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Agro-ecological Approach for Developing a Sustainable Farming and Food System

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Modern farming technologies have kept agricultural production apace with population growth, but inequities in the food distribution system still plague many families, countries, and regions. A growing awareness of the finite nature of critical nonrenewable resources, the undesirable impacts of the current conventional agriculture system, and the costs and other shortcomings of a globalized food system are causing us to rethink our basic assumptions about how and where to grow food. To ensure the sustainability of agriculture, the responsibility of improving the farming system is not only for those on the production side but also for consumers as well. At the cutting edge of this critical awareness is "agro-ecology," a new approach for establishing a sustainable farming and food system based on ecological methods and theory and community management. Achieving this agro-ecological approach will require a gradual phasing in of new farming practices and changes in consumer activities. To develop and adopt eco-specific, eco-friendly, and integrated agricultural resource management, education and research projects within communities and between countries and/or generations will be necessary.

Key words: soil carbon, sustainable agriculture, farmer, community, global warming

Introduction

During the latter half of the 20th century, intensive agriculture increased crop yields and was successful in meeting the growing demand for food, but it also degraded the natural resources upon which agriculture depends: soil, water, and natural genetic diversity (Pimentel *et al.,* 1995; Gliessman, 2006). Today, conventional agriculture is built around two related goals: the maximization of production and the maximization of profit. In pursuit of these goals, numerous practices have been developed without regard for their unintended long-term environmental consequences and without consideration of the ecological dynamics of agro-ecosystems. The Millennium Ecosystem Assessment (2005) conducted by the World Resource Institute revealed that the overuse and mismanagement of agricultural pesticides poison water and soil, while nitrogen (N) and phosphorus inputs and livestock wastes have become major pollutants of surface water, aquifers, and coastal wetlands and estuaries.

The world's population is expected to grow from just over 6 billion today to more than 8 billion by 2030, an increase of about a third, with another 2 to 4 billion added in the subsequent 50 years (Cohen, 2003). Tilman *et al.* (2001) predicted that feeding a population of 9 billion using conventional methods would mean converting another 1 billion ha of natural habitat to agriculture, primarily in the developing world, together with a doubling or tripling of N and phosphorous inputs, a two-fold increase in water consumption, and a three-fold increase in pesticide use.

The environmental degradation due to farming is becoming a serious problem at both local and global scales, and many conventional farmers are choosing to make the transition to practices that are more environmentally sound and have the po-

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tential for contributing to the long-term sustainability of agriculture. Sustainable agriculture would ideally produce good crop yields with reduced impacts on ecological factors such as soil fertility and minimal input of resources (Pimentel *et al.,* 1997).

The importance of low-input sustainable agriculture in reducing the use of energy and chemical inputs has been recognized (Poincelot, 1986). For example, recent policies of the Japanese government to develop more environmentally friendly farming practices and growing awareness of the importance of reducing chemical materials have led to a widespread interest in conservation farming. According to recent statistical data, 167,995 farms in Japan were engaged in conservation farming, accounting for 21.5% of the total cropping area in the country (Sustainable Agriculture Office, 2008). Conservation management increases the efficiency of conventional practices to reduce or eliminate the use of costly, scarce, or environmentally damaging inputs such as synthetic pesticides and fertilizers. Although these efforts have helped to reduce the negative impacts of conventional agriculture, they have not eliminated its dependence on external inputs and their damage to local environments.

To establish sustainable farming, alterative farming practices must be developed. Organic farming systems are one of the alternatives to conventional agriculture. Instead of synthetic inputs, organic farming uses cover crops, compost, and animal manure to build up soil fertility, and these practices ideally produce good crop yields with minimal impact on ecological factors (Pimentel *et al.,* 1997; Mäder *et al.,* 2002). Producers, sellers, and consumers of organic food regularly use the word "natural" to characterize organic farming or organic food, in contrast to the unnaturalness of conventional farming (Verhoog *et al.,* 2003).

However, large-scale organic farming has the potential to cause environmental damage and use massive amounts of energy. For example, intensive organic vegetable production has been shown to cause nitrate leaching from soil (Maeda *et al.,* 2003). In addition, commercial organic markets require the same huge amounts of energy as conventional markets and disturbed local production because local organic products often could not compete within the global organic market (Gliessman, 2006). In this regard, farming practices for sustainable agriculture should focus not only on replacing the chemicals used in farming but also on redesigning the agro-ecosystem to maximize the ecological, economic, and social synergies among them, while minimizing the conflicts.

In an agro-ecological system, farming is managed to provide a matrix with positive ecological qualities for wild biodiversity and ecosystem services and to develop a network of diverse communities to promote and achieve local independence. To ensure the sustainability of agriculture, the responsibility of improving the farming system is not only for those on the production side but also for consumers as well. Agro-ecology is a new approach for establishing a sustainable farming and food system based on ecological methods and theory and community management. This paper discusses agro-ecology as a new challenge for ensuring sustainable agriculture, the need to phase in the ecological approach, and some activities to develop the sustainable farming system in local communities and globally.

Converting to A Sustainable Farming System

For many conventional farmers, rapidly converting to sustainable farming designs and practices is neither possible nor practical. As a result, many conversion efforts proceed with slow steps toward the ultimate goal of sustainability, or they are simply focused on developing food production systems that are somewhat more environmentally sound. From the observed range of conversion efforts, four distinct phases of conversion can be discerned. These phases help us describe the steps that farmers actually take in converting from conventional to sustainable farming systems, and they can serve as a map outlining a stepwise, evolutionary conversion process. They are also helpful for categorizing agriculture research as it relates to conversion and for considering what additional steps might be needed to ensure that the conversion process promotes sustainability in food systems beyond the farm.

Figure 1 illustrates the phases of converting to a sustainable farming and food system, which involve field-level approaches, participatory research with farmers, community associate approaches, and community network approaches between countries.

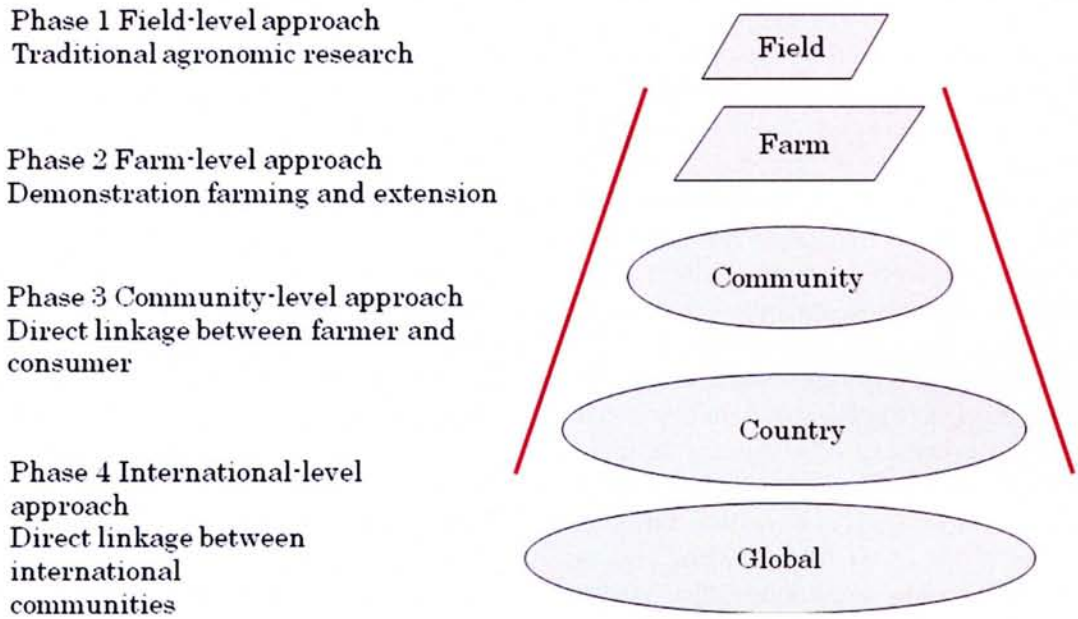

Fig. 1. Phases of converting to a sustainable farming and food system, which include field-level approaches, participatory research with farmers, community associate approaches, and community network approaches between countries.

Phase 1 involves experimental field-level research, answering questions such as which management practices will be effective for enhancing soil organic matter and eliminating N leaching. These approaches will reveal the optimum methods for managing agricultural resources, although the results may not be adaptive for local farmers. Phase 2 encompasses farmer-involved research, such as the adoption of cover crops for farmers' commercial fields. These approaches will modify the alternative methods to satisfy the farmers' needs, although some alternative methods may not provide direct benefits for farmers. Phase 3 involves community-based approaches, such as consumer-supported farming systems. These approaches may significantly enhance the sustainability of a community by improving food self-sufficiency; however, globalization of the food market may offset these community-based approaches. Therefore, phase 4 approaches will be needed to establish a community network between Japan and other countries. In this approach, it is important to account for differences in environments, farming techniques, and cultures among these international communities.

Phase 1: Field-Level Approach

The maintenance and improvement of soil quality in croplands are critical to sustaining agricultural productivity and environmental quality for future generations. A fertile soil provides essential nutrients for crop plant growth, supports a diverse and active biotic community, exhibits a typical soil structure, and allows for undisturbed decomposition. In general, an increase in soil organic matter (SOM) improves soil quality and increases the crop yield response. A study of soils in Michigan demonstrated potential crop-yield increases of about 12% for every 1% of organic matter increase (Magdoff, 1998). Decreasing SOM, however, causes low soil fertility and low cation exchange capacity, resulting in the need for additional fertilizer inputs to maintain economical yield.

SOM, which includes a vast array of carbon compounds originally created by plants, microbes, and other organisms, helps to maintain soil fertility and plays a variety of roles in the nutrient, water, and biological cycles (Tiessen *et al.,* 1994; Reeves, 1997). SOM is also critical for its function to support crop growth naturally, and it provides a place for water, air, and biological ecosystems to exist in the soil. Proper soil management also has great potential to contribute to carbon sequestration by transferring atmospheric carbon dioxide into long-lived pools and storing it securely so that it is not immediately re-emitted (Lal, 2004). The current pressure on the land resources of the world is enormous (Komatsuzaki and Ohta, 2007). Soil management practices that improve soil quality by enhancing SOM and fertility are expected to become more widespread because soil management also determines the level of food production and, to a great extent, the state of the global environment.

Table 1 lists farming practices that have been adopted to increase carbon stocks and their positive and negative impacts on agro-ecosystems. Practices directed toward the effective management of soil carbon are available, and many of these are feasible and relatively inexpensive to implement. Several agronomic practices increase the return of biomass carbon to the soil. Although increased N fertilizer use has made a large contribution to the growth in productivity, further increases in its use will lead to greater emissions of nitrous oxide.

Soil management for sustainable agro-ecosystems should be compatible with increasing SOM to improve soil quality for sustaining food productivity and controlling soil residual nutrients that aggravate environmental problems. Cover cropping is a unique technique for improving the N cycle in cultivated soil because it scavenges the residual soil

Table 1. Evaluation of farming practices adopted to increase carbon stocks

Treatment	Effect on organic matter (OM) input (changes to primary production and/or amount supplied to soil)	Effect on OM output (rate of mineralization)	Other positive effects	Negative secondary environmental effects	Additional carbon stock (t C ha^{-1} y^{-1})	References
No-till	Slightly lower production, slightly lower level of OM conversion into humus	Low rate (increased protection of OM due to improved soil aggregate)	Erosion control, reduced fuel consumption, enhanced soil biological diversity	Slightly lower production, use of pesticides, emission of N_2O to be confirmed	0.07–0.33	Robertson *et al.*, 2000; Arrouays *et al.*, 2002; Komatsuzaki *et al.*, 2008; Smith *et al.*, 2008.
Crop rotation	Increased OM input	Increased soil respiration	Break in insect and pest cycle	None	0.05–0.25	Lal, 2004; Smith *et al.*, 2008.
Cover crop	Annual production and increased OM returned (crop not harvested)	Increased soil respiration	Residual nutrient erosion control reduces fertilizer consumption, enhancing soil biological diversity	Emission of N_2O to be confirmed	0.15–0.25	Arrouays *et al.*, 2002; Lal, 2004; Komatsuzaki *et al.*, 2008; Smith *et al.*, 2008.
Manure application	Increased OM input, increased production by additional nutrient	Increased soil respiration	Improved soil productivity	If excessive inputs occur, N leaching and N_2O emission	0.05–0.75	Robertson *et al.*, 2000; Lal, 2004; Smith *et al.*, 2008.

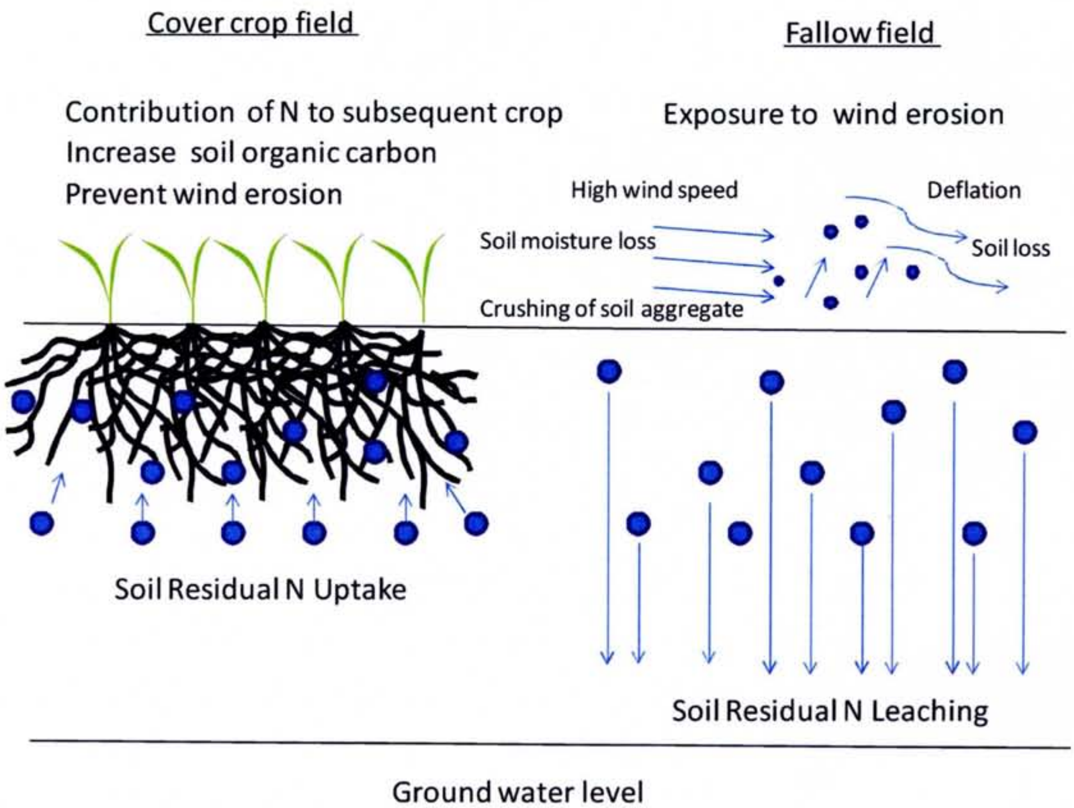

Fig. 2. Cover cropping benefits in upland (dry) fields compared with fallow treatment.

N and makes this nutrient available for subsequent crops (Komatsuzaki and Ohta, 2007). Figure 2 illustrates the benefits of cover cropping in upland (dry) fields compared with fallow treatment. Erodible field conditions consist of an unprotected soil surface that is smooth, bare, and dry. A strong, turbulent wind coupled with highly erodible field conditions causes wind erosion. However, a cover crop such as winter wheat or winter rye may be planted after soybeans to provide good soil cover and prevent wind erosion. Komatsuzaki *et al.* (2008) reported that rye cover crops accumulated more soil N as the residual soil N level increased. Based on the soil inorganic N distribution at cover crop growth termination, the inorganic N concentration at a depth of 60–90 cm was significantly lower for rye compared with hairy vetch or fallow fields (i.e., rye reduced N leaching), and this soil inorganic N reduction was observed to occur year-round. In addition, no-till with a rye cover crop showed the highest increased ratio of soil carbon storage, whereas winter fallow showed a decrease in soil carbon storage during the 5 years (Komatsuzaki *et al.,* 2008).

Phase 2: Participatory Research with Farmers

The conversion of conventional farms to sustainable ones often proceeds gradually, or sometime recedes, because sustainable farming practices often do not provide direct benefits to the present farmers. Therefore, participatory research with farmers will be necessary to develop sustainable farming systems on individual farms.

My colleagues and I are currently working on research projects with farmers who produce paddy rice in Ushiku, Japan. Wet paddy rice cultivation is one of the traditional agricultural techniques in Japan, and half of all Japanese cropland is cultivated with paddy rice. Japanese rice has a great monetary value because of its relatively high quality in the world marketplace. If a grower were to base the decision to grow rice solely on the market value of rough rice, it is doubtful that rice would be grown at all in Asia. However, when the overall value of rice paddies and their effects on the environment, such as flooding water in the fields, storing water after intense rainfalls, and the overall profitability of the land, are considered, the benefits of rice production outweigh the costs. Moreover, paddy fields have unique ways of regulating the movement, accumulation, and transformation of SOM and N because the fields are controlled by a long-term seasonal oxidation-reduction interaction.

Wet paddy farming also has benefits for improving water quality. In paddy fields, inorganic N can be effectively processed through nitrification and denitrification, ammonia volatilization, and plant uptake. However, these benefits occur only during the growing season, when paddies are flooded. After the rice is harvested in autumn, most paddy fields are not irrigated and are left fallow from autumn to spring. This practice dries out the soil, which can lead to N leaching (Tanaka, 2001). This problem is particularly serious in Ushiku, which is one of the major agricultural areas in the basin of Lake Kasumigaura.

In an effort to solve this problem, researchers from Ibaraki University, local farmers, and companies are collaborating together in a group named *Hurusato Saisei Iinkai.* Our group made a demonstration paddy field, and we prepared several farming systems, including cover cropping and tillage systems. Our findings indicate that, when planted with winter cover crops, paddies can have significant environmental benefits. Komatsuzaki *et al.* (2004) reported that winter annual non-legume cover crops provide an alternative means to conserve residual soil N following rice harvest. The paddy rice-winter cover crop system is an appropriate way to develop sustainable farming, because it can prevent the leaching of residual soil nutrients, add SOM, improve yields, and eliminate the need for fertilizer for rice growth. By having farmers participate in research, they can understand the environmental impact of farming and how to reduce these impacts by using alternative farming systems.

Phase 3: Community-Based Approach

The agricultural industry now functions in a global marketplace in which food moves quickly from one part of the world to another. The raw materials purchased from farmers at low prices are converted into an incredible array of processed, packaged, and preserved food items that hardly resemble the agricultural products they were made from. This food system often ignores the needs of consumers. For example, in 2008 frozen dumplings produced in China were accidentally contaminated with poisonous chemicals, which caused concern for Japanese consumers because frozen and processed foods are not required to indicate the area of production (Asashi Shinbun, 30 January 2008). From the standpoint of food choice and availability, consumers have never had it better. But the same global food system that forces out small-scale farmers and exploits third-world peasants also has brought a variety of negative changes to food consumers. Many of these changes have happened so slowly that we are not conscious of them.

This isolation of consumers from the sources of their food has caused ignorance or a lack of understanding of farming process by consumers. Through home gardening, however, consumers can learn about soil, water, plants, climate, and farming techniques. As a center for field science research and education, Ibaraki University started to offer service learning courses entitled "Let's Start an Organic Home Garden" for local residents in 2004. The participants' ages range from 20 to 70 years old, with most around 60 years old. They use 4 m by 4 m plots for home gardening training, and they grow about 20 kinds of vegetables from April to December. Participants also attend monthly lectures by university professors regarding soil management, crop biology, nutrient management, weed control, and pest management. All lectures are closely related to organic farming techniques, and some local farmers also invite participants to work in their fields as a demonstration.

Some people believe that home gardens have low productivity, but participants are surprised by the high productivity of home gardens because of the diversity of crops produced. Table 2 gives an example of the harvest yield from a 16-m^2 garden plot compared with a 16-m^2 plot of a commercial sugar corn field. The organic farming techniques that participants learn also provide enhanced environmental benefits compare with conventional farming because these techniques adopt mixed culture (rather than monoculture) and eliminate chemical inputs to the fields. Thus, organic home gardening promotes plant diversity, which enhances the biological diversity in the soil and surrounding envi-

Table 2. Comparison of fresh vegetable yields between 16-m^2 plots of a home garden versus a conventional farm

Fields	Species	No. of plants	Harvest (kg, fresh weight)
Home garden	Corn	10	2
	Bean (climbing)	10	3
	Bean (short)	10	0.5
	Eggplant	2	2
	Pepper	2	0.7
	Tomato	2	2
	Nappa	20	0.5
	Radish	10	5
	Red radish	20	0.4
	Soybean	10	1
	Potato	20	20
	Peanut	10	0.5
	Total		37.6
Conventional field	Corn	80	16

Data obtained from the field science center, Ibaraki University in 2009.

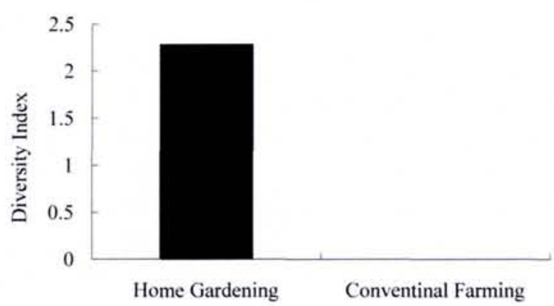

Fig. 3. Crop diversity index between home gardening and conventional farming.

Fig. 4. One home gardening participant said, "I've been cooking everyday for 40 years, but I never thought about the vegetables so much before I started home gardening".

ronment. The participants in these classes are motivated to consume more locally produced food, thus shortening the linkage between farmers and consumers (Fig. 3). In addition, participants have gained an understanding of how sustainable farming will be important to future generations (Fig. 4).

Phase 4: Building Community Research Networks with Other Countries

Modern farming technologies have kept production apace with population growth, but large inequities in the food distribution system still plague many families, countries, and regions. A growing awareness of the finite nature of critical nonrenewable resources, the undesirable impacts of the current conventional agriculture system, and the costs and other shortcomings of a globalize food system are causing us to rethink our basic assumptions about how and where to grow food.

Recent intensive research revealed the differences and common aspects of conservation rice farming systems in Indonesia and Japan (Syuaib 2006 and 2009. To develop ecological management practices for the sustainable farming system in the global scale, various approaches will be needed based on the characteristics of each ecosystem. Ecosystems within Indonesia and Japan are very different, although these countries are facing similar challenges with regard to global warming and globalization. Therefore, collaborative research between Ibaraki University and Bogor Agricultural University in Indonesia is being undertaken. Through these studies, researchers are discussing what is needed to modify the agro-ecosystems and how to collaborate to develop a community-based approach. These framework studies should help to reveal the appropriate changes in technology and development for each agro-ecosystem.

In Indonesia, modern farming technologies have kept production apace with population growth, but major problems with food distribution still plague many communities and regions (Syuaib, 2006). However, increasing synthetic chemical input to cropland to meet the increasing demand for food has led to decreasing biodiversity in agricultural areas of Indonesia. After the Green Revolution program was launched in the late 1960s, the application of chemical fertilizer dramatically increased due to the government's encouragement to achieve food self-sufficiency. Fertilizer consumption in the agricultural sector increased five-fold between 1975 and 1990 and continued to increase slightly afterward. However, as a result of the Asian economic crisis, in 1998 the Indonesian government reduced the subsidies for fertilizers, resulting in increasing costs for farmers for agricultural inputs. Since that time, farmers have been reducing the use of chemical fertilizers and have started to utilize more organic fertilizer and improve the methods for its application (Syuaib, 2006).

Public awareness of what "organic agriculture" is and consumer demand for organic crops are currently very low in Indonesia, where the benefits of organic farming are understood by only a few who are concerned about food safety for their own health. Through the efforts of nongovernmental organizations and the government, however, Indonesians have started to become interested in environmentally friendly organic farming (Hsieh, 2005).

Table 3 shows a comparison between organic and conventional farming with regard to soil carbon content and carbon storage. While the soil of an organic farm showed significantly higher soil carbon content than conventional soils after 4 years of continuous farming, there were no significant differences in soil bulk density between the two farming systems. However, soil carbon storage at the organic farm significantly increased compared with that of the conventional farm. Because organic farming showed significantly higher soil carbon storage, it may help not only to establish a sustainable food system in Indonesia but also to mitigate global warming.

As local environmental quality becomes increasingly degraded by agricultural practices, the importance of protecting and restoring soil resources is being recognized by the world community (Lal, 1998, 2001; Barford *et al.,* 2001). Sustainable management of soil received strong support at the Rio Summit in 1992 as well as in Agenda 21 (UNCED, 1992), the United Nations Framework Convention on Climate Change (UNFCCC, 1992), in articles 3.3 and 3.4 of the Kyoto Protocol (UNFCCC, 1998), and elsewhere. These agreements indicate that the world community recognizes the strong

Table 3. Comparison of soil carbon sequestration between organic and conventional rice fields in the top 10 cm of soil

	Soil bulk density (g ml^{-1})	Carbon content (%)	Soil carbon storage (Mg ha^{-1})
Organic	0.88	2.89	25.0
Conventional	0.80	2.22	17.6
Significance	ns	*	**

**,*, and ns indicate significance at the 1% and 5% level and not significant, respectively. Data from Komatsuzaki and Faiz (2009).

linkages between soil degradation and desertification, on the one hand, and loss of biodiversity, threats to food security, increases in poverty, and risks of accelerated greenhouse effects and climate change, on the other. This situation suggests that a global support network is needed to help conserve local environments, such as Indonesia's organic farmlands.

Conclusion

Agriculture dominates land and water usage like no other human enterprise, with agro-ecosystems providing critical products for human sustenance. Farmers, consumers, researchers, and policymakers in many parts of the world have begun to develop and promote sustainable agriculture. However, sustainable farming practices need to be adopted on a much larger scale to achieve the Millennium Development Goals that be set by the United Nations for hunger, poverty, and environmental sustainability in developing countries and to maintain the health of ecosystems in rural areas of industrialized countries. Recent intensive research has revealed that sustainable farming practices can help to mitigate global warming, conserve biodiversity, and maintain soil fertility and productivity. However, these farming practices often do not return enough to farmers directly. Therefore, political and social incentives will be required based on the common understanding that healthy soils and agroecosystems are essential for developing a sustainable society not only at the regional scale but also at the global scale.

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