphorus detector (Wong et al. 1991). Based on this study, it was concluded that GC and ELISA showed good agreement; furthermore, ELISA can be effectively used to detect 4-nitrophenol and parathion in the same sample.

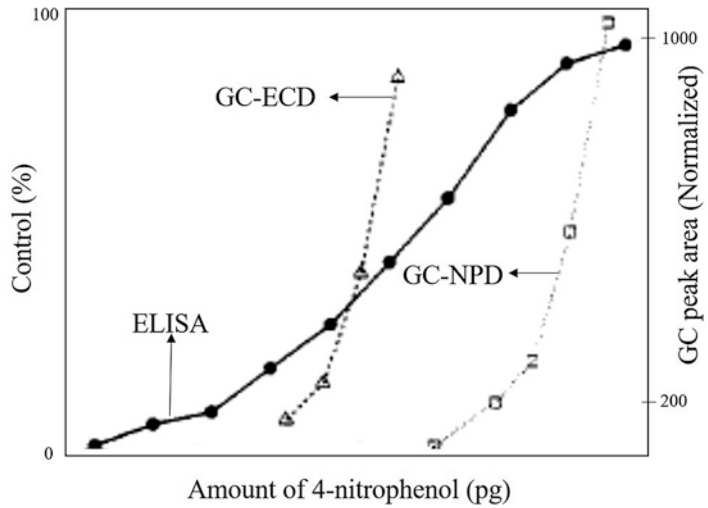


Fig. 8 Comparison of the efficiency of ELISA against GC-electron capture detector and GC-nitrogen phosphorus detector for the detection of 4-nitrophenol (Wong et al. 1991)

Later, King and Nam (1996) coupled ELISA with SFE for the detection of pesticides (King and Nam 1996). Kizza and Yaw reported the use of multidimensional column with ultraviolet detection for the determination of nitrate, nitrite, and organic pesticides in soil solution (Nkedi-Kizza and Owusu-Yaw 1992). A convective-dispersive transport model with a sorption term was used to model the transport of NO_3^-, NO_2^-, and Baygon through the column (Nkedi-Kizza and Owusu-Yaw 1992).

$$\frac{R\delta C}{\delta p} = \frac{1}{P}\frac{\delta^2 C}{\delta X^2} - \frac{\delta C}{\delta X} \tag{1}$$

Where $R = 1 + \frac{\rho K_D}{\theta} \quad p = \left(\frac{vt}{L}\right)$.

And $P = \frac{vL}{D} \quad X = \frac{x}{L}$.

Here, R is the retardation factor, C is the solution concentration (mg·L^{-1}), p is the pore volume, P is the Peclet number, x is the distance, t is the time in hours, L is the length of the column, D is the hydrodynamic dispersion coefficient (cm^2·h^{-1}), ρ is the bulk density, K_D is the sorption coefficient (mL·g^{-1}), and θ is the volumetric water content. Figure 9 shows the chromatogram for nitrate, nitrite, and Baygon (Nkedi-Kizza and Owusu-Yaw 1992). They concluded that the new high performance liquid chromatography (HPLC) analytical method is a versatile

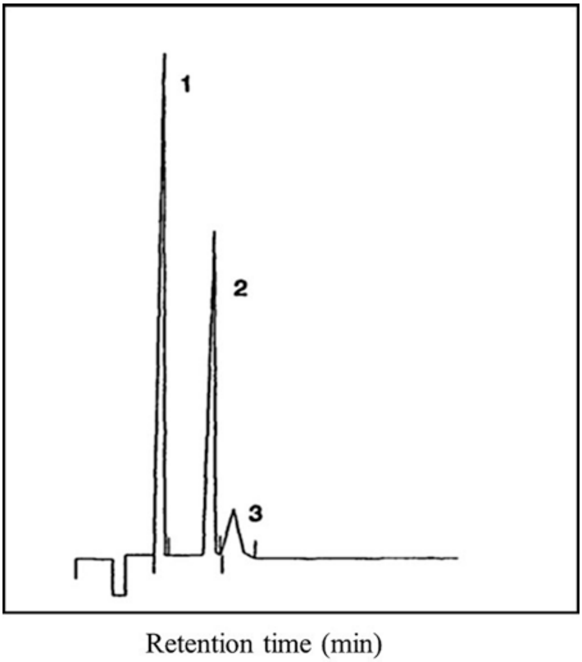


Fig. 9 Chromatogram for (1) nitrate, (2) nitrite, and (3) Baygon using a column of Omnipak Pax-500, Elutant (**a**) 80% methyl alcohol, (**b**) 20% 50 mM sodium chloride (Nkedi-Kizza and Owusu-Yaw 1992)

technique for the simultaneous determination of nitrate, nitrite, and pesticides with UV absorbance in the range of 210–254 nm and sample injection requirement of 20 μL.

Garcia Sanchez and Aguilar Gallardo (1992) used hydrolysis-induced fluorescence spectrometry for determination of azinphos-methyl residue in soil (Garcia Sanchez and Aguilar Gallardo 1992). Figure 10 shows the excitation and emission spectra for anthranilic acid. The results obtained were reported to be better than that of HPLC (Garcia Sanchez and Aguilar Gallardo 1992).

Basta and Olness (1992) reported a method for the simultaneous resin extraction of alachlor, atrazine, and metribuzin in soil extracts. Pesticides were extracted using anion exchange, cation exchange, and non-polar resin followed by an analysis using dual-column chromatography (Basta and Olness 1992). Gael et al. investigated the determination of atrazine, simazine, cyanazine, deethylatrazine, and deisopropyl atrazine in soil samples (Durand et al. 1992). They compared the results for (1) GC-MS-MS (with collisionally activated dissociation and multi-reaction monitoring), (2) GC-LRMS (low-resolution mass spectroscopy) (with low resolving power of 1000) and (3) GC-HRMS (high-resolution mass spectroscopy). The authors concluded that GC-MS-MS with multi-reaction monitoring and GC-HRMS are useful techniques for the detection of chlorotriazines in soil, with GC-MS-MS having more selectivity than GC-HRMS (Durand et al. 1992). The major limitation is that the limit of detection of GC-MS-MS and GC-HRMS, which is approximately 1.5–2 orders of magnitude lower than that of a triple quadrupole or a single quadrupole GC-MS (Durand et al. 1992). GC and HPLC are time-consuming, expensive, and require specialized instrumentation.

The use of ELISA for the detection of pesticides was first reported in 1980 (Lawruk et al. 1993). The detection of pesticides using magnetic particle-based ELISA was reported by different groups; the use of this method for the detection of metolachlor was first introduced by Lawruk et al. (1993). This magnetic

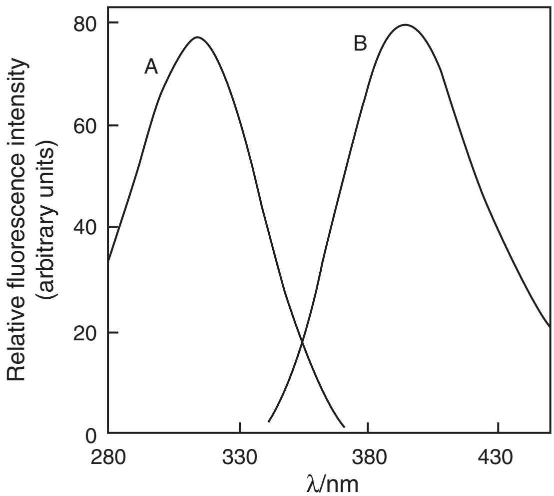


Fig. 10 (**a**) Excitation and (**b**) emission spectra for anthranilic acid using water-ethanol: (40:60) with λ_{exc} = 324 nm and λ_{emi} = 394 nm (Garcia Sanchez and Aguilar Gallardo 1992)

particle-based system was reported to be rapid and sensitive. The authors also showed detection limits of parts per billion, thereby satisfying the sensitivity requirements for environmental monitoring. Later, Dequaire et al. reported the use of a disposable immunomagnetic electrochemical sensor with a magnetic particle-based solid phase and a Nafion-film-coated screen-printed electrode for the detection of pesticides (Dequaire et al. 1999). These devices were reported to be simple, cost-effective, and highly efficient (Dequaire et al. 1999).

Rogers et al. introduced the use of a reusable fiber-optic enzyme biosensor-based technique for the detection of pesticides and insecticides (Rogers et al. 1991a, b, c). Kotoucek and Opraviliva reported the use of fast-scan differential pulse voltammetry for the detection of nitro-based pesticides using dropping mercury electrodes (Kotouček and Opravilová 1996). Vijay Kumar et al. reported the use of various spectroscopy techniques for the detection of organophosphate pesticides (Kumar et al. 2013), including the use of UV-visible spectroscopy, Fourier-transform infrared spectroscopy (FTIR), nuclear magnetic resonance spectroscopy, X-ray diffraction, and electrochemical methods for the detection of pesticides. This brought out the significance of other techniques for the detection of pesticides. Timperley et al. reported the use of UV-vis spectroscopy for the characterization of 18 different organophosphorous nerve agents and pesticides (Timperley et al. 2006). The significance of this work arises from the fact that organophosphorous pesticides and nerve agents usually do not show significant absorbance in the UV region and can be converted by suitable chemical modifications, as shown in Fig. 11 (Timperley et al. 2006).

Venugopal et al. reported the spectrophotometric detection of Malathion (Venugopal et al. 2012). Samples were prepared as discussed by Norris et al. (1954). The proposed method does not require any solvents and is simple, along with being less expensive (Venugopal et al. 2012). The nature of the interactions, degradation mechanisms, and pH dependency of reactions with atrazine (2-chloro-4-ethylamino-

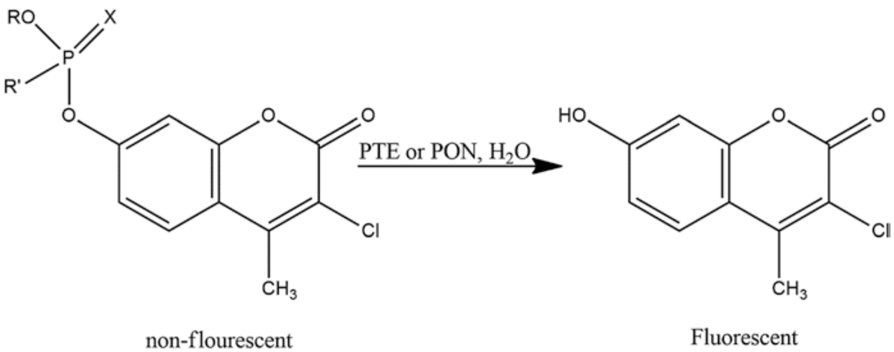


Fig. 11 Chemical modification of an oroganophosphorous pesticide, which is non-fluorescent to fluorescent compound (Timperley et al. 2006)

6-isopropylamino-8-triazine), which is one of the most commonly used herbicides with a half-life between 2 months and 5 years, were reported by Martin-Neto et al. (2001) and Sposito et al. (1996). Atrazine undergoes abiotic degradation with hydroxyatrazine (AT-OH), which is nonphytotoxic. Wang et al. reported the existence of weak hydrogen bonding interactions (proton transfer), and hydrophobic interactions between atrazine and humic compounds extracted from soil (Wang et al. 1990a, b). Later, Welhouse and Bleam reported that a lone pair of electrons on nitrogen is highly delocalized in the triazine ring, thereby existing in four different isomeric forms; it has a strong tendency to form complexes with amide or carboxylic acid groups (Welhouse and Bleam 1992). Gamle et al. and Wang et al. proposed that the surface Bronsted acidity of soil colloids catalyze the conversion of AT to AT-OH.

UV-vis spectroscopy studies by Martin-Neto et al. showed that the degradation/conversion of atrazine is highly pH dependent (Wang et al. 1990a). When the pH of the solution is above 3.5, the peak at 223 nm (corresponding to AT) retained its shape, even after 4 days. On changing the pH to 2.3 or on increasing the acidity, the peak intensity of the AT band reduced by 25% and a new band corresponding to AT-OH started to appear. This was followed by an increase in the reaction rate as the pH was increased to 1.7. Martin-Neto et al. elucidated the application of FTIR spectroscopy for following the pH dependency and degradation rate of atrazine (Sposito et al. 1996; Martin-Neto et al. 2001). The results obtained using FTIR spectroscopy exactly matched the results obtained from UV-Vis spectroscopy, confirming the fact that spectroscopic techniques will open new areas for the detection and estimation of various pesticides.

Conclusion

The use of pesticides for enhancing food production resulted in extensive environmental pollution, coupled with a dramatic decrease in food production. Pesticides and their degradation products are extremely toxic—not only to human beings, but also to other living organisms. The photo degradation products of Aldrin are far more toxic than the parent compound; they are transferred through various natural resources, thereby contaminating the natural resources in the process. The major limitations of chromatographic techniques include the requirement for a large amount of solvent, long analysis time, need for expert technicians, and high costs for running the experiments. These limitations have resulted in the development of new techniques based on spectroscopy for the detection and estimation of pesticides. The major advantage of these techniques is that they induce less harm to the environment and other living beings.

References

Alavanja, M. C. R., Hoppin, J. A., & Kamel, F. (2004). Health effects of chronic pesticide exposure: Cancer and neurotoxicity. *Annual Review of Public Health, 25*(1), 155–197.

Alternative and Biological Pest Controls | Commons Abundance Network. (n.d.).

Application of chemically modified fused silica fibers in the extraction of organics from water matrix samples and their rapid transfer to capillary columns. (n.d.). [Online]. Available: https://www.researchgate.net/publication/292092766_Application_of_chemically_modified_fused_silica_fibers_in_the_extraction_of_organics_from_water_matrix_samples_and_their_rapid_transfer_to_capillary_columns. Accessed: 01 Sept 2016.

Balinova, A. M., & Balinov, I. (1991). Determination of herbicide residues in soil in the presence of persistent organochlorine insecticides. *Fresenius' Journal of Analytical Chemistry, 339, 6*, 409–412.

Barker, S. A. (2007). Matrix solid phase dispersion (MSPD). *Journal of Biochemical and Biophysical Methods, 70*(2), 151–162.

Basta, N. T., & Olness, A. (1992). Determination of alachlor, atrazine, and metribuzin in soil by resin extraction. *Journal of Environmental Quality, 21*(3), 497.

Benson, W. R. (1969). The chemistry of pesticides. *Annals of the New York Academy of Sciences, 160*(1), 7–29.

Bertazzi, P. A., Consonni, D., Bachetti, S., Rubagotti, M., Baccarelli, A., Zocchetti, C., & Pesatori, A. C. (2001). Health effects of dioxin exposure: A 20-year mortality study. *American Journal of Epidemiology, 153*(11), 1031–1044.

de Bertrand, N., Durand, G., & Barceló, D. (1991). Extraction, cleanup and liquid chromatographic-diode array determination of carbamate pesticides in soil samples. *Journal of Environmental Science and Health Part A: Environmental Science and Engineering and Toxicology, 26*(4), 575–597.

Bradberry, S. M., Cage, S. A., Proudfoot, A. T., & Vale, J. A. (2012). Poisoning due to pyrethroids. *Toxicological Reviews, 24*(2), 93–106.

Bushway, R. J., Li, L., Paradis, L. R., & Perkins, L. B. (1995). Determination of thiabendazole in potatoes, fruits, and their processed products by liquid chromatography. *Journal of AOAC International, 78*(3), 815–820.

Carabias-Martínez, R., Rodríguez-Gonzalo, E., Revilla-Ruiz, P., & Hernández-Méndez, J. (2005). Pressurized liquid extraction in the analysis of food and biological samples. *Journal of Chromatography A, 1089*(1–2), 1–17.

Compelling Evidence of Human Health Effects of Pesticides. (n.d.). [Online]. Available: http://www.twn.my/title2/susagri/2015/sa417.htm. Accessed: 27 Aug 2016.

Conway, G. R., & Barbier, E. B. (2013). *After the green revolution: Sustainable agriculture for development*. London: Routledge.

Dequaire, M., Degrand, C., & Limoges, B. (1999). An immunomagnetic electrochemical sensor based on a perfluorosulfonate-coated screen-printed electrode for the determination of 2,4-dichlorophenoxyacetic acid. *Analytical Chemistry, 71*(13), 2571–2577.

Durand, G., Forteza, R., & Barceló, D. (1989). Determination of chlorotriazine herbicides, their dealkylated degradation products and organophosphorus pesticides in soil samples by means of two different clean up procedures. *Chromatographia, 28*(11–12), 597–604.

Durand, G., de Bertrand, N., & Barceló, D. (1991). Mobile phase variations in thermospray liquid chromatography-mass spectrometry of pesticides. *Journal of Chromatography, 562*(1–2), 507–523.

Durand, G., Gille, P., Fraisse, D., & Barceló, D. (1992). Comparison of gas chromatographic-mass spectrometric methods for screening of chlorotriazine pesticides in soil. *Journal of Chromatography, 603*(1–2), 175–184.

Eskenazi, B., Bradman, A., & Castorina, R. (1999). Exposures of children to organophosphate pesticides and their potential adverse health effects. *Environmental Health Perspectives, 107*(Suppl 3), 409–419.

Garcia Sanchez, F., & Aguilar Gallardo, A. (1992). Spectrofluorimetric determination of the insecticide azinphos-methyl in cultivated soils following generation of a fluorophore by hydrolysis. *Analyst, 117*(2), 195–198.

Gimeno-García, E., Andreu, V., & Boluda, R. (1996). Heavy metals incidence in the application of inorganic fertilizers and pesticides to rice farming soils. *Environmental Pollution, 92*(1), 19–25.

Hawthorne, S. B., Grabanski, C. B., Martin, E., & Miller, D. J. (2000). Comparisons of soxhlet extraction, pressurized liquid extraction, supercritical fluid extraction and subcritical water extraction for environmental solids: Recovery, selectivity and effects on sample matrix. *Journal of Chromatography. A, 892*(1–2), 421–433.

Huang, S.-D., Cheng, C.-P., & Sung, Y.-H. (1997). Determination of benzene derivatives in water by solid-phase microextraction. *Analytica Chimica Acta, 343*(1), 101–108.

Kadenczki, L., Arpad, Z., Gardi, I., Ambrus, A., Gyorfi, L., Reese, G., & Ebing, W. (1992). Column extraction of residues of several pesticides from fruits and vegetables – A simple multiresidue analysis method. *Journal of AOAC International, 75*(1), 53–61.

Kane, M., Dean, J. R., Hitchen, S. M., et al. (1993). Experimental design approach for supercritical fluid extraction. *Analyst, 271*, 83–90.

Karalliedde, L., Wheeler, H., Maclehose, R., & Murray, V. (2000). Possible immediate and long-term health effects following exposure to chemical warfare agents. *Public Health, 114*(4), 238–248.

Karami-Mohajeri, S., & Abdollahi, M. (2011). Toxic effects of organophosphate, carbamate, and organochlorine pesticides on cellular metabolism of lipids, proteins, and carbohydrates: A comprehensive review. *Human & Experimental Toxicology, 30*(9), 1119–1140.

King, J. W., & Nam, K.-S. (1996). Coupling enzyme immunoassay with supercritical fluid extraction. In *Immunoassays for residue analysis* (vol. 621, pp. 422–438). 0 vols. American Chemical Society, USA.

Kligerman, A. D., Doerr, C. L., Tennant, A. H., & Zucker, R. M. (2000). Cytogenetic studies of three triazine herbicides: I. In vitro studies1. *Mutation Research Genetic Toxicology and Environmental Mutagenesis, 465*(1–2), 53–59.

Kotouček, M., & Opravilová, M. (1996). Voltammetric behaviour of some nitropesticides at the mercury drop electrode. *Analytica Chimica Acta, 329*(1), 73–81.

Kumar, V., Upadhay, N., Wasit, A., Singh, S., & Kaur, P. (2013). Spectroscopic methods for the detection of organophosphate pesticides – A preview. *Current World Environment Journal, 8*(2), 313–318.

Lawruk, T. S., Lachman, C. E., Jourdan, S. W., Fleeker, J. R., Herzog, D. P., & Rubio, F. M. (1993). Determination of metolachlor in water and soil by a rapid magnetic particle-based ELISA. *Journal of Agricultural and Food Chemistry, 41*(9), 1426–1431.

Liao, W., Joe, T., & Cusick, W. G. (1991). Multiresidue screening method for fresh fruits and vegetables with gas chromatographic/mass spectrometric detection. *Journal Association of Official Analytical Chemists, 74*(3), 554–565.

Longnecker, M. P., Rogan, W. J., & Lucier, G. (1997). The human health effects of Ddt (dichlorodiphenyltrichloroethane) and Pcbs (polychlorinated biphenyls) and an overview of organochlorines in public health. *Annual Review of Public Health, 18*(1), 211–244.

López-Mesas, M., Crespi, M., Brach, J., & Mullender, J. P. (2000). Clean-up of a pesticide-lanolin mixture by gel permeation chromatography. *Journal of Chromatographic Science, 38*(12), 551–555.

Martin-Neto, L., Traghetta, D. G., Vaz, C. M. P., Crestana, S., & Sposito, G. (2001). On the interaction mechanisms of atrazine and hydroxyatrazine with humic substances. *Journal of Environmental Quality, 30*(2), 520.

McHugh, M., & Krukonis, V. (2013). *Supercritical fluid extraction: Principles and practice*. New York: Elsevier.

Miyahara, M., Okada, Y., Takeda, H., Aoki, G., Kobayashi, A., & Saito, Y. (1994). Multiresidue procedures for the determination of pesticides in food using capillary gas chromatographic, flame photometric, and mass spectrometric techniques. *Journal of Agricultural and Food Chemistry, 42*(12), 2795–2802.

Mustafa, A., & Turner, C. (2011). Pressurized liquid extraction as a green approach in food and herbal plants extraction: A review. *Analytica Chimica Acta, 703*(1), 8–18.

Nkedi-Kizza, P., & Owusu-Yaw, J. (1992). Simultaneous high-performance liquid chromatographic determination of nitrate, nitrite, and organic pesticides in soil solution using a multidimensional column with ultraviolet detection. *Journal of Environmental Science and Health, Part A Environmental Science Engineering, 27*(1), 245–259.

Norris, M. V., Vail, W. A., & Averell, P. R. (1954). Pesticide residues, colorimetric estimation of malathion residues. *Journal of Agricultural and Food Chemistry, 2*(11), 570–573.

Omeroglu, P. Y., Boyacioglu, D., Ambrus, Á., Karaali, A., & Saner, S. (2012). An overview on steps of pesticide residue analysis and contribution of the individual steps to the measurement uncertainty. *Food Analytical Methods, 5*(6), 1469–1480.

Oniszczuk, A., Waksmundzka-Hajnos, M., Skalicka-Woźniak, K., & Głowniak, K. (2013). Comparison of matrix-solid phase dispersion and liquid–solid extraction connected with solid-phase extraction in the quantification of selected furanocoumarins from fruits of Heracleum leskowii by high performance liquid chromatography. *Industrial Crops and Products, 50*, 131–136.

Raju, J., & Gupta, V. K. (1991). A simple spectrophotometric determination of endosulfan in river water and soil. *Fresenius' Journal of Analytical Chemistry, 339*(6), 431–433.

Rogers, K. R., Cao, C. J., Valdes, J. J., Eldefrawi, A. T., & Eldefrawi, M. E. (1991a). Acetylcholinesterase fiber-optic biosensor for detection of anticholinesterases. *Fundamental and Applied Toxicology: Official Journal of the Society of Toxicology, 16*(4), 810–820.

Rogers, K. R., Eldefrawi, M. E., Menking, D. E., Thompson, R. G., & Valdes, J. J. (1991b). Pharmacological specificity of a nicotinic acetylcholine receptor optical sensor. *Biosensors & Bioelectronics, 6*(6), 507–516.

Rogers, K. R., Valdes, J. J., & Eldefrawi, M. E. (1991c). Effects of receptor concentration, media pH and storage on nicotinic receptor-transmitted signal in a fiber-optic biosensor. *Biosensors & Bioelectronics, 6*(1), 1–8.

Rosenfeld, J. M. (1999). Solid-phase analytical derivatization: Enhancement of sensitivity and selectivity of analysis. *Journal of Chromatography. A, 843*(1–2), 19–27.

Saillenfait, A.-M., Ndiaye, D., & Sabaté, J.-P. (2015). Pyrethroids: Exposure and health effects – An update. *International Journal of Hygiene and Environmental Health, 218*(3), 281–292.

Schade, G., & Heinzow, B. (1998). Organochlorine pesticides and polychlorinated biphenyls in human milk of mothers living in northern Germany: Current extent of contamination, time trend from 1986 to 1997 and factors that influence the levels of contamination. *Science of The Total Environment, 215*(1–2), 31–39.

Senanayake, N., & Karalliedde, L. (1987). Neurotoxic effects of organophosphorus insecticides. *The New England Journal of Medicine, 316*(13), 761–763.

Shafer, T. J., Meyer, D. A., & Crofton, K. M. (2005). Developmental neurotoxicity of pyrethroid insecticides: Critical review and future research needs. *Environmental Health Perspectives, 113*(2), 123–136.

Singh, R. B. (2000). Environmental consequences of agricultural development: A case study from the Green Revolution state of Haryana, India. *Agriculture, Ecosystems and Environment, 82*(1–3), 97–103.

Sposito, G., Martin-Neto, L., & Yang, A. (1996). Atrazine complexation by soil humic acids. *Journal of Environmental Quality, 25*(6), 1203.

Sterling, T. D., & Arundel, A. V. (1986). Health effects of phenoxy herbicides: A review. *Scandinavian Journal of Work, Environment & Health, 12*(3), 161–173.

Suchan, P., Pulkrabová, J., Hajšlová, J., & Kocourek, V. (2004). Pressurized liquid extraction in determination of polychlorinated biphenyls and organochlorine pesticides in fish samples. *Analytica Chimica Acta, 520*(1–2), 193–200.

Taylor S. G. (Florida Department of Agriculture and Consumer Services, Tallahassee, FL). (1991). General method for determination of pesticides in soil samples from pesticide mixer/loader sites. *Journal Association of Official Analytical Chemists, USA 74*, 878–883.

Timperley, C. M., Casey, K. E., Notman, S., Sellers, D. J., Williams, N. E., Williams, N. H., & Williams, G. R. (2006). Synthesis and anticholinesterase activity of some new fluorogenic analogues of organophosphorus nerve agents. *Journal of Fluorine Chemistry, 127*(12), 1554–1563.

Venugopal, N. V. S., Sumalatha, B., & Syedabano. (2012). Spectrophotometric determination of malathion in environmental samples. *Journal of Chemistry, 9*(2), 857–862.

Vijverberg, H. P. M., & vanden Bercken, J. (1990). Neurotoxicological effects and the mode of action of pyrethroid insecticides. *Critical Reviews in Toxicology, 21*(2), 105–126.

Wan, H. B., & Wong, M. K. (1996). Minimization of solvent consumption in pesticide residue analysis. *Journal of Chromatography. A, 754*(1), 43–47.

Wang, Z.-D., Gamble, D. S., & Langford, C. H. (1990a). Interaction of atrazine with Laurentian fulvic acid: Binding and hydrolysis. *Analytica Chimica Acta, 232*, 181–188.

Wang, Z.-D., Pant, B. C., & Langford, C. H. (1990b). Spectroscopic and structural characterization of a Laurentian fulvic acid: Notes on the origin of the color. *Analytica Chimica Acta, 232*, 43–49.

Welhouse, G. J., & Bleam, W. F. (1992). NMR spectroscopic investigation of hydrogen bonding in atrazine. *Environmental Science & Technology, 26*(5), 959–964.

Wesseling, C., Keifer, M., Ahlbom, A., McConnell, R., Moon, J.-D., Rosenstock, L., & Hogstedt, C. (2002). Long-term neurobehavioral effects of mild poisonings with organophosphate and n-methyl carbamate pesticides among banana workers. *International Journal of Occupational and Environmental Health, 8*(1), 27–34.

What are Pesticides|Definition|Types|Uses and Effects. (2016). *Chemistry*.

Wolfe, W. H., Michalek, J. E., Miner, J. C., et al. (1990). Health status of air force veterans occupationally exposed to herbicides in Vietnam: I. Physical health. *JAMA, 264*(14), 1824–1831.

Wong, J. M., Li, Q. X., Hammock, B. D., & Seiber, J. N. (1991). Method for the analysis of 4-nitrophenol and parathion in soil using supercritical fluid extraction and immunoassay. *Journal of Agricultural and Food Chemistry, 39*(10), 1802–1807.

Zacharia, & Tano, J. (2011). Identity, physical and chemical properties of pesticides. In M. Stoytcheva (Ed.), *Pesticides in the modern world – trends in pesticides analysis*. Rijeka: InTech.

Organic Animal Husbandry

A. K. M. Ahsan Kabir

Introduction

Organic animal husbandry is not static. It is under continuous development. Many of the initial blunders and mistakes have, in cooperation with others, been altered and corrected, and work continues (Hammarberg 2001). The differences between traditional, conventional and organic animal husbandry are on production guidelines. The organic animal husbandry is far more sophisticated and knowledge intesive system of animal production meant to safeguard not only the human health but also the welfare of animals and the environment on the whole (Chander and Mukherjee 2005). Organic livestock farming has set itself the goal of establishing environmentally friendly production, sustaining animals in good health, realising high animal welfare standards, and producing products of high quality (Sundrum 2001). In other hand, organic animal husbandry is a system designed to provide livestock with comfortable and stress-free living in accordance with their natural needs that promotes the use of certified organic and biodegradable inputs from the environment in terms of animal nutrition, health, housing and breeding, and deliberately avoids use of systhetic inputs such as drugs, feed additives and genetically engineered breeding inputs. We should bear in mind that some people start organic farming from a subjective image of an organic ideal and not from sound knowledge of agriculture. This does perhaps not lead to any serious consequences when it involves plant growing, but when it is associated with animal farming, the consequences can be serious. There is nothing in the organic regulation that stipulates any knowledge on how to run and manage an animal farm. It does not even state to strive for as natural a life as possible for the animals. Organic animal

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husbandry is one of the areas where the skills of organic farmers are most important and most frequently called upon. The real nature is far too tough for that.

Objectives of Organic Animal Husbandry

1. To raise animals with the fulfilment of their basic behavioral needs taking consideration the wider issues of environmental pollution and human health.
2. To diversify in keeping livestock on the holding and to utilize each nutrient at the household level. For example, special attention should be given to rabbits and poultry as income generated from this enterprise goes directly to the disadvantaged segments of the population, e.g., women and children. Their nitrogen-rich manure is used to increase vegetable production in the kitchen gardens, thus improving the family diet.
3. To meet the needs of showing the natural behavior of animals in their production systems for maximizing production and to reduce stress. For example, chickens like perching at night, and therefore, perching rails should be provided for this purpose. They should also be raised in deep litter system that allows them to scratch for ants and worms and dust bathe. Dark secluded nest should be provided as they like laying in dark secluded places. Goats being browsers in nature like having their forage suspended high enough so that they can attain an upright posture, etc.
4. The use of low external input which lessens the cost of production and allows for a sustainable system of production since most materials can be recycled in the farm and also locally available.
5. To recycle nutrient and to link the nutrient gap in soil, crops, and animals, i.e., animals feed on crops and cultivated crop by-products. The animal's waste in the form of farmyard manure is composted and taken back to the soil to replenish the lost soil nutrients through cultivation. This ensures the completion of nutrient cycle in the ecosystem.

Role of Livestock in Organic Agriculture

Organic farms are now-a-day not a despicable part of the census; it is required to combine it with the farms' profitability, environmental protection, food safety, and ethical concerns. The livestock sector is an integral part of the organic agricultural system which involves the sustainability of rural economics and demand for animal products. Organic livestock production systems allow the combination of food security and sustainability. A number of objectives are met in terms of production of milk, meat, eggs, and fiber, minimizing environmental damage and improving animal welfare, biodiversity, and environmental goods through

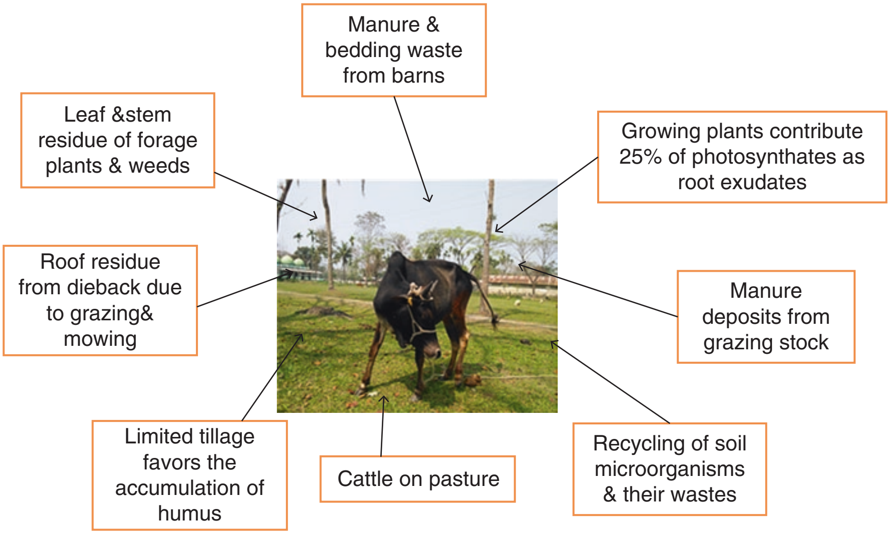

Fig. 1 Homegrown feed system: contributions of organic matter to the food web in a pasture. (Adapted to Kuepper and Beetz 2006)

organic livestock production systems. The key roles of livestock farming in organic agriculture are as follows:

1. *Acts as an internal flow of nutrients*

A process in which nutrients are returned to the soil through manure and compost is called nutrient cycling. Amending soils with animal manures can increase microbial biomass and enzymatic activity and alter the structure of the microbial community. In organic agriculture, both the sustainability and the productivity of the farming system depend on the internal flow of nutrients as represented by feed and manure. Livestock are kept based on homegrown feeds which implicate organic matter for nutrient recycling (Fig. 1).

2. *Helps in food safety and food security*

The demand of organic animal product (meat, milk, and egg) is increasing day by day. In organic farming system, the use of antibiotics, growth promoter, and steroids is strictly prohibited. As no harmful drugs are used in organic farming, the animal health is improved as well as the product quality.

3. *Helps in arable farming system*

In the arable system, livestock, particularly ruminant livestock, are certainly necessary for their role in utilizing the grass and are also important as a source of manure for transferring fertility to crops around the farm. Livestock also fulfill an additional role through their utilization of arable crop residues. In most situations, a system involving grassland and livestock is likely to be the most sustainable system of organic production (Fig. 2).

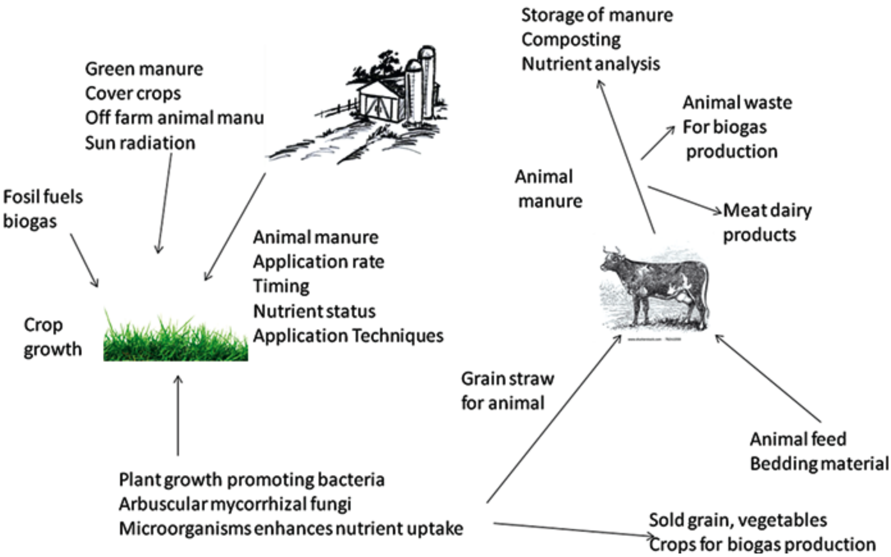

Fig. 2 Utilization of natural farm resources for promoting high energy efficiency in low-input organic farming. (Adapted to Arthurson and Jäderlund 2011)

4. *Helps in stabilizing agroecological system*

Organic systems are designed to achieve a balanced relationship between the components of soil, plants, and animals, which are as important as others in contributing the overall effect. Livestock is often the central point around which the organic farm operates, a major factor contributing to its success. It is important to organic agriculture, since it stabilizes the agroecological system and makes this more productive as it contributes soil fertility due to converted organic matter; crop residues, unutilized agricultural areas, and by-products of agricultural production are utilized by organic agricultural system and also create diversity with different species; and growing forage crops improves the crop rotation, the diversification, and the balance of the farming system (Fig. 3).

5. *Reduces tillage and weed control costs*

Tillage or cultivation is probably even more damaging to the soil food web than applying chemical fertilizer. Soil food web becomes overstimulated due to mechanical tillage. With this regard humus oxidized and "burn up" rapidly that causes humus decline along with the volume and diversity of the food web. Mechanical tillage is more costly than ploughing with animal. Cropping land prepared by livestock reduce soil food web damage and tillage cost as well. The animals feed the organic crops and secrete better feces that are free from weed seeds and any harmful residues. After proper treatment, these feces provide good source of nutrients free

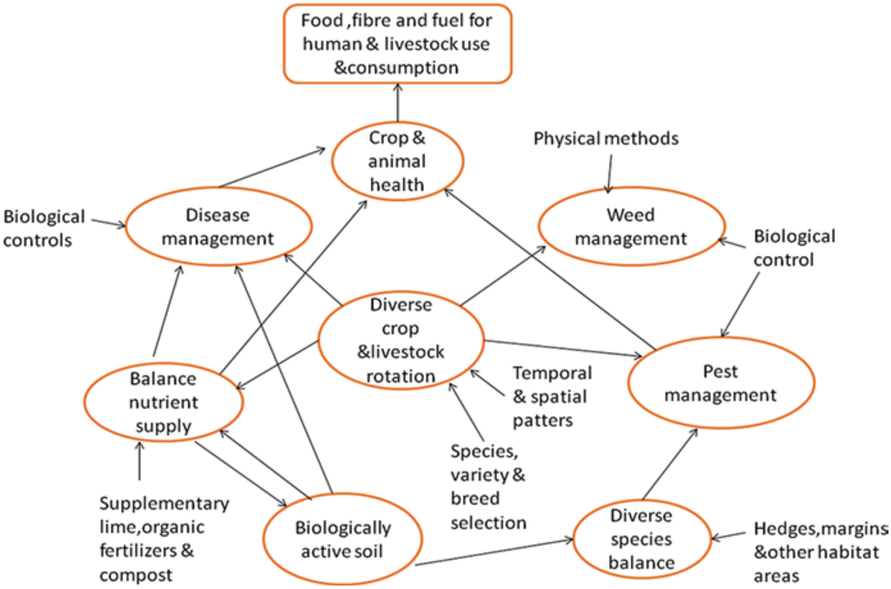

Fig. 3 Role of livestock farming in agroecological system. (Adapted to Reganold and Wachter 2016)

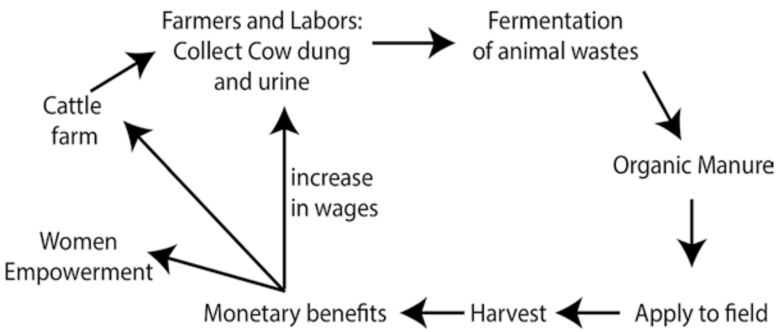

Fig. 4 Socio-commercial agri-biotech model for rural development in India by combining livestock and organic farming practices. (Adapted to Cukkemane 2016)

from weed seeds. Organic fertilizer use and draft animal weeding is currently now one of the best answers to the needs of smallholders for improved weed control.

6. *Reduces financial risks in organic farming*

Financial risk of farming is reduced by converting lower-quality grain crops and screenings into profit and spreading income more evenly over the year (Fig. 4).

Animal Welfare in Organic Agriculture

Animal welfare is one of the central principles in organic agriculture. Awareness of animal welfare issues has been growing in recent years. According to the Food and Agriculture Organization of the United Nations, about 70 billion animals were slaughtered in the world in meat, dairy, and egg industry in 2014. Majority of these animals are raised in the conventional, industrial agricultural system, known as confined animal feeding operations. These systems are designed to maximize the productivity and profit of the producer but create serious welfare problems to the animals. In organic farming, animals must be provided high-quality feed, adequate space, fresh air, natural light, exercise, access to outdoors, etc. Moreover, tail, teeth, and beak trimmings, commonly applied in conventional farming system to protect the animal from unhygienic condition and injury because of their high stocking density, are condemned in organic agriculture. According to the Animal Welfare Institute, a very small but growing number of farm animals are raised on a very high-quality feed, appropriate housing space, and natural light and air, get exercise, and have access to outdoors, and these are the prerequisites of organic livestock farming. David Fraser, a Professor of Land and Food System of the University of British Columbia in 1997, defined animal welfare into three different approaches focusing on natural living, biological functioning, and subjective experience approaches. In natural living approach, the welfare of an animal depends on its being allowed to perform its natural behavior and live a life as natural as possible; in biological functioning approach, animal welfare is related to the normal functioning of physiological and behavioral processes (often expressed as the animal's ability to cope with its environment); and in the subjective experience approach, the feelings of the animal (suffering, pain, and pleasure) determine the welfare of the animal.

Organic agriculture ensures that the animals are kept in most natural ways through protecting the animal welfare. To treat the animals humanely, organic principles and regulations are designed. Avoidable pain and suffering must be minimized. Requirements of animal welfare in organic agriculture include the following:

1. *Breed*: No specific breeds are fixed for organic farming. Breeds that are robust, able to adapt local condition, and disease resistant are required to ensure the health of the animal. This is why indigenous breeds and strains to a specific environment are preferred. The ultimate goal of breeding strategies focuses on health, not on improving productivity. Once the farm is fully organic, external purchases are confined to breeding stock only: all other livestock should be bred on the property. Replacement breeders may be introduced at an annual rate of 10–20% (depending on the certification organization) of the existing breeding stock. A limited provision does, however, exist in the standards for taking on agisted stock.
2. *Feed*: Organic farming emphasizes on organic feeds which are nutritious and natural. Feed must not contain any substances that artificially promote growth, synthetic amino acids, or genetically modified organisms (GMOs). The feed

must be organic that are produced by certified organic farmers which are good not only for growth and production but also for their health and welfare. For example, feed used for organic poultry production must not contain:

- Animal drugs, including hormones, to promote growth
- Feed supplements or additives in amounts above those needed for adequate nutrition and health maintenance
- Plastic feed pellets
- Urea or manure
- Mammalian or poultry slaughter by-products fed to mammals or poultry
- Feed, additives, or supplements in violation of the Food and Drug Administration
- Feed or forage to which any antibiotic, including ionophores, has been added

3. *Housing System*: Compared to conventional farming, organic husbandry offers much more space to the animal. There are strict rules for the animal's house. The number of animals kept in one space must be appropriate for their comfort. Free-range housing system is preferred because moving around, selecting food, and performing social contacts are natural needs of all animals. The animals must have access to natural air and light and must be able to go outdoors. Tethering animals are accepted only if it is essential for safety, welfare, or veterinary reasons.
4. *Health and Disease Prevention*: Healthy animals are one of the most important requirements of organic farming. High-quality feed and management must be given to the animal to ensure health and well-being. Some vaccines may be allowed against specific prevalent diseases. Limited chemicals and drugs may be used in case of emergency according to veterinarian concern, but chemicals and drugs must not be used routinely. Homeopathic treatments are preferred in case of drug treatment. Organic farming strengthens animals' natural resistance against diseases as it provides them suitable high-quality feed, exercise, and free-range access to the appropriate pasture.
5. *Freedom from Pain*: Any suffering must be kept as minimum as possible throughout the animals' life which is necessary in organic farming. During transportation, the comfort of the animal must be considered, and the travel time must be kept as short as possible. Before and during loading and unloading, the use of any type of electrical stimulation or allopathic tranquillizers is strictly prohibited. Loading facilities and transport vehicles may require certification from the respective authority. Except in circumstances deemed acceptable by the certifying office, transport time should not exceed 8 h from leaving the farm gate to the end point of the travel.
6. *Slaughtering*: Slaughtering methods must be designed to be as quick and painless as possible. Slaughter of organic animal must be carried out in an organic, certified, and approved abattoir. A thorough cleaning and rinsing after processing conventional livestock is required before organic animals are slaughtered.

Role of Organic Agriculture on Animal Health

Animal health is a major concern in organic livestock production system. It mainly focuses on organic feed, high-resistance local breeds, no use of antibiotics, housing, and rearing system of livestock. All of these factors directly and indirectly affect the health of animal and animal products. The better the health of the animal, the higher the quality of animal products. The animal health is influenced by the several factors mainly on diseases, feeding, housing system, and breed.

Reduce Incidence of Diseases

There are many common diseases that usually occur in our livestock. They are viral, bacterial, parasitic, or fungal diseases. The most common diseases in dairy cow are mastitis, infertility, milk fever, lameness, metabolic disorder, and ketosis. The incidence of milk fever, lameness, infertility, and metabolic disorders is reduced in organic livestock. In organic agriculture farming system, the dairy cows get proper facility of movement that helps to reduce lameness and metabolic disorders. Moreover, in the case of broiler, hock burn, footpad dermatitis, skin burn, blister, and obesity are reduced in organic livestock production system. Blister and obesity are major problems in broiler in the case of inorganic farming. Due to proper exercise, the incidence of blister and obesity is reduced and improves the quality of meat, increasing the dressing percentage. Organic management reduces stress, reducing the incidence of diseases and supporting animal welfare.

However, in organic agriculture system, local purebred strategies are followed; no synthetic breeds and GMOs are used. The disease resistance of local breeds is better than the synthetic breeds. The incidence of diseases in local breeds is less and they do not suffer from immunosuppression. Local breeds have more capability to cope with stress condition than the synthetic breeds. So in organic animal husbandry, the health condition of animal is better than any other production system.

Promotes Health of Animal

In organic livestock production system, the animals feed to organic feed. The requirements for organic feed vary from country to country and standards to standards but generally involve a set of production standards for growing, storage, processing, packaging, and shipping of livestock and livestock products. It is common for all the standards that feeds should be free from GMO, growth promoters, steroid hormone, feed additives, pesticides, and the routine use of antibiotics and vaccination. Thus, the organic feeds promote the health of animal by maintaining the normal physiology of animal and no hampering the normal metabolisms of the animal. However, Pasture-based diets improve ruminants' digestive health, making the rumen (first stomach) less acidic. This lower acidity increases the number of beneficial microorganisms that help ferment ruminants' high-fiber diet. Pasture-based systems have been shown to reduce hock lesions and other lameness, mastitis, veterinary expenses, and cull rates.

Reduces Pain and Stress Through Standard Animal Welfare

In the case of organic livestock farming, animals are reared in free-range system or semi-intensive system. In free-range system, animals get freedom to feed natural feeds, better grazing, more space to movement, and less stocking density. In this system animals are free from pain and other health hazard practices. Livestock housing in organic farming maintain normal behavior and physiology of health. Proper stocking density helps to reduce cannibalisms and to manage some vices like vent, feather, and toe pecking.

Organic Livestock Production Standards

Organic standards are sets of requirements that describe what practices can be considered organic. Typically, organic standards address various aspects of organic production, namely, general farm production requirements and conversion periods, crop production requirements and requirements for the collection of wild products, animal production requirements (including beekeeping), processing and handling requirements, social justice requirements, and labeling requirements. The requirements commonly found in organic standards are in the Common Objectives and Requirements of Organic Standards (COROS). Not all organic standards cover all of those areas, e.g., some organic standards do not cover animal production or address social justice. Some organic standards cover additional or more detailed areas, such as aquaculture or mushroom production. The International Federation of Organic Agriculture Movements (IFOAM) Standard is an example of a standard covering all of the above areas. In order for any operator to make marketing claims designating animals, processed foods, or non-processed food products as “organic,” “organically produced,” or other similar terminology, certification to national organic standards or to the standards of a recognized international authority is mandatory. The most common organic standards for animal production, handling, and product processing requirements are expressed below.

The European Union Organic (EU Organic) Standard for Livestock Production

The first EU legislation on organic farming – Council Regulation (EEC) No 2092/91 – was adopted in 1991. Legislation was first limited to plant products. It was revised in 1998 and in 2007 to include animal products and further rules for processing, controls, and marketing. In the year 1999, the European Union decided that certain common rules were to be in force within the whole common market and referred to regulation 1804/1999, and it has been reviewed periodically. The common standards are:

(A) *Origin of the animals*

1. Organic livestock must be born and raised on organic farms.
2. For breeding purposes, nonorganically raised animals may be brought onto a holding under specific conditions. Such animals and their products may be deemed organic after compliance with the conversion period.
3. Animals existing on the holding at the beginning of the conversion period and their products may be deemed organic after compliance with the conversion period.

(B) *Husbandry practices and housing conditions*

1. Personnel keeping animals must possess the necessary basic knowledge and skills as regards the health and the welfare needs of the animals.
2. Particular attention should be paid to housing conditions, husbandry practices, and stocking densities to ensure that the developmental, physiological, and ethological needs of animals are met. Moreover, the choice of breeds should take account of their capacity to adapt to local conditions.
3. The number of livestock must be limited with a view to minimizing overgrazing and poaching of soil, erosion, or pollution caused by animals or by the spreading of their manure.
4. Additionally, in order to avoid environmental pollution, in particular of natural resources such as the soil and water, organic production of livestock should in principle provide for a close relationship between such production and the land.
5. As organic stock farming is a land-related activity, animals should have, whenever possible, access to open air or grazing areas.
6. Organic livestock must be kept separate from other livestock.
7. Tethering or isolating livestock is prohibited, unless for individual animals for a limited period of time and in so far as this is justified for safety, welfare, or veterinary reasons.
8. The duration of transport of livestock must be minimized to ensure the welfare of the animals.
9. Suffering, including mutilation, must be kept to a minimum during the entire life of the animal, including at the time of slaughter.

(C) *Breeding*

1. With regard to reproduction, natural methods must be used. Artificial insemination is however allowed.
2. Hormones or similar substances are not permitted, unless as a form of veterinary therapeutic treatment in case of an individual animal.

3. Cloning animals and/or transferring embryos are also strictly forbidden.
4. Farmers should choose appropriate breeds. This would prevent the animals from suffering.

(D) *Feed*

1. The feed for livestock should primarily be obtained in the farm where the animals are kept or from farms in the same region.
2. Farmers have to provide 100% organic feed to their cattle in order to market their products as organic or to use the EU logo.
3. Nonorganic feed materials from plant origin, feed materials from animal and mineral origin, feed additives, certain products used in animal nutrition, and processing aids can only be used if they have been authorized for use in organic production.
4. Farmers must also use minimal feed additives and processing aids. In some cases of essential need or for a particular nutritional purpose however, it is permitted to use additives.
5. Growth promoters and synthetic amino acids are prohibited.
6. Suckling mammals must be fed with natural, preferably maternal milk.

(E) *Disease prevention and veterinary treatment*

1. Farmers can prevent diseases by selecting the appropriate breed and strain. Choosing the appropriate stocking density and adequate housing maintained in hygienic conditions will also avoid illnesses.
2. When the animals are ill, chemically synthesized allopathic veterinary medicinal products including antibiotics may be used where necessary and under strict conditions. This is only allowed when the use of phytotherapeutic, homeopathic, and other products is inappropriate.
3. The use of immunological veterinary medicines is permitted.

The United States Department of Agriculture (USDA) Standard

Organic Livestock Requirements

Organic certification verifies that livestock are raised according to the USDA organic regulations throughout their lives. Like other organic products, organic livestock must be:

1. Produced without genetic engineering, ionizing radiation, or sewage sludge
2. Managed in a manner that conserves natural resources and biodiversity
3. Raised per the National List of Allowed and Prohibited Substances
4. Overseen by a USDA National Organic Program-authorized certifying agent, meeting all USDA organic regulations

Organic Livestock Standards

1. Farmers and ranchers must accommodate the health and natural behavior of their animals year-round. For example, organic livestock must be:
   (a) Generally, managed organically from the last third of gestation (mammals) or second day of life (poultry)
   (b) Allowed year-round access to the outdoors except under specific conditions (e.g., inclement weather)
   (c) Raised on certified organic land meeting all organic crop production standards
   (d) Raised per animal health and welfare standards
   (e) Fed 100% certified organic feed, except for trace minerals and vitamins used to meet the animal's nutritional requirements
   (f) Managed without antibiotics, added growth hormones, mammalian or avian by-products, or other prohibited feed ingredients (e.g., urea, manure, or arsenic compounds)
2. To determine if a farm complies with the USDA organic regulations, certifying agents review the farm's written organic system plan and on-site inspection findings.

Prevention

Since organic farmers can't routinely use drugs to prevent diseases and parasites, they mostly use animal selection and management practices. Only a few drugs, such as vaccines, are allowed.

Treatment

1. Pain medication and dewormers (for dairy and breeder stock) are examples of allowed animal drugs. These therapies are only allowed if preventive strategies fail and the animal becomes ill.
2. If approved interventions fail, the animal must still be given all appropriate treatment(s). However, once an animal is treated with a prohibited substance (e.g., antibiotics), the animal and/or its products must not be sold as organic posttreatment.

Animal Welfare Standards

Organic livestock must be raised in a way that accommodates their health and natural behavior:

(a) Access to the outdoors
(b) Shade
(c) Clean, dry bedding
(d) Shelter
(e) Space for exercise
(f) Fresh air
(g) Clean drinking water
(h) Direct sunlight

Ruminant Pasture Standards

1. Organic ruminant livestock – such as cattle, sheep, and goats – must have free access to certified organic pasture for the entire grazing season. This period is specific to the farm's geographic climate but must be at least 120 days. Due to the weather, season, or climate, the grazing season may or may not be continuous.
2. Organic ruminants' diets must contain at least 30% dry matter (on average) from certified organic pasture. Dry matter intake (DMI) is the amount of feed an animal consumes per day on a moisture-free basis. The rest of its diet must also be certified organic, including hay, grain, and other agricultural products.
3. Nonruminant livestock must graze on certified organic pasture throughout the entire grazing season for the geographic region. Depending on region-specific environmental conditions (e.g., rainfall), the grazing season will range from 120 to 365 days per year.
4. Per the USDA organic regulations, the grazing season is the period of time when pasture is available for grazing due to natural precipitation or irrigation.
5. Outside the grazing season, ruminants must have free access to the outdoors year-round except under specified conditions (e.g., inclement weather). Ruminant slaughter stocks are exempt from the 30% DMI from pasture requirement for the last fifth of their lives (up to 120 days).

The IFOAM Standard for Animal Husbandry

Animal Management

General Principle

Organic livestock husbandry is based on the harmonious relationship between land, plants, and livestock, respect for the physiological and behavioral needs of livestock, and the feeding of good-quality organically grown feedstuffs.

Requirements

1. Landless animal husbandry systems are prohibited.
2. The operator shall ensure that the environment, facilities, stocking density, and flock/herd size provide for the behavioral needs of the animals.
3. In particular, the operator shall ensure the following animal welfare conditions:

   (a) Sufficient free movement and opportunity to express normal patterns of behavior, such as space to stand naturally, lie down easily, turn around, groom themselves, and assume all natural postures and movements such as stretching, perching, and wing flapping
   (b) Sufficient fresh air, water, feed, and natural daylight to satisfy the needs of the animals
   (c) Access to resting areas, shelter, and protection from sunlight, temperature, rain, mud, and wind adequate to reduce animal stress

   Note for requirement 3:

   (i) Animals whose management system requires tethering to make use of grazing can still be managed in compliance with these requirements.
   (ii) On holdings where, due to their geographical location and structural constraints, it is not possible to allow free movement of animals, tethering of animals may be allowed for a limited period of the year or of the day. In such cases, animals may not be able to turn around freely, but other requirements of animal welfare conditions must be fulfilled.

4. Herd animals shall not be kept in isolation from other animals of the same species. This provision does not apply to small herds for mostly self-sufficient production. Operators may isolate male animals, sick animals, and those about to give birth.
5. Construction materials and methods and production equipment that might significantly harm human or animal health shall not be used.
6. The livestock and poultry houses should be well facilated for controlling pests and management of diseases. For the management of pests and diseases in livestock housing, the following methods should be given priorities: (a) preventative methods such as disruption and elimination of habitat and access to facilities; (b) mechanical, physical, and biological methods; (c) substances (other than pesticides) used in traps; (d) substances listed in Appendix 5 of this standard or regional or other exceptions. Other products may be used if required by law for the control of notifiable diseases.
7. When animals are kept in house, the operator shall ensure that:

   (a) Adequate natural bedding materials are provided. Bedding materials that are normally consumed by the animals shall be organic.
   (b) Building construction provides for insulation, heating, cooling, and ventilation of the building, ensuring that air circulation, dust levels, temperature,

relative air humidity, and gas concentrations are within levels that are not harmful to the livestock.
   (c) No animals shall be kept in closed cages.
   (d) Animals are protected from predation by wild and feral animals.
   (e) The above animal welfare requirements are fulfilled.

8. All animals shall have unrestricted and daily access to pasture or a soil-based open-air exercise area or run, with vegetation, whenever the physiological condition of the animal, the weather, and the state of the ground permit. Such areas may be partially covered. Animals may temporarily be kept indoors because of inclement weather, health condition, reproduction, and specific handling requirements or at night. Lactation shall not be considered a valid condition for keeping animals indoors.
9. The maximum hours of artificial light used to prolong natural day length shall not exceed a maximum that respects the natural behavior, geographical conditions, and general health of the animals. For laying hens, a minimum daily rest period of 8 continuous hours without artificial light shall be respected.

Conversion Period

General Principle

The establishment of organic animal husbandry requires an interim period, the conversion period. Animal husbandry systems that change from conventional to organic production require a conversion period to develop natural behavior, immunity, and metabolic functions.

Requirements

1. All the requirements of this standard for land and animals must be met for the duration of the conversion period before the resulting product may be considered as organic. Land and animals may be converted simultaneously.
2. The start of the conversion period shall be calculated from the date of application for agreement with the control body. The conversion period may be calculated retroactive to the application only on the basis of sound and incontrovertible evidence of full application of the standard for a period at least as long as 12 months before sowing or planting in the case of annual production, 12 months before grazing or harvest for pastures and meadows, and 18 months before harvest for other perennials.
3. Where existing animals on a farm are converted to organic, they shall undergo a onetime minimum conversion period at least according to the following schedule: production conversion period; meat, 12 months; dairy, fibers, and other nonslaughter animal products, 90 days; and eggs, 42 days.

Sources of Animal/Origin

General Principle

Organic animals are born and raised on organic holdings.

Requirements

1. Animals shall be raised organically from birth. When organic livestock is not available, conventional animals may be brought in according to the following age limits: (a) 2-day-old chickens for meat production, (b) 18-week-old hens for egg production, (c) 2 weeks for any other poultry, (d) piglets up to 6 weeks and after weaning, and (e) dairy calves up to 4 weeks old that have received colostrum and are fed a diet consisting mainly of full milk.
2. Breeding stock may be brought in from conventional farms to a yearly maximum of 10% of the adult animals of the same species on the farm. Female adult breeding replacements must be nulliparous and be converted to organic management prior to the start of their gestation. Exceptions of more than 10% may be granted, limited to the following circumstances: (a) unforeseen severe natural or man-made events, (b) considerable enlargement of the farm, (c) establishment of a new type of animal production on the farm, and (d) holdings with less than ten animals.

Breeds and Breeding

General Principle

Breeds are adapted to local conditions.

Requirements

1. Breeding systems shall be based on breeds that can reproduce successfully under natural conditions without human involvement.
2. Artificial insemination is permitted.
3. Embryo transfer techniques and cloning are prohibited.
4. Hormones are prohibited to induce ovulation and birth unless applied to individual animals for medical reasons and under veterinary supervision.

Mutilations

General Principle

Organic farming respects the animal's distinctive characteristics.

Requirements

1. Mutilations are prohibited.

2. The following exceptions may be used only if animal suffering is minimized and anesthetics are used where appropriate: (a) castrations, (b) tail docking of lambs, (c) dehorning, (d) ringing, and (e) mulesing which is permitted until December 31, 2015.

Animal Nutrition

General Principle

Organic animals receive their nutritional needs from organic forage and feed of good quality.

Requirements

1. Animals shall be fed organic feed. Operators may feed a limited percentage of nonorganic feed under specific conditions in the following cases: (a) organic feed which is of inadequate quantity or quality, (b) areas where organic agriculture is in early stages of development, and (c) grazing of nonorganic grass or vegetation during seasonal migration. In no such case may the percentage of nonorganic feed exceed 10% dry matter per ruminant and 15% dry matter per nonruminant calculated on an annual basis. Operators may feed nonorganic feed for a limited time under specific conditions, following extreme weather conditions or man-made or natural disasters beyond the control of the operator.
2. Animals shall be offered a balanced diet that provides all of the nutritional needs of the animals in a form allowing them to exhibit their natural feeding and digestive behavior.
3. The prevailing part (at least more than 50%) of the feed shall come from the farm unit itself, surrounding natural grazing areas, or be produced in cooperation with other organic farms in the region. Exceptions may be permitted in regions where organic feed production is in an early stage of development or temporarily deficient, or in cases of unpredictably low crop production on the farm or in the region.
4. For the calculation of feeding allowances only, feed produced on the farm unit during the first year of organic management may be classed as organic. This refers only to feed for animals that are being produced within the farm unit. Such feed may not be sold or otherwise marketed as organic.
5. The following substances are prohibited in the diet: (a) farm animal by-products (e.g., abattoir waste) to ruminants; (b) slaughter products of the same species; (c) all types of excrements including droppings, dung, or other manure; (d) feed subjected to solvent extraction (e.g., hexane) or the addition of other chemical agents; (e) synthetic amino acids and amino acid isolates; (f) urea and other synthetic nitrogen compounds; (g) synthetic growth promoters or stimulants; (h) synthetic appetizers; (i) preservatives, except when used as a processing aid; and (j) artificial coloring agents.

6. Animals may be fed with vitamins, trace elements, and supplements from natural sources. Synthetic vitamins, minerals, and supplements may be used when natural sources are not available in sufficient quantity and quality.
7. All ruminants shall have daily access to roughage. Ruminants must be grazed throughout the entire grazing season(s). Ruminants may be fed with organic carried fresh fodder during the grazing season where weather and soil conditions do not permit grazing. The organic carried fresh fodder shall not exceed 20% of the amount of forage grazed during the grazing season. Animal welfare shall not be compromised.
8. Fodder preservatives such as the following may be used: (a) bacteria, fungi, and enzymes, (b) natural products of food industry, (c) plant-based products, and (d) vitamins and minerals subject to natural sources which are not available in sufficient quantity and quality. Synthetic chemical fodder preservatives such as acetic, formic, and propionic acid are permitted in severe weather conditions.
9. Young stock from mammals shall be provided maternal milk or organic milk from their own species and shall be weaned only after a minimum period as specified below: (a) calves and foals, 3 months; (b) piglets, 6 weeks; and (c) lambs and kids, 7 weeks.

Veterinary Medicine

General Principle

Organic management practices promote and maintain the health and well-being of animals through balanced organic nutrition, stress-free living conditions, and breed selection for resistance to diseases, parasites, and infections.

Requirements

1. The operator shall take all practical measures to ensure the health and well-being of the animals through preventative animal husbandry practices such as:
   (a) Selection of appropriate breeds or strains of animals
   (b) Adoption of animal husbandry practices appropriate to the requirements of each species, such as regular exercise and access to pasture and/or open-air runs, to encourage the natural immunological defense of animal to stimulate natural immunity and tolerance to diseases
   (c) Provision of good-quality organic feed
   (d) Appropriate stocking densities
   (e) Grazing rotation and management
2. If an animal becomes sick or injured despite preventative measures, that animal shall be treated promptly and adequately, if necessary in isolation and in suitable housing. Operators shall give preference to natural medicines and treatments, including homeopathy, Ayurvedic medicine, and acupuncture.

3. The use of synthetic allopathic veterinary drugs or antibiotics will cause the animal to lose its organic status. Producers shall not withhold such medication where doing so will result in unnecessary suffering of the livestock.
4. The animal may retain its organic status if:
   (a) The operator can demonstrate compliance with requirement 1 of veterinary medicine.
   (b) Natural and alternative medicines and treatments are unlikely to be effective to cure sickness or injury or are not available to the operator.
   (c) The chemical allopathic veterinary drugs or antibiotics are used under the supervision of a veterinarian.
   (d) Withdrawal periods shall be not less than double of that required by legislation, or a minimum of 14 days, whichever is longer.
   (e) This exception is not granted more than three times on a given animal.
5. Prophylactic use of any synthetic allopathic veterinary drug is prohibited.
6. Substances of synthetic origin used to stimulate production or suppress natural growth are prohibited.
7. Vaccinations are allowed only in the following cases:
   (a) When an endemic disease is known or expected to be a problem in the region of the farm and where this disease cannot be controlled by other management techniques
   (b) When a vaccination is legally required

Transport and Slaughter

General Principle

Organic animals are subjected to minimum stress during transport and slaughter.

Requirements

1. Animals shall be handled calmly and gently during transport and slaughter.
2. The use of electric prods and other such instruments is prohibited.
3. Organic animals shall be provided with conditions during transportation and slaughter that reduce and minimize the adverse effects of stress, loading and unloading, mixing different groups of animals, extreme temperatures, and relative humidity. The type of transport shall meet the specific needs of the species being transported.
4. The operator shall ensure an adequate food and water supply during transport and at the slaughterhouse.
5. Animals shall not be treated with synthetic tranquilizers or stimulants prior to or during transport.
6. Each animal or group of animals shall be identifiable at each step in the transport and slaughter process.

7. Slaughterhouse journey transportation times from farm or market to slaughterhouse shall not exceed 8 h, subject to regional or other exceptions. When there is no certified organic slaughterhouse within 8 h travel time, an animal may be transported for a longer period if the animals are given a rest period and access to water.
8. Those responsible for transportation and slaughtering shall avoid contact (sight, sound, or smell) of each live animal with dead animals or animals in the killing process.
9. Each animal shall be effectively stunned before being bled to death. The equipment used for stunning shall be in good working order. Exceptions can be made according to religious practice. Where animals are bled without prior stunning, this should take place in a calm environment.

Conclusion

Livestock farming highlighted in organic animal husbandry principles may be a useful strategy to overcome the challenges in sustainability, food security, and food safety of life. Organic animal husbandry play to recognise the dual role of organic farming. On the one hand, it will strive to meet the consumers' demand for high quality food products; on the other, it will fulfill an important role in protection and improvement of water and soil quality as a result of organic land manangement practices. Furthermore, organic livestock farming could be also an interesting strategy for the eternal rural development issue and to solve the farms' decreasing profitability problem. So, for clean food production and/or good environment as well as healthy life, the knowledge and skills on organic animal husbandry is needed.

References

Arthurson, V., & Jäderlund, L. (2011). Utilization of natural farm resources for promoting high energy efficiency in low-input organic farming. *Energies, 4*(5), 804–817. https://doi.org/10.3390/en4050804.

Cukkemane A. (2016) Socio-commercial agri-biotech model for rural development in India by combining livestock and organic farming practices. Journal of Advanced Research in Biotechnology 1(1):1–4.

Chander M., & Mukherjee, R. (2005). Organic animal husbandry: Concept, status and possibilities in India-A review. The Indian Journal of Animal Sciences 75(12):1460–1469.

Hammarberg, K. E. (2001). Animal welfare in relation to standards in organic farming. Acta Veterinaria Scandinavica Supplementum. 95:17–25.

Kuepper, G. L., & Beetz, A. (2006). Pastures: Going organic. National sustainable agriculture information service. ATTRA, 1-800-346-9140; www.attra.ncat.org.

Reganold, J. P., & Wachter, J. M. (2016). Organic agriculture in the twenty-first century-a review. *Nature Plants, 2*, 15–221. https://doi.org/10.1038/nplants.2015.221.

Sundrum, A. (2001). Organic livestock farming: a critical review. Livestock Production Science 67(3):207–215.

Biochar in Organic Farming

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Introduction

Biochar is charcoal made from biomass of plant origin and agricultural waste—hence the name "biochar." It is a fine-grained charcoal produced at relatively low temperatures through pyrolysis, which is the slow burning of organic matter in a low- or no-oxygen environment. Biochar is a solid material obtained from the carbonization (i.e., thermochemical conversion) of biomass in an oxygen-limited environment. In more technical terms, biochar is produced by the thermal decomposition of organic material (biomass such as wood, manure, or leaves) under limited supply of oxygen and at relatively low temperatures (<700 °C) (Lehmann 2009). This process mirrors the production of charcoal, which is perhaps the most ancient industrial technology developed by mankind. Biochar can be distinguished from charcoal (which is used mainly as a fuel) in that the primary application of biochar is as a soil amendment with the intention to improve soil functions and reduce emissions from biomass that would otherwise naturally degrade to greenhouse gases (International Biochar Initiatives 2006). Although the history of biochar extends thousands of years, its science is still relatively poorly understood (Whitman and Lehmann 2009).

According to the Standardized Product Definition and Product Testing Guidelines for Biochar released by the International Biochar Initiative (IBI), biochar is a solid material obtained from the thermochemical conversion of biomass in an oxygen-limited environment. IBI stated that "biochar can be used as a product itself or as an

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ingredient within a blended product, with a range of applications as an agent for soil improvement, improved resource use efficiency, remediation and/or protection against particular environmental pollution, and as an avenue for greenhouse gas (GHG) mitigation" (Laufer and Tomlinson 2013).

The maintenance of a threshold level of organic matter in the soil is crucial for maintaining the physical, chemical, and biological integrity of the soil and also for the soil to perform its agricultural production and environmental functions (Izaurralde et al. 2001; Srinivasarao et al. 2012, 2013). Hence, the conversion of organic waste to produce biochar using the pyrolysis process is one viable option that can enhance the natural rates of carbon sequestration in the soil, reduce farm waste, and improve the soil quality (Srinivasarao et al. 2012, 2013). Biochar has the potential to increase conventional agricultural productivity and enhance the ability of farmers to participate in carbon markets beyond the traditional approach by directly applying carbon into the soil (McHenry 2009). This has led to renewed interest of agricultural researchers to use charcoal/black carbon/biochar as a soil amendment for stabilizing soil organic matter. Converting waste biomass into biochar would transfer very significant amounts of carbon from the active to inactive carbon pool, presenting a compelling opportunity to intervene in the carbon cycle. The use of biochar as a soil amendment is proposed as a new approach to mitigate human-induced climate change along with improving soil productivity.

To sequester carbon, a material must have a long residence time and should be resistant to chemical processes such as oxidation to CO_2 or reduction to methane. It has been suggested by many authors (Izaurralde et al. 2001; McHenry 2009) that the use of biochar as a soil amendment meets the above requirements; the biomass is protected from further oxidation from the material that would otherwise have degraded to release CO_2 into the atmosphere. Such partially burnt products (more commonly called pyrogenic carbon or black carbon) may act as an important long-term carbon sink because their microbial decomposition and chemical transformation are probably slow.

Origin and History of Biochar

The word "biochar" is a combination of *bio-* as in "biomass" and *char* as in "charcoal." The term has been used in the scientific literature of the twentieth and twenty-first centuries. The use of biochar in agriculture is not new. In ancient times, farmers used it to enhance the production of agricultural crops. One such example is slash-and-burn cultivation, which is still being practiced in some parts of Northeast India.

Pre-Columbian Amazonians are believed to have used biochar to enhance soil productivity. They seem to have produced it by smoldering agricultural waste (i.e., covering burning biomass with soil) in pits or trenches. European settlers called it *terra preta*. Following observations and experiments, a research team working in French Guiana hypothesized that the Amazonian earthworm *Pontoscolex corethrurus* was the main agent of fine powdering and incorporation of charcoal debris to the mineral soil.

Terra preta (literally "black soil" in Portuguese) is a type of very dark, fertile artificial soil found in the Amazon Basin. It is also known as Amazonian dark earth or Indian black earth. In Portuguese, its full name is *terra preta do [de] índio* (meaning black soil of the Indian, Indians' black earth). *Terra preta* owes its characteristic black color to its weathered charcoal content (Mao et al. 2012). It was made by adding a mixture of charcoal, bone, and manure to the otherwise relatively infertile Amazonian soil. A product of indigenous soil management and slash-and-char agriculture (Dufour 1990), the charcoal is very stable and remains in the soil for thousands of years, binding and retaining minerals and nutrients (Anon. 2006; Kleiner 2013).

Terra preta is characterized by the presence of low-temperature charcoal residues in high concentrations (Mao et al. 2012); high quantities of tiny pottery shards; organic matter, such as plant residues, animal feces, fish and animal bones, and other material; and nutrients, such as nitrogen, phosphorus, calcium, zinc, and manganese (Glaser 2005). Fertile soils such as *terra preta* show high levels of microorganic activities and other specific characteristics within particular ecosystems.

The technique of using charcoal to improve the fertility of soils originated in the Amazon basin at least 2500 years ago. The native Indians of the region would create charcoal and incorporate it in small plots of land from 1 to 80 ha in size. *Terra preta* remains highly fertile, even with little or no application of fertilizers. *Terra preta* sites have been found mainly along the major rivers of the Amazon basin. Thousands of years after its creation, it has been reported to regenerate itself at the rate of 1 cm per year (Lehmann et al. 2007) by the local farmers and caboclos in Brazil's Amazonian basin, who seek it for use and for sale as valuable potting soil. These prehistorically modified soils of ancient sites of central Amazonia have been called a model for sustainable agriculture in the twenty-first century (Sombroek 1966).

Uses of Biochar

The primary uses of biochar are briefly outlined in the following sections.

Carbon Sink

The natural decomposition of biomass along with burning and agricultural waste add large amounts of CO_2 to the atmosphere. Biochar that is stable, fixed, and has "recalcitrant" carbon can store large amounts of GHGs in the ground for centuries, potentially reducing or stalling the growth of atmospheric GHG levels. At the same time, its presence in the earth can improve water quality, increase soil fertility, and raise agricultural productivity.

Biochar can sequester carbon in the soil for hundreds to thousands of years, like coal. Such a carbon-negative technology would lead to a net withdrawal of CO_2 from the atmosphere, while producing consumable energy. This would help in mitigating global warming by GHG remediation. The sustainable use of biochar could reduce global net emissions of carbon dioxide, methane, and nitrous oxide without endangering food security, habitats, or soil conservation.

Soil Amendment

The soil health benefits from biochar are enormous. Many benefits are related to the extremely porous nature of biochar. This structure is found to be very effective at retaining both water and water-soluble nutrients. Biochar as a habitat for many beneficial soil micro-organisms is of paramount importance. When precharged with these beneficial organisms, biochar becomes an extremely effective soil amendment that promotes good soil and plant health. In addition, biochar has been found to reduce the leaching of *Escherichia coli* through sandy soils depending on the application rate, feedstock, pyrolysis temperature, soil moisture content, soil texture, and surface properties of the bacteria.

Biochar can be used as a soil amendment to improve yield in plants that require high potash and elevated pH levels. Moreover, biochar can improve water quality, reduce soil emissions of GHGs, reduce nutrient leaching, reduce soil acidity, and reduce irrigation and fertilizer requirements. Under certain circumstances, biochar also has been found to induce plant systemic responses to foliar fungal diseases and to improve plant responses to diseases caused by soilborne pathogens.

The various impacts of biochar depend on the properties of the biochar, as well as the amount applied. Furthermore, there is still a lack of knowledge about the important mechanisms and properties. Biochar impact may depend on regional conditions, including soil type, soil condition (depleted or healthy), temperature, and humidity. Modest additions of biochar to soil reduce nitrous oxide emissions by up to 80% and eliminate methane emissions, and both are more potent greenhouse gases than CO_2.

Biochar is applied to soil for conditioning and fertilization purposes; application can also be helpful for the reduction of toxic components. Studies have shown that biochar is also capable of adsorbing heavy metals such as lead, cadmium, nickel, and some notable organic soil contaminants that can cause harm to human, plants, and animals (Ameloot et al. 2013). Hence, biochar as an additive to a soil can be expected to improve its overall adsorption capacity and affect toxicity because there is a decrease in transportability and depletion of the presence of metal or organic compounds. Due to its low cost and limited environmental impact, biochar would be a promising strategy for remediation of polluted environment (Cho et al. 2013). However, because of its high adsorption capacity, biochar may reduce the efficacy of soil-applied pesticides that are needed for weed and pest control. The amending of biochar has negative effects on the efficacy of pesticides and herbicides, the degradation rate of organics and some sediments, and soil organisms (Nartey and Zhao 2014). High-surface-area biochars may be particularly problematic in this regard. However, the long-term effects of biochar addition to soil need to be fully explored to understand the behavior of biochar.

Slash-and-Char Farming

The age-old practice of slash-and-burn farming leaves only 3% of the carbon from the organic material in the soil. Slash-and-char can keep up to 50% of the carbon in a highly stable form (Schmidt 2013). Switching from slash-and-burn to slash-and-char farming techniques in Brazil could decrease both deforestation of the Amazon basin and carbon dioxide emissions, as well as increase crop yields. Returning the biochar into the soil rather than removing it all for energy production reduces the need for nitrogen fertilizers, thereby reducing the costs of and emissions from fertilizer production and transport. Additionally, by improving the soil's ability to be tilled, fertility, and productivity, biochar-enhanced soils can indefinitely sustain agricultural production; non-enriched soils quickly become depleted of nutrients, forcing farmers to abandon the fields, producing a continuous slash-and-burn cycle, and continuing the loss of tropical rainforest. Using pyrolysis to produce bioenergy also has the added benefit of not requiring infrastructure changes the way processing biomass for cellulosic ethanol does. In addition, the biochar produced can be applied by the currently used machinery for tilling the soil or equipment used to apply fertilizer.

Water Retention Through Biochar

The most amazing fact is that biochar is hygroscopic. Hence, the presence of biochar in soil would be a desirable added material in many locations due to its ability to attract and retain water. Water retention is possible because of the porous structure and high surface area of biohar. As a result, nutrients, phosphorus, and agrochemicals are retained for the plants' benefit. Plants are therefore healthier, and less fertilizer leaches into surface or groundwater.

Synthesis of Biochar

From time immemorial, heating or carbonizing wood for the purpose of manufacturing biochar has been practiced (Emrich 1985). Carbonization is as old as civilization itself (Brown 1917). There are different ways to make biochar, but all of them involve heating biomass with little or no oxygen to drive off volatile gasses, leaving carbon behind. This simple process, called thermal decomposition, is usually achieved from pyrolysis or gasification. Pyrolysis is the temperature-driven chemical decomposition of biomass without combustion (Demirbas 2004). In commercial biochar pyrolysis systems, the process occurs in three steps: first, moisture and some volatiles are lost; second, unreacted residues are converted to volatiles, gasses, and biochar, and third, there is a slow chemical rearrangement of the biochar (Demirbas 2004). A summary of biomass conversion processes through pyrolysis in relation to their common feed stocks, typical products, and the applications and uses of these products including biochar has been presented elsewhere (Sohi et al. 2009).

At the instant of burning, the biomass carbon exposed to fire has three possible fates. The first and least possible fate of biomass exposed to fire is that it remains un-burnt. The other two possible fates are 1) it is volatized to carbon dioxide or numerous other minor gas species, or 2) it is pyrolyzed to biochar (Graetz and Skjemstad 2003). These methods can produce clean energy in the form of gas or oil along with biochar. This energy may be recoverable for another use, or it may simply be burned and released as heat. It is one of the few technologies that are relatively inexpensive, widely applicable, and quickly scalable.

To differentiate between the different pyrolysis reactors, the following nomenclature was recommended by Emrich (1985):

Kilns: Kilns are used in traditional biochar making, solely to produce biochar.

Retorts and converters: Industrial reactors that are capable of recovering and refining not only the biochar but also products from volatile fractions (liquid condensates and syngases) are referred to as retorts or converters.

Retorts: The term "retort" refers to a reactor that has the ability to pyrolyze pilewood or wood logs over 30 cm long and over 18 cm in diameter (Emrich 1985).

Converters: Converters produce biochar by carbonizing small particles of biomass, such as chipped or pelletized wood.

Slow pyrolysis: This is a process in which large biomass particles are heated slowly in the absence of oxygen to produce biochar.

Fast pyrolysis: Reactors are designed to maximize the yields of bio-oil and typically use powdery biomass as feedstock.

Various Methods of Biochar Production

The major criteria to consider are the targeted final products: (1) biochar and heat; (2) biochar, bio-oil, and gases; (3) biochar, carbon black, and syngas (gas mixtures that contain varying amounts of CO and H); and (4) syngas (Pelaez-Samaniego et al. 2008). Depending upon the requirement, a suitable procedure is followed for the production of biochar alone or combination with other useful co-products. However, biochar production technology is more than just the equipment needed to produce biochar. It necessarily includes entire integrated systems, which can contain various components that may or may not be part of any particular system. Brazil is by far the largest biochar producer in the world, producing 9.9 million tons/year. Other important biochar producing countries are Thailand (3.9 million tons/year), Ethiopia (3.2 million tons/year), Tanzania (2.5 million tons/year), India (1.7 million tons/year), and the Democratic Republic of Congo (1.7 million tons/year).

Biochar can be produced at scales ranging from large industrial facilities down to the individual farm (Lehmann and Joseph 2009) and even at the domestic level (Whitman and Lehmann 2009), making it applicable to a variety of socioeconomic situations. A number of pyrolysis technologies are commercially available, which yield different proportions of biochar and bioenergy products, such as bio-oil and syngas. The gaseous bio-energy products are typically used to generate electricity; the bio-oil may be used directly for low-grade heating applications and, potentially, as a diesel substitute after suitable treatment (Elliott 2007). To make biochar technology popular among farmers, it is imperative to develop a low-cost biochar kiln at the community level or a low-cost biochar stove at the individual farmer's family level.

Heap Method

Charcoal making is a traditional practice to generate income in various parts of India. In the traditional method, a heap with a pyramid-like structure (earth kiln) is prepared by keeping wood logs and roots of plants for making charcoal. To allow the combustion products to escape, vents are opened, starting from the top and working downwards. When the smoke production stops, the cooling process is started by covering the stack with a layer of moist earth. The cooling process takes several days before the earth is removed and the biochar produced is separated from the surrounding carbonized portions. Earth-mound kilns equipped with a chimney are the most advanced among earth kilns. The ability to alter the chimney diameter according to the oxygen demand and precise control of the draft of the chimney (which is dependent on height) results in better control of the pyrolysis process (Emrich 1985).

Biochar production from the invasive shrubby weed *Prosopis julifera* is practiced in the rain-fed tracts of the Ramanathapuram district of Tamil Nadu during the off-season. Generally, people use the heap method of charcoal production because it is easy and the cost involved in char production is very low. Generally, fiber waste from coconuts, paddy straw, or any available agricultural waste is used to prepare paste mixed with clay soil to cover the heap structure containing wood logs. Finally, it is covered with sand from outside and water is applied over it. Entire wood logs are converted into charcoal after burning inside the heap for 3–4 days. The charcoal is transported to various districts of Tamil Nadu and also certain states such as Maharashtra and Gujarat for industrial purposes (Srinivasarao et al. 2013).

Similarly, a very simple biochar kiln (the "Holy Mother Biochar Kiln") has been designed by Sarada Matt (Holy Mother) at Almora, Uttarakhand, India (Reddy 2011a). Bricks and clay are used in the construction. The biomass is added continuously as the fire is continuous. The primary air source at the bottom is kept open as long as biomass is added. It is convenient to operate the kiln during less windy days. As the biomass reaches the level just below the secondary air vents, further addition of biomass should be stopped and the primary air inlet is closed. After some time, water is sprinkled to extinguish the embers (quench). The biochar can be collected immediately or after some time. This is the simplest process for using the wasted/waste biomass. Here, pine needles are used for converting into biochar. Pine needle management is a big task in these parts of the Himalayas because often they lead to forest fires, destroying many trees.

Drum Method

Kilns that are built in place are typically constructed from soil or other local materials, located close to biomass resources, and small. They are economically viable if the cost of construction and transportation of biochar is lower than the cost of transporting and processing biomass. In a modified method, char production is done in a pyrolysis kiln. Venkatesh et al. (2010) developed a low-cost charring kiln by modifying oil drums at Central Research Institute for Drland Research (CRIDA), Hyderabad. A cylindrical metal oil drum (200 L capacity) with both sides intact was procured from a local market and was modified for use as a charring kiln. A square-shaped hole of 16 × 16 cm was made on the center of the top side of the drum for loading the crop residues. On the opposite side (bottom) of the oil drum, a total of 36 holes, each measuring 4 cm^2, were made in concentric circles; a 5-cm^2 hole at the center covered 20% of the total surface area of the bottom portion of the oil drum to facilitate uniform circulation of air from below.

After making sufficient modifications, the inner sides of the charring kiln were cleaned by burning some waste jute bags to make it free from residual hydrocarbon. Another metal sheet measuring 20 × 20 cm was made ready to cover the top square hole at the end of burning process to stop the circulation of air. A sufficient amount of clay soil was collected for sealing purposes. Later, preliminary trials were conducted by using the charring kiln to study the conversion efficiency of maize stalks into biochar at different loading rates and partial combustion time.

Purakayastha (2012) developed a cylindrical low-cost pyrolysis kiln made from fire brick at Indian Agricultural Research Institute (IARI), New Delhi. The gap between the two fire brick walls is filled with perlite, which acts as insulator to check the heat loss through dissipation. The used oil drum is placed on a stand inside the brick kiln for heating. The drum is filled with agricultural residues with not too tight packing, and the drum is closed from the top with a metal lid with a provision for the escape of syngas. Heating is provided by a wood log externally at the bottom of the drum until the desired temperature (300–400 °C) is reached. This method requires 2 h for complete preparation of good-quality biochar, with a biochar yield of approximately 50%. The cost of the fabrication of a pyrolysis kiln is approximately Rs. 50,000. Biochar can also be prepared in oil drum without construction of a fire brick kiln.

Central Institute for Agricultural Engineering (CIAE), Bhopal has developed a portable charring kiln that converts crop residues into char through a pyrolysis process for smokeless kitchen fuel (briquette) production. It can be used for different bioresidues, including soybean straw, pigeon peas, and cotton stalks as input materials. It consists of an mild steel (M.S) drum, a handle, and a door. Similarly, a modified portable metallic kiln was used at the Indian Council for Agricultural Research

(ICAR) Research Complex for the North Eastern Hill Region (NEH) to produce biochar from the waste of a plywood factory and weed biomass. Biochar was also made from pine needles, maize stalk, and weed biomass using a hot air oven at 350 °C for 4 h. The weed species were *Lantana camara*, *Ageratum*, *Setaria*, *Gynura sp.*, and *Avena fatua*. Each biomass was oven-dried at a temperature of 65 °C for 24 h before charring. Then, the biomass was crushed to <25 mm in size and placed in stainless steel containers of 100-mm diameter and 150-mm height and were further pyrolyzed. The yield of biochar varied from 23.2% to 47.7%. The highest biochar recovery was obtained from pine needles compared to other types of biomass (Srinivasrao et al. 2013).

In Tamil Nadu, the biochar is prepared from various crop residues such as the dried leaves of banana, chickpea stover, the outer shells of the Jatropha pods, millet cones and dust, shells of palm fruits, and sugarcane wastes. These are collected and tightly packed in an oil drum by placing a PVC tube of 6-in. diameter at the center of the drum (Srinivasarao et al. 2013). At the top of the drum, agriculture wastes are loaded, loose packs of the same are burnt, and it is closed for a while to undergo the pyrolysis process Sugumaran and Sheshadri (2010) designed a large-sized charring kiln or cylindrical drum-like structure with the top cut out to place the chimney. Above the firing portion, an iron-perforated sheet with holes is fixed. The bottom side of the drum is closed with iron sheets and provided with four legs. For carbonization, the kiln is loosely packed with about 100 kg of dry biomass. After loading the biomass, the kiln is closed with a metal lid attached to a conical chimney. A small amount of biomass in the firing portion is ignited in the kiln and the door is closed tightly to start the pyrolysis process. This method takes 1–2 h to prepare biochar, with biochar yield of 30–45% depending on the biomass type. The cost of a charcoal kiln with a chimney is approximately Rs. 20,000.

Indian Institute of Technology (IIT), Mumbai has developed a biochar unit for bamboo waste, which can be used for charring of other non-powdery biomass with minor modifications. The uniqueness of this biochar unit lies in the fact that polluting gases are all driven out from a central channel; the bottom of the channel ends with a perforated chimney-like structure kept inside the drum. The drum is loosely packed with residues; when these are ignited, the smoke starts coming out through the chimney. Initially, the residues are ignited in presence of oxygen; later, the oxygen supply is cut off slowly by covering the upper side of the drum with a perforated lid. The cost of the whole setup is around Rs. 35,000 (Srinivasarao et al. 2013).

Continuous Biochar Production Unit

The ICAR Research Complex for NEH Region has procured a unit for biochar production. The unit is capable of converting up to 300 kg/h of woody biomass into biochar. Shredded biomass is introduced to the partial-oxidation reactor, a controlled O_2-limited environment that contains some limited atmospheric air, where it is carbonized at 300–550 °C for 2–30 min. The feedstock introduction rate and residence time in the reactor are process dependent and can vary widely depending on operating conditions. Air and gases are motivated by a suction blower, which controls the rates of production. Temperatures are controlled by managing the ratio of available air to biomass and ensuring that it is well below the complete combustion ratio. This management of air to biomass allows for the preservation of solid carbon through the process and drives off nitrogen, oxygen, hydrogen, and other biomass constituent components (Srinivasarao et al. 2013).

Biochar Stove

Primitive stoves or open fires by burning wood, straw, dung, or coal cause air pollution that can harm respiratory and cardiac health, as well as exacerbate global warming. New stove technologies can produce both heat for cooking and biochar for carbon sequestration and soil building. These stoves are much more efficient and emit less gas (Srinivasarao et al. 2013). The United Nations Environment Program now recognizes that Atmospheric Brown Clouds (ABCs) are a major contributor to climate change Crystal et al. (2012). ABCs are caused by particulate emissions from the inefficient combustion of biomass and fossil fuels; they include both black particles (soot) that heat the atmosphere by absorbing sunlight and white particles that reflect sunlight and contribute to cooling. Black carbon has a significant effect on global warming, second only to carbon dioxide (Ramanathan and Carmichael 2008). Unfortunately, even some improved (non-biochar-making) cook stoves that are otherwise efficient users of wood still emit large amounts of black carbon. Gasifier stoves, both natural draft and fan-assisted, had very low black carbon emissions. There are two basic types of stoves that can be used to produce charcoal and heat: the top-lit updraft gasifier (TLUD) and the Anila stove. The TLUD operates as a gasifier by creating a stratified pyrolysis/combustion regime with four basic zones: raw biomass, flaming pyrolysis, gas combustion, and charcoal combustion (Anderson and Reed 2004).

U.N. Ravikumar, an environmentalist and engineer with the Centre for Appropriate Rural Technology at India's National Institute of Engineering, developed the modern Anila stove. The key aims of the design are to reduce the indoor air pollution that results from cooking and to take advantage of the abundance of bioresidues found in rural areas in developing countries. The engineering principle that underlines the Anila stove is top-lit updraft gasification, which essentially means that the hardwood fuel burns from the top down and simultaneously combusts the syngas that is released by the biomass. The stove is made from steel and weighs about 10 kg (Iliffe 2009).

Fan-assisted and non-fan-assisted biochar cooking stoves were developed at Hyderabad by Reddy (2011b). In this process, energy liberated from residue during controlled burning is used for cooking purposes, and biochar is produced as a leftover material. However, the yield of biochar is less in this method as compared to other methods of biochar preparation.

Classes of Biochar

At present, four biochar properties are classified on the basis of carbon storage value, fertilizer value (P, K, S, and Mg only), and fertilizer grade for six plant nutrients (N, P, K, S, Ca, and Mg), The liming value and particle size distribution are per the IBI biochar classification tools (IBI 2006).

Carbon Storage Class

Biochars are classified by the quantity of organic carbon (C_{org}) estimated to remain in soil for at least 100 years (BC_{+100}). This carbon storage value is referred to as stock BC_{+100} (sBC_{+100}) and can be used when estimating the long-term soil carbon sequestration potential of a specific biochar. Carbon storage value is based on the C_{org} content and the ratio of hydrogen to organic carbon (H/C_{org}) of a biochar. H/C_{org} offers an approximation of the extent of fused aromatic carbon ring structures of biochar, a key indicator of biochar carbon persistence in soils.

Fertilizer Class

Plant nutrients are the chemical elements required by plants to sustain growth. Depending on the plant requirement for a given nutrient, they are referred to as either macronutrients or micronutrients. Mineral macronutrients include N, P, K, S, Ca, and Mg (C, O, H contained in plants are obtained from CO_2 and H_2O and are not considered mineral nutrients). When nutrients are combined into plant-available forms in mineral or organic compounds, they are called fertilizers.

The nutrient content of biochars is largely influenced by feedstock type and processing conditions. Nutrient availability to plants is related to the nature of the chemical compounds in which the nutrient occurs (Camps Arbestain et al. 2015). Feedstock type and nutrient content provide the fertilizer grade for the six nutrients (N, P, K, S, Ca, and Mg), and also a classification system for the levels of four nutrients (P, K, S, and Mg) in a biochar.

The *fertilizer class* is based on the ability of P, K, S, and Mg in a biochar to satisfy the expected yield and nutrient removal demands of maize—one of the main crops grown worldwide. Biochar application rates ranging from 1 to 10 t/ha are used in the classification system. Available levels of P, K, S, and Mg, as measured in a laboratory, must be known in order to classify the fertilizer value of the biochar.

If a specific nutrient is able to meet the demands of maize, the quantity of that nutrient required in tons is written as a subscript next to the nutrient. For example, a fertilizer classification of $P_{3t}Mg_{9t}$ implies that biochar applied at 3 t/ha and 9 t/ha would satisfy the maize requirements for P and Mg, respectively. The fertilizer would be assigned Class 2 because two nutrients (P and Mg) satisfy maize requirements, whereas K and S would still be insufficient even at 10 t/ha (the maximum application rate considered). According to the present classification, a biochar will not have any fertilizer value if, when applied at 10 t/ha, it cannot completely fulfil the hypothetical demand of an "average" maize crop for at least one of the four nutrients considered in the classification system (P, K, S, and Mg).

Fertilizer Grade

The fertilizer grade refers to the content of plant nutrients expressed as a proportion by weight in a fertilizer. Because the total content of a specific nutrient in biochar may differ from its available fraction, the information provided by the fertilizer grade of biochar for that nutrient should refer to its available fraction. Here, the fertilizer grade for six nutrients (N, P, K, S, Ca, and Mg) will be provided. Those for available P, K, Ca, and Mg are expressed as oxides rather than on an elemental basis to conform to typical reporting conventions for commercially available fertilizers. End users are encouraged to make use of this information together with available information on soil fertility so that the needs for a specific crop demand are adequately satisfied and balanced with other sources of fertilizer where needed.

Liming Class

Soil acidity can be a major constraint to plant growth. To ameliorate acidic soils, agricultural liming materials are used to raise soil pH to levels optimum for crop growth. Liming materials are typically made from carbonates, oxides, or hydroxides of Ca and Mg. Calcitic limestone (pure calcium carbonate, $CaCO_3$) is a common liming material and is used as a reference for other liming materials; liming values are reported as an equivalent proportion of the liming effect that calcium carbonate would have (percent $CaCO_3$-eq).

The inorganic constituents of the ash fraction of biochars are made up of metal carbonates, silicates, phosphates, sulfates, chlorides, and hydroxides. Some biochars with high amounts of these inorganic compounds can have significant liming value and can be used as soil conditioners to ameliorate acidic soils.

Particle Size Class

Water is essential for plant growth. It is taken up via plant roots in soils. Water in soil also facilitates important physical processes such as infiltration, drainage, gas diffusion, and movement of nutrients. Oxygen in soils is also essential for plant and microbial respiration. It diffuses through soils from surface air. In waterlogged soils, oxygen is depleted and plant growth for most agricultural crops typically decreases.

Biochar has been shown to improve soil functions related to water retention and soil aeration, such as increased water holding capacity and plant available water as well as improved drainage and aeration, as is known for any organic matter additions. These functions are to a certain extent dictated by biochar particle size. Other factors include internal porosity of biochar, properties of the host soil, and its interaction with biochar over time.

Practical Applications of Biochar

Biochar has many applications. Some of the primary uses are described in this section.

Use in Animal Farming

In animal farming, the major uses of biochar are as a silage agent, as a feed additive/supplement, as a litter additive, in slurry treatment, in manure composting, and in water treatment for fish farming. At present, approximately 90% of the biochar used in Europe is for animal farming. Compared to field applications, a farmer will notice its effects in animals within a few days. When used as a feed supplement, the incidence of diarrhea rapidly decreases, feed intake is improved, allergies disappear, and the animals become calmer.

Use as a Soil Conditioner

Such uses of biochar are in carbon fertilizer, in compost, as substitute for peat in potting soil, in plant protection, and as compensatory fertilizer for trace elements. In certain very poor soils (mainly in the tropics), positive effects on soil fertility were seen when applying untreated biochar. These include a higher capacity of the soil to store water, aeration of the soil, and the release of nutrients by raising the soil's pH value. In temperate climates, soils tend to have a humus content of more than 1.5%, meaning that such effects only play a secondary role. Indeed, the high adsorption of plant nutrients released in the soil can instead often have a negative effect on plant growth, at least in the short and medium term. These are the reasons why, in temperate climates, biochar should only be used when first loaded with nutrients and when the char surfaces have been activated through microbial oxidation. The best method of loading nutrients is to co-compost the char. This involves adding 10–30% biochar to the biomass to be composted (Schmidt 2012). The co-composting of biochar results not only in a valuable soil conditioner. The compost can be used as a highly efficient substitute for peat in potting soil, greenhouses, nurseries, and other special cultures. When biochar is used as a carrier for plant nutrients, efficient mineral and organic long-term fertilizers can be produced.

Such fertilizers prevent the leaching of nutrients, which is a negative aspect of conventional fertilizers. The nutrients are available as and when the plants need them. Through the stimulation of microbial symbiosis, the plant takes up the nutrients from the porous carbon structure. Through mixing biochar with such organic waste as wool, molasses, ash, slurry, and pomace, organic carbon-based fertilizers can be produced. These are at least as efficient as conventional fertilizers, and they have the advantage of not having the well-known adverse effects on the ecosystem. The biochars contain all trace elements originally contained in the pyrolyzed biomass. During pyrolysis, the crucial trace elements (more than 50 metals) become part of the carbon structure, thereby preventing them being leached out and making them available to plants via root exudates and microbial symbiosis.

A range of by-products are produced during pyrolysis. These remain stuck to the pores and surfaces of the biochar. In many cases, they have the ability to mobilize a plant's internal immune systems, thereby increasing its resistance to pathogens (Elad et al. 2010).

Use in the Building Sector

Biochar is used in the building sector for insulation, air decontamination, decontamination of earth foundation, humidity regulation, and protection against electromagnetic radiation (i.e., electrosmog) (Schmidt 2012). The major properties of biochar are its extremely low thermal conductivity and its ability to absorb water up to six times its weight. These properties mean that biochar is just the right material for insulating buildings and regulating humidity. In combination with clay, but also with lime and cement mortar, biochar can be added to sand at a ratio of up to 50%. This creates indoor plasters with excellent insulation and breathing properties, which are able to maintain humidity levels in a room at 45–70% in both summer and winter. This prevents not just dry air, which can lead to respiratory disorders and allergies, but also dampness through air condensing on the outside walls, which can lead to mold developing (Schmidt 2013). Such biochar-mud plaster adsorbs smells and toxins—a property that does not just benefit smokers. Alongside their use in housing, biochar-mud plasters are particularly good for warehouses, factories, agricultural buildings, schools, and other locations frequented by people. Biochar is a very efficient adsorber of electromagnetic radiation, meaning that biochar-mud plaster is very good at preventing "electrosmog."

In the Textile Industry

The primary uses of biochar in the textile industry include as thermal insulation for functional clothing, as a fabric additive for functional underwear, as a deodorant for shoe soles as well, as filling for mattresses, and as filling for pillows. In Japan and China, bamboo-based biochars are already being woven into textiles (Lin and Chang 2008) to gain better thermal and breathing properties and to reduce the development of odors through sweat. The same aim is pursued through the inclusion of biochar in inlay soles and socks.

Biochar adsorbs perspiration and odors, shields against electromagnetic radiation (electrosmog), and removes negative ions from the skin. Moreover, it acts as a thermal insulator by reflecting heat, thereby enabling comfortable sleep without any heat build-up in summer. In Japan, pillows have been filled with biochar for a long time, which is supposed to prevent insomnia and neck tension.

Other Applications

Other applications of biochar include the following:

- In decontamination: Biochar is used as soil additive for soil remediation.
- In soil substrates: Because biochar as highly adsorbing, biochar in soil substrates may help in cleaning wastewater contaminated by heavy metals.
- As a barrier to prevent pesticides from getting into surface water: The sides of fields and ponds may be equipped with 30- to 50-cm deep barriers of biochar to filter out pesticides.
- In the treatment of pond and lake water: Biochar is effective in adsorbing pesticides and fertilizers, as well as at improving water aeration.
- In biogas production: When biochar is used as a biomass additive, methane and hydrogen yield is increased; at the same time, CO_2 and ammonia emissions decrease (Inthapanya and Peterson 2012).
- In biogas slurry treatment: By treating biogas slurry with lacto-ferments and biochar, nutrients are better stored and emissions are prevented (Schmidt 2012).
- In the treatment of wastewater: Biochar is used as an active carbon filter, as a pre-rinsing additive, as a soil substrate for organic plant beds, and in composting toilets.
- In the treatment of pure water: Biochar may be used in pure water treatment in microfilters, in controlling emissions, in room air filters, as carbon fibers, in plastic electronics, as semiconductors, in batteries, in metallurgy, in metal reduction, in cosmetics, in soaps and skin cream, in therapeutic bath additives, in paints and coloring, as food colorants, in industrial paints, as substitutes for lignite medicines, in detoxification, and as carriers for active pharmaceutical ingredients.

- In electronics to shield against electromagnetic radiation: Biochar can be used in microwave ovens, television sets, power supplies, computers, and power sockets, among others, to shield against electromagnetic radiation. This property can also be used in functional clothing as protection for parts of the body that are particularly sensitive to radiation.

Influence of Biochar on Soil Physical Properties

On Soil Structure

The incorporation of biochar into soil can alter the soil's physical properties, such as structure, pore size distribution, and density with logical implications in soil aeration, water holding capacity, plant growth, and soil workability. Sohi et al. (2010) proposed an analogy between the impact of biochar addition and the observed increase in soil water repellency as a result of fire. The rearrangement of amphiphilic molecules by heat from a fire might not affect the soil, but it could affect biochar itself during pyrolysis (Doerr et al. 2000). In addition, the soil hydrology may be affected by partial or total blockage of soil pores by the smallest particle size fraction of biochar, thereby decreasing water infiltration rates. Liu and Zhang (2012) reported that, when 40 t ha^{-1} biochar is applied, the soil water stable aggregate (>0.25 mm) in the 0- to 15-cm soil layer had a remarkable increase than other treatments, especially the macroaggregate with particle sizes larger than >2 mm. They also suggested that biochar incorporation into upland red soil will increase crop productivity and improve soil structure.

On Soil Density

The application of biochar can reduce the overall bulk density of the soil. This is primarily because biochar has a bulk density that is much lower than that of mineral soils. The tensile strength of the hard setting soil under investigation also decreased with an increasing rate of biochar application. Jein and Wang (2013) stated that application of 5% biochar decreased the bulk density from 1.42 to 1.08 Mg m^{-3}.

On Soil Surface Area

The specific surface area of biochar is generally higher than sand and comparable to or higher than clay. Thus, it will cause a net increase in the total soil specific surface when added as an amendment. There is evidence that suggests that biochar application into soil may increase the overall net soil surface area and, consequently, may improve soil water retention and soil aeration. The direct effect is related to the large inner surface area of biochar. An increased soil specific surface area and physical conditions may also benefit native microbial communities.

On Soil Porosity

Biochar has a very porous nature; thus, its application to soil will improve soil aeration. Jein and Wang (2013) reported an increase in porosity from 41.24% (control) to 52.43% in treatment where biochar was applied at a rate of 5%. Improved aeration is partly due to an increase in macro-porosity, with a resulting higher air-filled porosity and improved supply of oxygen to soil under a wide range of soil water conditions. However, the extent of changes will depend on the porosity characteristics of different biochar types and application rates. The pore size distribution of biochar depends on the anatomical structure of parent feedstock and process conditions of pyrolysis, such as charring temperature and activation.

On Soil Water

The influence of biochar on soil physical properties will affect soil's response to water, aggregation, workability, shrink-swell dynamics, permeability, and soil water retention. This change may be due to physical changes in the soil, whereby small particles of char block soil pores and reduce water infiltration rates. Glaser et al. (2002) found that Amazonian char rich anthrosols had field water retention capacity of 18%, which was higher than the surrounding soil that had no char. The hydrophobic polyaromatic backbone reduces the entry of water into the aggregate pores, leading to an increased aggregate stability and water availability. Uzoma et al. (2011) reported that the lower bulk density and porous nature of added biochar increased water use efficiency consequent to improvements in field capacity and hydraulic conductivity. The results of this study also indicate that application of cow manure biochar to sandy soil is not only beneficial for crop growth, but it also significantly improves the physico-chemical properties of the coarse soil. An increase in the water holding capacity of both sandy and silt loam soil due to the application of biochar was also reported by Granatstein et al. (2009).

Influence of Biochar on Soil Chemical Properties

The application of biochar alters the soil chemical properties in terms of pH, total and available nutrients, cation exchange capacity (CEC), amount of exchangeable cations, base saturation, and the content of exchangeable Al^{3+} (which is decreased with biochar). Biochar is an organic material with high surface area, high porosity, and variable charge, which has the potential to increase CEC, surface sorption capacity, and base saturation when added to soil. The broad array of beneficial properties associated with biochar addition to soil may function alone or in combination to influence nutrient transformations. In the context of nutrient availability, the impact of biochar addition on pH may be important. Southavong et al. (2012) observed that the pH of the soil was significantly increased when biochar was applied. This was further confirmed by the work of Nigussie et al. (2012), who reported that the highest mean value of pH was observed in soils treated with 10 t ha^{-1} biochar, whereas the lowest values were recorded for the control (0 t ha^{-1}). The increase in soil pH due to application of biochar was generally dominated by carbonates of alkali and alkaline earth metals. Another reason for the increase in soil pH consequent to application of biochar could be the high surface area and porous nature of biochar, which increase the CEC of the soil. Results of the study conducted by Chang et al. (2014) revealed that the increase in pH as a result of biochar application also reduced the exchangeable acidity and toxicity of Al_3^+ in acid soils.

On Cation Exchange Capacity of Soil

The CEC of freshly produced biochar is relatively low; only aged biochar shows high cation retention. Peng et al. (2011)) reported that amending with 1% biochar increased the CEC by 3.9–17.3%. Granatstein et al. (2009) studied the effects of biochar on soils of different textures; they concluded that, in both sandy and silt loam soil, the CEC increases with an increased rate of biochar. Biochar has a greater ability than other soil organic matter to adsorb cations due to its greater surface area, negative surface charge, and greater charge density. This makes it potentially more capable of retaining nutrients and providing these to growing plants.

On Nutrient Retention in Soil and Availability

Higher nutrient availability for plants is the result of both direct nutrient addition by biochar and greater nutrient retention. The long-term benefits of nutrient availability include a greater stabilization of organic matter, concurrent slower nutrient release from added organic matter, and better retention of cations due to a greater CEC. Lehmann and Rondon (2006) reported that applied biochar helps the soil to retain nutrients, which remain available to plants for a long time and thus increase plant growth and yield. Nutrient concentration in soil leachate is reduced in the order of PO43- > NH4+ > NO3- > K+, whereas the residual surface and subsurface soil become accumulated with high organic carbon, available N, P, and K, which proves that biochar improves the retention of nutrients in soil (Elangovan 2014; Dainy 2015).

Effects of Biochar on Soil Biological Properties

Applied biochar has considerable effects on soil biological properties. The soil biota is vital to the functioning of soils and provides many essential ecosystem services. Understanding the interactions between biochar and soil biota is therefore vital. The effects occur mainly through promoting arbuscular mycorrhizal fungi. Kolb et al. (2009) demonstrated that biochar caused a significant increase in microbial efficiency as a measure of units of CO_2 released per microbial biomass carbon in the soil. The addition of biochar to the soil increased N fixation by both free living and symbiotic diazotrophs and led to a 30–40% increase in bean yield with biochar up to 50 g kg^{-1}.

In addition, biochar application to soil alters the soil microbial population and shifts the functional groups in soil organic compounds. The structure of biochar provides a refuge for small beneficial soil organisms, such as symbiotic mycorrhizal fungi, which can penetrate deeply in to the pore space of biochar where sporulation occurs with less competition from saprophytes. Yamato et al. (2006) stated that increases in the root amount and colonization rate of arbuscular mycorrhizal fungi were observed on maize after biochar application. A more rapid cycling of nutrients in soil organic matter and microbial biomass as well as better colonization of roots by arbuscular mycorrhizal fungi will improve nutrient availability and crop yields by retention of nutrients against leaching in highly weathered soils of the humid tropics that have little CEC and better plant access to fixed P due to inoculation by mycorrhizae.

On Soil Enzyme Activity

Applied biochar has considerable influence on soil enzyme activity. Mineralization of soil organic matter is an important microbial mediated process by which carbon, nitrogen, and other nutrients are converted from organic forms into inorganic forms. Soil microbes must produce soil enzymes to catalyze the breakdown of soil organic matter and to make readily-usable dissolved compounds for growth and metabolism. Demise et al. (2014) studied the effect of biochar on soil enzyme activities and found that both urease and β-glucosidase enzyme activity increased with the application of biochar when compared to controls. Higher enzyme activity could be due to the higher microbial biomass in the biochar treatments that released more urease enzyme than the other treatments.

Influence of Biochar on Crop Productivity

Applied biochar would obviously augment crop productivity in view of the enormous beneficial influence of biochar on varied soil physical and chemical properties. For increasing any agricultural crop production, the use of organic manures along with inorganic fertilizers is well established, thus revealing the complementary effects of manures and fertilizers in improving the growth, yield, and yield attributes. Yield increase with biochar application has been documented in a controlled environment as well as in the field. Asai et al. (2009) studied the effects of biochar application on the grain yield of upland rice in northern Laos. With an application rate of 4 t ha^{-1}, they found double the increase in yield. Revell (2011) reported that the addition of biochar had no significant impact on pepper yield in either silt loam or sandy loam soil. However, N often increased yield in both soils at biochar application rates of 2.5% and below, especially in the sandy loam. This shows the importance of adding an N source with biochar, which is not inherently rich in nitrogen because much of the N in the feed material is lost during pyrolysis.

Constraints on the Use of Biochar

The primary constraint on the use of biochar is that a large amount of biomass is required for conversion. Numerous other applications of biomass are in vogue in society. The crop residues and other biomass are used for animal feeding, soil mulching, bio-manure making, thatching for rural homes, and fuel for domestic and industrial use.

One factor determining how much biochar may be produced is the existence of competing demands for biomass feedstock. The production of biochar is, of course, not the only use that can be made of biomass. Numerous other applications for various types of biomass have been used in the past, are in current demand, and may become popular in the future (Srinivasarao et al. 2013). Once the environmental costs of carbon-based greenhouse gas emissions have been suitably internalized, it is expected that market forces and price mechanism will be the dominant factors in implementing the use of biomass resources between competing demands (Woolf et al. 2008).

Other constraints on biochar production methods arise because emissions of CH_4, N_2O, soot, or volatile organic compounds combined with low biochar yields (e.g., from traditional charcoal kilns or smoldering slash piles) may negate some or all of the carbon-sequestration benefits, cause excessive carbon-payback times, or be detrimental to health (Woolf et al. 2010). However, to promote the application of biochar as a soil amendment and as a climate change abatement option, research, development and demonstration on biochar production and application are very vital (Srinivasarao et al. 2013).

Biochar and Climate Change

Biochar has considerable impact on maintaining soil biodiversity and on mitigating climate change. The application of biochar may help to reduce toxic components because biochar is capable of adsorbing heavy metals such as lead, cadmium, nickel, and some notable organic soil contaminants that can cause harm to humans, plants, and animals. For that reason, biochar as an additive to soil can be expected to improve its overall adsorption capacity and affect toxicity because there is a decrease in the transportability and depletion of the presence of metal and organic compounds. Due to its low cost and limited environmental impact, biochar seems to be a promising strategy for the remediation of polluted environments (Srinivasarao et al. 2013).

The production of biochar, in combination with its storage in soil, has been suggested as one possible means of reducing the atmospheric CO_2 concentration (Lehmann et al. 2006). Biochar's climate-mitigation potential stems primarily from its highly recalcitrant nature (Cheng et al. 2008), which slows the rate at which photosynthetically fixed carbon (C) is returned to the atmosphere. In addition, biochar has several potential co-benefits. It is a source of renewable bioenergy; it can improve agricultural productivity, particularly in low-fertility and degraded soils, where it can be especially useful to the world's poorest farmers; it reduces the losses of nutrients and agricultural chemicals in run-off; it can improve the water-holding capacity of soils; and it is producible from biomass waste (Lehmann and Joseph 2009; Lenton and Vaughan 2009). Of the possible strategies to remove CO_2 from the atmosphere, biochar is notable, if not unique, in this regard (Woolf 2010).

Various pyrolysis technologies are commercially available. They yield different proportions of biochar and bioenergy products, such as bio-oil and syngas. Pyrolysis processes are classified into two major types, fast and slow, which refer to the speed at which the biomass is altered. Fast pyrolysis, with biomass residence times of a few seconds at most, generates more bio-oil and less biochar than slow pyrolysis, for which biomass residence times can range from hours to days (Woolf 2010).

CO_2 is removed from the atmosphere by photosynthesis. Sustainably procured crop residues, manures, biomass crops, timber and forestry residues, and green waste are pyrolyzed by modern technology to yield bio-oil, syngas, process heat, and biochar. As a result of pyrolysis, immediate decay of these biomass inputs is avoided. The outputs of the pyrolysis process serve to provide energy, avoid emissions of GHGs such as methane (CH_4) and nitrous oxide (N_2O), and amend agricultural soils and pastures. The bioenergy is used to offset fossil-fuel emissions, while returning about half of the C fixed by photosynthesis to the atmosphere. In addition to the GHG emissions avoided by preventing the decay of biomass inputs, soil emissions of GHGs are also decreased by biochar amendment to soils. The biochar stores carbon in a recalcitrant form that can increase soil water- and nutrient-holding capacities, which typically result in increased plant growth. This enhanced productivity is a positive feedback that further enhances the amount of CO_2 removed from the atmosphere. The slow decay of biochar in soils, together with tillage and transport activities, also returns a small amount of CO_2 to the atmosphere (Woolf et al. 2010).

Economics of Biochar Use

The success of biochar use seems to be dependent on a reduction of biochar's price. Biochar's price is, however, largely dependent on the biochar production system, source, and availability of raw materials, transportation, application costs, and efficacy of applied biochar in soil amendments and the mitigation of climate change. Biochar is sold as a soil amendment, with a price that varies significantly based on location, density, porosity, quality, and availability (Srinivasarao et al. 2013).

The economic cost of implementing biochar production and use is important. It determines how readily and rapidly the technology might be deployed. Furthermore, it must compete for finances and resources with other technologies that may likewise be aimed at climate change abatement and soil quality improvement (Woolf 2008). Transportation distance has significant effects on costs, whereas ramifications for GHG emissions are low. Costs are the most sensitive to transportation distance. Therefore, biochar systems are most economically viable as distributed systems with low transportation requirements (Roberts et al. 2010).

Biochar provides a net benefit when total benefits exceed total costs. This requires that the values of biochar soil improvement, carbon sequestration, and energy production exceed the sum of biochar capital, operating, distribution, and application costs. In practice, there are several problems with calculating biochar net benefits. Estimates of the biochar soil amendment value vary by crop and soil type, and different studies have produced widely varying results. The persistence of soil benefits over time and the rate used to discount future benefits also greatly affect estimates of soil amendment value. Similarly, estimates for the social value of sequestered carbon vary greatly, being dependent on uncertain costs of future climate change and again on the rate at which these are discounted (Timmons 2016).

Various companies in North America, Australia, and England sell biochar or biochar production units. In Sweden, the Stockholm Solution is an urban tree planting system that uses 30% biochar to support healthy growth of the urban forest (Austin 2009). The Qatar Aspire Park now uses biochar to help trees cope with the intense heat of their summers (Srinivasarao et al. 2013).

At the 2009 International Biochar Conference, a mobile pyrolysis unit (3.6 m in length by 2.1 m in height) with a specified intake of 1000 lb (450 kg) was introduced for agricultural applications (Austin 2009). Application rates of 2.5–20 tons per hectare (1.0–8.1 t/acre) appear to be required to produce significant improvements in plant yields. Biochar costs in developed countries vary from $300 to $7000 per ton, which is generally too high for farmers/horticulturalists and prohibitive for low-input field crops. In developing countries, constraints on agricultural biochar relate more to biomass availability and production time. An alternative is to use small amounts of biochar in lower-cost biochar-fertilizer complexes (Joseph et al. 2013).

References

Anderson, P., & Reed, T. B. (2004). Biomass gasification: Clean residential stoves, commercial power generation, and global impacts. Prepared for the LAMNET Project International Workshop on "Bioenergy for a Sustainable Development," 8–10 Nov 2004, Viña del Mar, Chile.

Anonymous. (2006). Cornell University: Amazonian Terra Preta can transform poor soil into fertile. *Science Daily*.

Ameloot, N., Graber, E. R., Verheijen, F. G. A., & De Neve, S. (2013). Interactions between biochar stability and soil organisms: review and research needs. *European Journal of Soil Science, 64*, 379–390.

Asai, H., Samson, B. K., Stephan, H. M., Songyikhangsuthor, K., Homma, K., Kiyono, Y., Inoue, Y., Shiraiwa, T., & Horie, T. (2009). Biochar amendment techniques for upland rice production in Northern Laos: 1. Soil physical properties, leaf SPAD and grain yield. *Field Crops Research, 111*, 81–84.

Austin, A. (2009). A new climate change mitigation tool. *Biomass Magazine. BBI International*.

Brown, N. C. (1917). *The hardwood distillation industry in New York*. The New York State College of Forestry at Syracuse University, USA.

Camps Arbestain, M., Amonette, J. E., Singh, B., Wang, T., & Schmidt, H.-P. (2015). A biochar classification system and associated test methods. In J. Lehmann & S. Joseph (Eds.), *Biochar for environmental management – science and technology* (2nd ed.). New York: Routledge.

Chang, H. Y., Ahmed, O. H., & Majid, N. M. A. (2014). Improving phosphorus availability in an acid soil using organic amendments produced from agro-industrial wastes. http://dx.doi.org.

Cheng, F. Y., Huang, C. W., Wan, T. C., Liu, Y. T., Lin, L. C., & Lou Chyr C. Y. (2008). Effects of free-range farming on carcass And meat qualities of black-feathered Taiwan native chicken. *Asian Australian Journal of Animal Science, 21*(8), 1201–1206.

Cho, S., Charles, P. F., Francisco, D., Scott, J. W., Craig, W. H., John, B. K., Pamela, L. R., Lorin, D. W., & Jeffrey, B. B. (2013). Herd-level risk factors associated with fecal shedding of Shiga toxinencoding bacteria on dairy farms in Minnesota, USA. *Canadian Veterinary Journal B, 54*(7), 693–697.

Crystal, S., Margaret, L. B., Grace, E. H., Clay, B., Maren, P., Paul, J., Vandana, S., Liu, H., Patricia, S., Christopher, S., & Dena, M. B. (2012). Are organic foods safer or healthier than conventional alternatives?: A systematic review. *Annals of Internal, Medicine, 157*(5), 348–366.

Dainy, M. S. M. (2015). Investigations on the efficacy of biochar from tender coconut husk for enhanced crop production. Ph.D.(Ag) thesis, Kerala Agricultural University, Thrissur, 245 p.

Demirbas, A. (2004). Effects of temperature and particle size on biochar yield from pyrolysis of agricultural residues. *Journal of Analytical and Applied Pyrolysis, 72*, 243–248.

Demise, W., Liu, Z., & Chang, M. (2014). Effect of biochar on carbon fractions and enzyme activity of red soil. *Catena, 121*, 214–221.

Doerr, S. H., Shakesby, R. A., & Walsh, R. P. D. (2000). Soil water repellency: Its causes, characteristics and hydro-geomorphological significance. *Earth Science Reviews, 51*, 33–65.

Dufour, D. L. (1990). Use of tropical rainforests by native Amazonians. *Bioscience, 40*, 652.

Elad, Y., David, D. R., Harel, Y. M., Borenshtein, M., Kalifa, H. B., Silber, A., & Graber, E. R. (2010). Induction of systemic resistance in plants by biochar, a soil-applied carbon sequestering agent. *Phytopathology, 100*, 913–921.

Elangovan, R. (2014). Effect of biochar on soil properties, yield and quality of cotton-maize cowpea cropping sequence. Ph.D.(Ag) thesis, Tamil Nadu Agricultural University, Coimbatore, 425 p.

Elliott, D. C. (2007). Historical developments in hydroprocessing bio-oils. *Energy & Fuels, 21*, 1792–1815.

Emrich, W. (1985). *Handbook of biochar making. The traditional and industrial methods*. Boston: D. Reidel Publishing Company.

Glaser, B. (2005). https://www.terradaprata.com.br

Glaser, B., Lehmann, J., & Zech, W. (2002). Ameliorating physical and chemical properties of highly weathered soils in the tropics with charcoal—a review. *Biology and Fertility of Soil, 35*, 219–230.

Graetz, R. D., & Skjemstad, J. O. (2003). *The charcoal sink of biomass burning on the Australian continent* (CSIRO Atmospheric Research Technical Paper No. 64). Australia: Aspendale, CSIRO.

Granatstein, D., Kruger, C. E., Collins, H., Galinato, S., Garcia-Perez, M., & Yoder, J. (2009). *Use of biochar from the pyrolysis of waste organic material as a soil amendment*. Final Project Report. Center for Sustaining Agriculture and Natural Resources, Washington State University, Wenatchee, 181 p. http://www.ecy.wa.gov/biblio/0907062.html.

IBI, International Biochar Initiative. (2006). www.biochar-international.org.

Iliffe, R. (2009). Is the biochar produced by an Anila stove likely to be a beneficial soil additive? UKBRC Working Paper 4. www.biochar.org.uk.

Inthapanya, S. K, & Preston, T. R. (2012). Biochar increases biogas production in a batch digester charged with cattle manure. *Livestock Research for Rural Development, 24*. December 2012.

Izaurralde, R. C., Rosenberg, N. J., & Lal, R. (2001). Mitigation of climate change by soil carbon sequestration: issues of science, monitoring, and degraded lands. *Advances in Agronomy, 70*, 1–75.

Jien, S. H., & Wang, C. S. (2013). Effects of biochar on soil properties and erosion potential in a highly weathered soil. *Catena, 110*, 225–233.

Joseph, S., Graber, E. R., Chia, C., Munroe, P., Donne, S., Thomas, T., Nielsen, S., Marjo, C., Rutlidge, H., Pan, G. X., Li, L., Taylor, P., Rawal, A., & Hook, J. (2013). Shifting paradigms on biochar: micro/nano-structures and soluble components are responsible for its plant-growth promoting ability. *Carbon Management, 4*, 323–343.

Kleiner, K. (2013). The bright prospect of biochar: Article: Nature reports climate change. nature.com.

Kolb, S. E., Fermanich, K. J., & Dornbush, M. E. (2009). Effect of charcoal quantity on microbial biomass and activity in temperate soils. *Soil Science Society of America Journal, 73*, 1173–1181.

Laufer, J., & Tomlinson, T. (2013). Biochar field studies: An IBI research summary. info@biochar-international.org.

Lehmann, J., & Joseph, S. (2009). Biochar for environmental management: An introduction. In J. Lehmann & S. Joseph (Eds.), *Biochar for environmental management: Science and technology* (pp. 1–12). London: Earthscan.

Lehmann, J., & Rondon, M. (2006). Biochar soil management on highly weathered soils in the humid tropics. In N. Uphoff et al. (Eds.), *Biological approaches to sustainable soil systems* (pp. 517–530). Boca Raton: CRC Press.

Lehmann, J., Gaunt, J., & Rondon, M. (2006). Biochar sequestration in terrestrial ecosystems—a review. *Mitigation and Adaptation Strategies for Global Change, 11*, 403–427.

Lehmann, J., Kaampf, N., Woods, W. I., Sombroek, W., Kern, D. C., & Cunha, T. J. F. (2007). *Historical ecology and future explorations* (p. 484). Kluwer Academic Publishers; The Netherlands.

Lehmann, J. (2009). Biological carbon sequestration must and can be a win-win approach. *Climate Change, 97*, 459.

Lenton, T., & Vaughan, N. (2009). *Geoengineering responses to climate change* (pp. 73–140). New York: Springer.

Lin, C. M., & Chang, C. W. (2008). Production of thermal insulation composites containing bamboo charcoal. *Textile Research Journal, 78*, 555–560.

Liu, X. H., & Zhang, X. C. (2012). Effect of biochar on pH of alka-line soils in the loess plateau: results from incubation experiments. *International Journal of Agriculture and Biological, 14*, 745–750.

Mao, J.-D., Johnson, R. L., Lehmann, J., Olk, J., Neeves, E. G., Thompson, M. L., & Schmidt-Rohr, K. (2012). Abundant and stable char residues in soils: Implications for soil fertility. *Environmental Science and Technology, 46*, 9571–9576.

McHenry, M. P. (2009). Agricultural bio-char production, renewable energy generation and farm carbon sequestration in Western Australia: Certainty, uncertainty and risk. *Agriculture, Ecosystems & Environment, 129*, 1–7.

Nartey, D. O., & Zhao, B. (2014). Biochar preparation, characterization, and adsorptive capacity and its effect on bioavailability of contaminants: An overview. Advances in Materials Science and Engineering, 2014.

Nigussie, A., Kissi, E., Misganaw, M., & Ambaw, G. (2012). Effect of biochar application on soil properties and nutrient uptake of Lettuce (*Lactuca sativa*) grown in chromium polluted soils. *American-Eurasian Journal of Agricultural and Environmental Sciences, 12*, 369–376.

Pelaez-Samaniego, M. R., Garcia-Perez, M., Cortez, L. B., Rosillo- Calle, F., & Mesa, J. (2008). Improvements of Brazilian carbonization industry as part of the creation of a global biomass economy. *Renewable and Sustainable Energy Reviews, 12*, 1063–1086.

Peng, X., Ye, L. L., Wang, C. H., Zhou, H., & Sun, B. (2011). Temperature-and duration-dependent rice straw-derived biochar: Characteristics and its effects on soil properties of an Ultisol in southern china. *Soil and Tillage Research, 112*, 159–166.

Purakayastha, T. J. (2012). Preparation and utilization of biochar for soil amendment. In H. Pathak, P. K. Aggarwal, & S. D. Singh (Eds.), *Climate change impact, adaptation and mitigation in agriculture: Methodology for assessment and applications* (pp. 280–294). New Delhi: Indian Agricultural Research Institute.

Ramanathan, V., & Carmichael, G. (2008). Global and regional climate changes due to black carbon. *Nature Geoscience, 1*, 221–227.

Reddy, B. (2011a). Holy mother biochar Kiln. http://okgeo.org; http://ohanda.org.

Reddy, B. (2011b). Biochar production and use. http://www.slideshare.net/saibhaskar/biochar-production-and-uses-dr-reddy-5242206.

Revell, K. T. (2011). The effect of fast pyrolysis biochar made from poultry litter on soil properties and plant growth. M.Sc. thesis, Virginia Polytechnic Institute and State University, Blacksburg, 75p.

Roberts, K. G., Gloy, B. A., Joseph, S., Scott, N. R., & Lehmann, J. (2010). Life cycle assessment of biochar systems: Estimating the energetic, economic, and climate change potential. *Environmental Science & Technology, 44*, 827–833.

Schmidt, H. P. (2012). 55 uses of biochar. *Ithaka Journal, 1/2012*, 286–289. www.ithaka-journal.net.

Schmidt, H. P. (2013). Biochar as building material for an optimal indoor climate. *Ithaka Journal, 2013*, x–y.

Sohi, S., Lopez-Capel, E., Krull, E., & Bol, R. (2009). *Biochar, climate change and soil: A review to guide future research* (CSI-RO Land & Water Science Report 05/09). Canberra: CSIRO.

Sohi, S., Krull, E., Lopez-Capel, E., & Bol, R. (2010). A review of biochar and its use and function in soil. *Advances in Agronomy, 105*, 47–82.

Sombroek, W. G. (1966). A reconnaissance of the soils of the Brazilian Amazon region (p. 283, Vol. 672). Verslagen van Landbouwkundige Onderzoekingen; Wageningen, The Netherlands: Amazon soils.

Southavong, S., Peterson, T. R, Man, N. van (2012). Effect of biochar and biodigester effluent on growth of water spinach (*Ipomoea aquatic*) and soil fertility. *ResearchGate*. Feb, 2012.

Srinivasarao, C., Vankateswarlu, B., Lal, R., Singh, A. K., Kundu, S., Vittal, K. P. R., Balaguruvaiah, G., Vijaya Shankar Babu, M., Ravindra Chary, G., Prasadbabu, M. B. B., & Yellamanda Reddy, T. (2012). Soil carbon sequestration and agronomic productivity of an Alfisol for a groundnut-based system in a semiarid environment in southern India. *European Journal of Agronomy, 43*, 40–48.

Srinivasarao, Ch., Gopinath, K. A., Venkatesh, G., Dubey, A. K., Wakudkar, H., Purakayastha, T. J., Pathak, H., Pramod Jha., Lakaria, B. L., Rajkhowa, D. J., Mandal, S., Jeyaraman, S., Venkateswarlu, B., & Sikka, A. K. (2013). Use of biochar for soil health enhancement and greenhouse gas mitigation in India: Potential and constraints, central research institute for dryland agriculture, Hyderabad, Andhra Pradesh. 51p.Publ. CRIDA, Hyderabad NICRA Bulletin 1/2013 Website: http://nicra-icar.in.

Sugumaran, P., & Sheshadri, S. (2010). *Biomass charcoal briquetting: Technology for alternative energy based income generation in rural areas*. Taramani: Shri AMM Murugappa Chettiar Research Centre. 20 p.
Timmons, D. (2016). Biochar economics: A cost-effectiveness analysis. Conference Presentations USBI: US biochar initiatives University Of Massachusetts, Boston. www.biochar-us.org.
Uzoma, K. C., Inoue, M., Andry, H., Zahoor, A., & Nishihara, E. (2011). Influence of biochar application on sandy soil hydraulic properties and nutrient retention. *Journal of Food, Agriculture and Environment, 9*, 1137–1143.
Venkatesh, G., Korwar, G. R., Venkateswarlu, B., Gopinath, K. A., Mandal, U. K., Srinivasarao, Ch., & Grover, M. T. (2010). Preliminary studies on conversion of maize stalks into biochar for terrestrial sequestration of carbon in rainfed agriculture. In *National symposium on climate change and rainfed agriculture* (pp. 388–391). Hyderabad: CRIDA. 18–20 February, 2010.
Whitman, T., & Lehmann, J. (2009). Biochar – one way forward for soil carbon in offset mechanisms in Africa? *Environmental Science and Policy, 12*, 1024–1027.
Woolf, D. (2008). Biochar as a soil amendment: A review of the environmental implications. http://orgprints.org/13268/.
Woolf, D., Amonette, J. E., Street-Perrott, F. A., Lehmann, J., & Joseph, S. (2010). Sustainable biochar to mitigate global climate change. *Nature Communications, 1*, 1–9.
Yamato, M., Okimori, Y., Wibowo, I. F., Anshori, S., & Ogawa, M. (2006). Effects of the application of charred bark of *Acacia mangium* on the yield of maize, cowpea and peanut, and soil chemical properties in south Sumatra, Indonesia. *Soil Science and Plant Nutrition, 52*, 489–495.

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