Chapter 2
Biodiversity Agriculture Supports Human Populations

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Abstract The "Green Revolution" has increased food production to meet world population growth, therefore global food production is at present sufficient to feed all the world's people. However, the modern agricultural system is no longer sustainable due to deterioration of soil conditions. Alternative agricultural methods that aim to conserve biodiversity and soil functioning are not intensively studied, thus the productivity of alternative methods is often not compatible with conventional agricultural practice, and most people are skeptical of the feasibility of introducing alternative methods. Recent advancements in studies of biodiversity and ecological functioning are now supporting early trials by advanced farmers, who respect biodiversity in their fields. In this review, I would like to present some ecological theories to support biodiversity agriculture and its potential to support human populations.

Keywords Above- and below-ground interaction • Conservation tillage • Ecological theory • Food security • Soil conservation

2.1 Introduction

The world produces sufficient food to feed its population, but still there remain more than one billion people who suffer from food insecurity and malnutrition (IAASTD 2009). Agricultural activities are now one of the major factors affecting global environmental change through reducing biodiversity, increasing greenhouse gas (GHG: CO_2, N_2O, and CH_4) emissions and accelerating eutrophication and pollution of aquatic systems. Agriculture's main challenge will be to produce sufficient food and fiber for a growing global population at an acceptable environmental cost.

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To meet the global demand for food without significant increases in prices, it has been estimated that we need to produce 50–110 % more food, in light of the growing impacts of agricultural activities on climate change (Godfray et al. 2010; Tilman et al. 2011). Closing ‘yield gaps’ on underperforming lands, increasing cropping efficiency, shifting diets, and reducing waste can double food production while greatly reducing the environmental impacts of agriculture (Foley et al. 2011). However, most of these discussions are based on the assumption that the agricultural production is sustainable using modern agricultural technology.

Biodiversity loss is obviously a major driving force of ecosystem change (Hooper et al. 2012). Even in the field of agriculture, loss of biodiversity is linked to degradation of ecosystem function. Carbon loss (decomposition), nitrogen mineralization, and leaching are influenced by both land use and soil biota (de Vries et al. 2013). Intensification of agriculture decreases soil biodiversity, thus soil degradation is inevitable under the modern agricultural system. Soil degradation includes physical factors (e.g., decline in soil structure, crusting, compaction, accelerated erosion); chemical factors (e.g., nutrient depletion, elemental imbalance, acidification, salinization); and biological factors (e.g., reduction in soil organic matter (SOM), and the activity and species diversity of soil microorganisms) (Lal 2004). Conserving soil biodiversity and utilizing its ecosystem functioning is beneficial not only for agriculture but also for consumers (Robertson and Swinton 2005). Many ecosystem services are synergistic; for example, soil carbon storage keeps CO_2 from the atmosphere and also promotes soil fertility, soil invertebrate diversity, plant water-use efficiency, and soil conservation (Lal 2004), and these ecosystem services are supported by biodiversity (Hooper et al. 2005)

2.2 Green Revolution and Organic Farming

Green Revolution technology has been criticized for its deficiencies (Swaminathan 2006; Robertson and Swinton 2005). Economists stress that, because market-purchased inputs are needed for production, only resource-rich farmers can take advantage of high-yielding crops. Environmentalists emphasize that the excessive use of fertilizers and pesticides, as well as the monoculture of a few crop cultivars, will create serious environmental problems, including the breakdown of resistance in plants and the degradation of soil fertility by disturbing the stoichiometry.

Organic farming is probably an alternative to modern intensive farming. Organic farming uses organic fertilizers to sustain fertility of soil and reduce chemicals to control pests and weeds. Badgley et al. (2007) argued that the global population can be supported by organic farming. The principal objection to the proposition that organic agriculture can contribute significantly to the global food supply is the fact that organic yields are typically lower than conventional yields (Seufert et al. 2012), necessitating more land to produce the same amount of food as conventional farms. However, when using best organic management practices yields are closer to conventional yields (−13 %). Organic agriculture also performs better under certain conditions—for example, organic legumes or perennials, on weak-acidic to weak-alkaline soils, in rainfed conditions, achieve yields that are only 5 % lower than conventional yields (Seufert et al. 2012).

2.3 Biodiversity, Ecological Functioning, and Ecosystem Services

Recent experimental advancements in biodiversity and ecological functioning were mainly obtained in laboratory microcosms, benthos communities (Cardinale et al. 2012), and model grassland studies (Tilman et al. 2001). Varying component species numbers from one (monoculture) to 16 species (average species richness in natural grasslands in Minnesota), Tilman et al. (2001) showed that plant production was higher with increasing species richness. Increase in species richness heightens the chances of involving functional species (sampling effect; c.a. legumes that fix atmospheric nitrogen thus increase nitrogen resources in soil) and also enhances functional diversity (niche complementarity effect).

Niche complementarity explains the decrease in nitrate nitrogen concentration in soil with increasing plant species richness. The greater the species richness, the more efficiently the plant uptakes nitrogen by root due to complement root depth and morphology compared to monoculture soil.

The longer the experiment continues, the higher the stability of primary production (Tilman et al. 2006b). This is explained by the portfolio effect of different species that respond differently to environmental conditions such as drought, high and low temperature, etc. The ratio of predators to prey in aboveground communities tends to increase with plant species richness (Haddad et al. 2011). Therefore this mechanism also contributes to the stability of primary production. Tilman et al. (2006a) concluded that natural short grass prairie is the most productive for supplying biomass for energy use under no-fertilization conditions.

Organic farming avoids utilization of synthetic fertilizers, chemical pesticides, and herbicides. The recent ecological studies on biodiversity suggest that increasing plant species richness leads to efficient nutrient use, fewer outbreaks of pests and pathogens, and stable yields for a certain period. Some organic farming techniques, such as intercropping, use of companion plants, patchy land use, and also agroforestry all increase plant biodiversity compared to monoculture.

2.4 Soil Sustainability

Modern agricultural practice is degrading soil by accelerating erosion (Montgomery 2004) and disturbing stoichiometry of nutrients essential for human health (Jones et al. 2013). Organic farming is a system aimed at producing food with minimal harm to ecosystems, animals, or humans. Intensive cultivation, on the other hand, always damages soil biodiversity. Not surprisingly, therefore, comparisons of soil biodiversity in conventional and organic farming showed that conventional farming had been more damaging (Altieri 1999; Chappell and LaValle 2009; Gomiero et al. 2011). Conservation tillage offers an alternative approach involving soil management practices that minimize the disruption of the soil's structure, composition, and natural biodiversity, thereby minimizing erosion and degradation, and water contamination (Holland 2004).

Soil carbon is a good indicator of soil functions. The following technologies should be considered to increase C sequestration in cropland soil: no- and reduced-tillage; residue mulch and cover crops; integrated nutrient management; and biochar used in conjunction with improved crops and cropping systems (Lal 2009). However, biodiversity both above- and belowground also plays an important role in increasing soil carbon. High-diversity mixtures of perennial grassland plant species stored 500 % and 600 % more soil C and N than, on average, did monoculture plots of the same species during a 12-year-long grassland experiment (Fornara and Tilman 2008).

Soil aggregate stability depends on plant community properties, such as composition of functional groups, diversity, and biomass production. Soil aggregate stability increased significantly from monocultures to plant species mixtures (Pérès et al. 2013). Root-derived carbon (C) is preferentially retained in soil compared to aboveground C inputs, and microbial communities assimilating rhizodeposit-C are sensitive to their microenvironment. There was ten times more labeled microbial-C (derived from living roots) in the rhizosphere compared to non-rhizosphere soil (Kong and Six 2012). Weeds are considered to be useless in agricultural soil. However, keeping living roots, even of weeds, can enhance microbial activities in soil.

2.5 Soil Biodiversity and Its Functioning

Producing enough food with fewer effects on the environment requires a radical shift in thinking by the agricultural and environmental communities.

Plants are competing neighbors in terms of both shoots and roots. Wild plants are stronger competitors for below-ground resources than are crop plants (Kiaer et al. 2013). However, some Japanese advanced farmers have been successfully growing crops with weeds in their croplands. Introducing weeds as living mulch increases plant biodiversity including crop species. The farmers reduced tillage and fertilization, and no chemical pesticides are sprayed. All these practices enhance not only the aboveground biodiversity of both plants and insects but also soil biodiversity due to less soil disturbance, and increase the amount and diversity of resources for soil organisms. These farmers slash weeds several times during the crop-growing season, thereby reducing aboveground competition between weeds and crops. Adopting these practices is expected to increase soil biodiversity.

Experimental introduction of no-tillage with weed management rapidly changed the soil microbial community and soil carbon sequestration. Our trial in Sumatra, Indonesia, compared tillage, and no-tillage with a combination of bagasse mulch, in a sugarcane plantation, where productivity of sugarcane had been declining during 30-years of continuous cropping after clear-cutting the forest. All weeds at tillage treatments were suppressed by herbicide, whereas those at no-tillage treatments were hand picked. Soil fungal community structure clearly reflected the treatment one-year after beginning the experiment, and there was an increase in soil carbon content (Miura et al. 2013).

Converting from conventional practice to no-tillage with weed mulch efficiently increased the soil carbon pool despite the carbon input to the soil being very small compared to standard manure application in Japan (Arai et al. 2014).

2.6 Conclusion

Comparison of conventional practice and no-tillage with weed mulch shows a contrast, especially in terms of soil biodiversity (Fig. 2.1). There is a growing body of theoretical and empirical studies on the capacity of biodiversity within cropland to improve both stability in production and synergetic effects on production, and to reduce crop loss due to pests and pathogens. These studies are suggesting that ecological analysis is urgently needed to support a novel sustainable cropping system that will support and be supported by biodiversity other than crop plants.

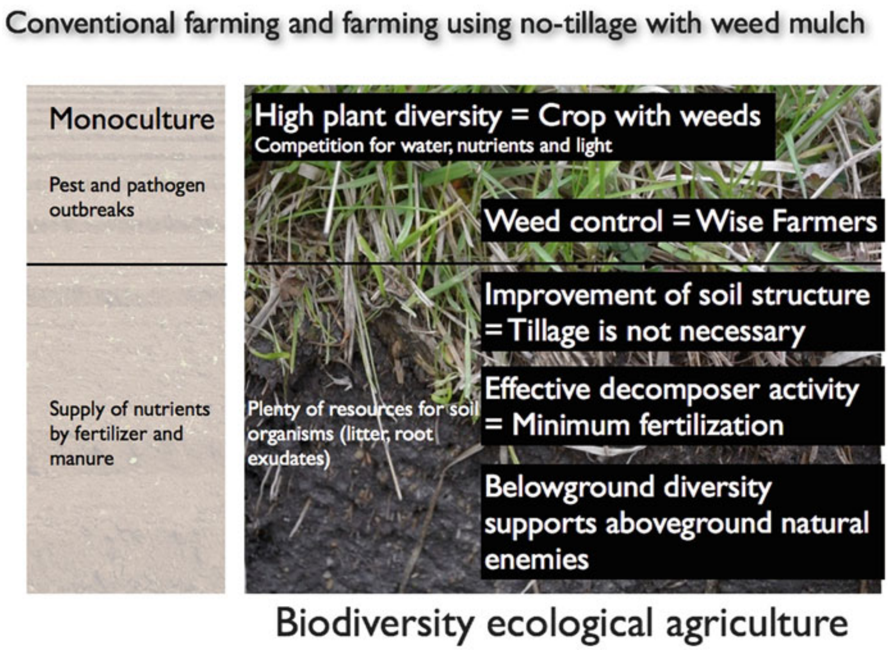

Fig. 2.1 Conventional farming and farming using no-tillage with weed mulch

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