3 Ecological Intensification: A Step Towards Biodiversity Conservation and Management of Terrestrial Landscape

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Abstract

The current model of agricultural intensification has increased crop yields and profits for farmers. However, this increase takes place by significant loss of biodiversity as well as ecosystem services, which has become a global concern. In agricultural landscapes, biodiversity loss impairs the functionality of ecosystem in the form of pollination, natural pest control, habitat provision and water purification. In order to restore biodiversity along with maintaining agricultural production, there is need for farmers to switch to a novel farming approach that can optimize ecosystem functions and enhance crop yields. Reports reveal that ecological intensification has potential to ameliorate environmental externalities while preserving crop yields and profitability. To intensify ecological processes in agricultural landscapes, a potential strategy is to employ management practices that reduce or substitute synthetic agrochemical use, maintain or enhance landscape heterogeneity and connectivity. Intensification of eco-friendly nature may be achieved by wildlife-friendly approaches in the form of organic farming, conservation farming, agroforestry, integrated pest management and intercropping. However, lack of comprehensive information on the net benefits of ecological intensification farming practices is currently preventing widespread adoption by farmers. To increase uptake, it is critical that scientists address not only the ecological facets of biodiversity-friendly farming practices but also the economic and social facets.

Keywords

Agricultural intensification · Agroforestry · Biodiversity · Conservation agriculture · Ecological intensification · Intercropping · Organic agriculture

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Abbreviations

IPM	Integrated Pest Management
GMOs	Genetically Modified Organisms
NGO	Nongovernmental Organization
SOM	Soil Organic Matter

3.1 Introduction

The conservation of biodiversity in terrestrial landscapes is a key linchpin for combatting the triple Anthropocene challenge of declining biodiversity, climate change and land degradation. Biodiversity is the variety of all living organisms or species within ecosystems and is important for ecosystem functioning. The current best estimate is that there are roughly 8.7 million living species on the planet (Mora et al. 2011). Biodiversity provides many valuable services to the ecosystem and human well-being such as food, income, natural pest control, pollination and water quality (Banerjee et al. 2020; Raj et al. 2020). Together these services have been estimated to be worth over US$125–145 trillion per annum (Costanza et al. 2014).

Globally, the issue of biodiversity loss is of concern given that it will negatively affect ecosystem services that are important for the survival of mankind (Wagg et al. 2014; Jhariya et al. 2019a, 2019b). Across the globe, humankind has intervened tremendously into the natural succession of ecosystems. A large portion (about 40%) of terrestrial landscape has been converted into agriculture globally (Fahrig et al. 2011), making farmers the largest group of ecosystem managers on earth. Currently, farmers are faced with a huge challenge of producing enough food to global population of 9–12 billion till 2050 while reducing the adverse consequences of cultivation towards environment (HLPE 2017; Meena et al. 2018). To meet the ever increasing demand for agricultural products, farmers may be forced to convert more forestland into agricultural production or employ agricultural intensification farming methods on the existing agricultural land, which is likely to increase damage to the environment. There are divergent opinions on how farmers can safeguard loss of biodiversity caused by agriculture. Some have advocated for the adoption of an intensive farming system that should be practiced on small areas, sparing forestland from conversion to farmlands. Other believes that farming and biodiversity conservation can coexist on the same piece of land (Bommarco et al. 2013; Tscharntke et al. 2012; Vongvisouk et al. 2016).

Crop field size enlargement, increased use of agrochemicals, monoculture and reduction in landscape heterogeneity have caused a significant loss of biodiversity (Emmerson et al. 2016; Landis 2017; Pretty 2018; Meena and Lal 2018). Many arable landscapes face pollution by agrochemicals which negatively affect biodiversity and associated ecosystem services on which agriculture depends. Research reports suggest that effective conservation of biodiversity in agricultural sector can be stimulated through reducing fertilizers and pesticides inputs as well as increasing crop diversity and landscape heterogeneity (Gonthier et al. 2014; Sanchez-Bayo and Wyckhuys 2019). A farming system that is ecologically based creates an opportunity for the establishment of a resilient agro-ecosystem, which allows farmers to increase crop yields without exerting loss to biodiversity (Bommarco et al. 2013; Kleijn et al. 2018; Kumar et al. 2020).

3.2 Agricultural Intensification and Biodiversity Conservation

Agricultural intensification considers cultivation practices that rely on high inputs to obtain maximum yield per hectare of crops or livestock. It is often pointed as a strategy for reducing agricultural encroachment into forests. Before the industrialization of agriculture in the 1960s, the most common strategy to increase agricultural production was to clear natural vegetation to expand agricultural land (Tilman et al. 2001, 2002). As human populations increased and arable land dwindled, the novel approach was to maximize the agricultural output on the existing agricultural setup supported by higher inputs. The continued expansion of agricultural land is causing shrinkage of natural habitats (Benton et al. 2003; Meena et al. 2020a, b). Where remnants of natural or semi-natural habitats exist in agro-ecosystems, they support less biodiversity because of increased habitat fragmentation and isolation as well as agrochemical drifts in crop field edges (Egan et al. 2014; Landis 2017). Heavy uses of pesticides and pesticide drift have a risk of limiting organisms that are beneficial to the farmer. Empirical evidence shows that pollinators are reduced in agricultural landscapes with heavy use of agrochemicals (Potts et al. 2010; Kennedy et al. 2013; Shackelford et al. 2013). In agro-ecosystems, pollinators provide important ecosystem services to flowering crops and wild plants.

Agricultural intensification is featured by high usage of agrochemicals per unit area, increased mechanization and soil tillage, reduced landscape heterogeneity, and low crop diversity (Fig. 3.1). There are some reports indicating that in the past 50 years, irrigated land area doubled, the use of fertilizers increased sevenfold and global food production more than tripled, reducing world hunger (Foley et al. 2011; Tilman et al. 2011). However, the increase in global food production was at the expense of biodiversity loss (Tscharntke et al. 2005). Agricultural intensification is one of the factors responsible for loss of biodiversity, including birds (Donald et al. 2006; Mineau and Whiteside 2013; Traba and Morales 2019), vascular plants (Storkey et al. 2012), invertebrates (Medan et al. 2011) and soil organisms (Wagg et al. 2014).

In high-input farming systems, the heavy dependence and overuse of agrochemicals may cause damage the various beneficial organisms (Catarino et al. 2015). The leakage of fertilizer from intensively managed conventional farms pollutes surface waters and causes damage to aquatic organisms (Geiger et al. 2010; Beketov et al. 2013). As a result of pollution from fertilizers, algal blooms proliferate in nutrient-loaded water bodies, causing damage to freshwater biodiversity (Kibria et al. 2013). Many agrochemicals drift far from the point of application,

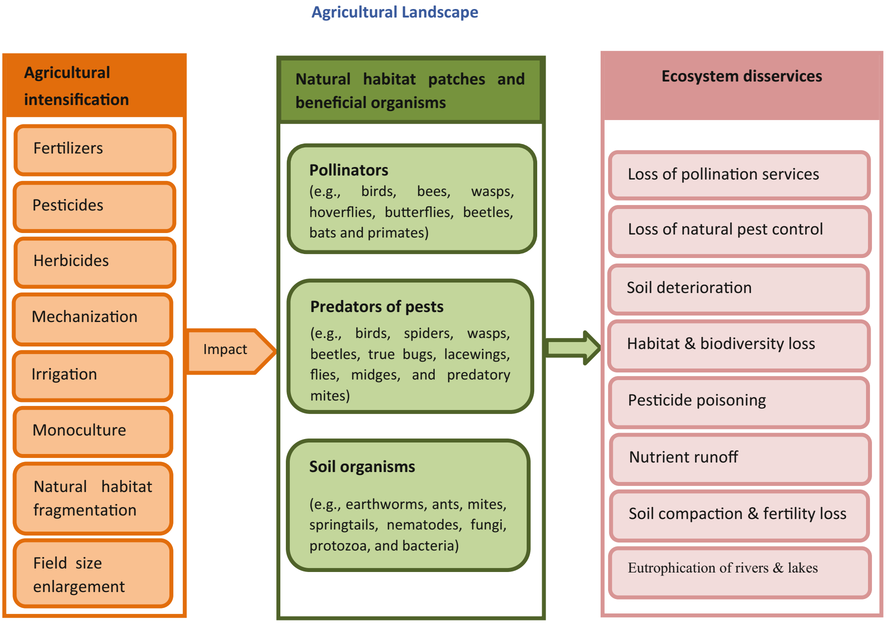

Fig. 3.1 The impact of agricultural intensification on organisms beneficial to farmlands and the associated ecosystem disservices

causing damage to non-target organisms (Martín-López et al. 2011; Egan et al. 2014; Chagnon et al. 2015). Herbicides such as atrazine are endocrine disruptors that can cause reproductive problems in mammals, amphibians, and fish. Wildlife poisoning by highly toxic pesticides can cause substantial decline in species populations including rare ones. Many bird species are directly affected by poisoning from broad-spectrum pesticides such as organophosphates, carbamates and anticoagulant rodenticides (BLI 2008; Mitra et al. 2011). Birds get their exposure by consuming seeds contaminated with pesticides. Broad-spectrum herbicides tend to work for reduction of weeds and insect population which is actually the food material for birds. Furthermore, beneficial insects such as bees, spiders and beetles are negatively affected by broad-spectrum insecticides. In agro-ecosystems, predatory mammals and raptors are often indirectly poisoned by anticoagulant rodenticides. Wildlife habitats can be altered by the application of herbicides, which in turn threaten the survival of predatory mammals. Pesticides can reduce the abundances and activities of earthworms, symbiotic mycorrhizae, and other soil-dwelling organisms (Meena et al. 2020).

Global concern of agro-ecosystem services is the matter of great concern as it may reflect reduced functioning as biodiversity continues to decline due to continued use of biodiversity-unfriendly farming practices (Power 2010). The most affected ecosystem services are biological pest control (Bengtsson 2015), crop pollination (Deguines et al. 2014), biogeochemical cycling and health of soil (Matson et al.

1997). Monoculture is another common feature of intensive agriculture which provides a uniform range of habitats that are colonized by a limited range of species. To prevent loss of ecosystem services due to agricultural intensification, there is need to search for a novel farming system that is ecologically based.

3.3 Ecological Intensification and Biodiversity Conservation

The conventional farming system remains primarily driven by the 'intensification' of external inputs to increase yield and sustain food requirements of the world's growing population (Norton et al. 2009). There are varying ideas on how to increase crop yield and farmers' profits without encroaching further into natural areas or causing loss to biodiversity. Some believe that agricultural intensification can make farming more efficient and productive on limited land area while others believe that it must be replaced with a system that is environmentally friendly. Since the agricultural intensification model is not compatible with biodiversity conservation goals, scientists are advocating for a transition to agro-ecological intensification (Bommarco et al. 2013; de Molina and Casado 2017; Cui et al. 2018; Garibaldi et al. 2019). Ecological intensification refers to a farming system that relies on local rather than external inputs (e.g., agrochemicals) to increase yield while maintaining or enhancing biodiversity and ecological functions (Bommarco et al. 2013; Cassman 1999; Garibaldi et al. 2019). Various bioresource-enhancing farming practices already exist (Fig. 3.2) and, if widely adopted by farmers, they have potential to reverse the damage to the environment caused by conventional farming.

A principal question is whether the ecological intensification approach can 'erase' the ecological footprints of agricultural intensification, while meeting food production needs. As already highlighted by Kovács-Hostyánszki et al. (2017), this approach is surrounded by uncertainties, largely stemming from inadequate information on how to implement it, whether an individual farmer can realize positive net economic benefits and the unpredictability of natural systems. Ecological intensification relies on natural systems such as the use of organic fertilizers (e.g., livestock manure and compost), pollinators, natural pesticides and natural enemies of crop pests. Currently, there are differences between scientists and farmers in the way they perceive potential benefits of ecological intensification. Scientists believe that ecological intensification can replace the expensive external farm inputs with ecosystem services but there is lack of evidence to prove that it can increase yield and farmer's profits. In the absence of motivating factors such as increases in yield and profitability or receiving financial support to conserve biodiversity, it is unlikely that farmers will radically change their way of farming (Pannell 2003; Schoonhoven and Runhaar 2018). Some governments and international conservation NGOs have schemes designed to incentivize farmers to implement biodiversity-friendly farming techniques. For example, schemes such as paying farmers for environmental services (PES) provide incentives to farmers for adopting land management techniques that can reduce negative impacts on biodiversity.

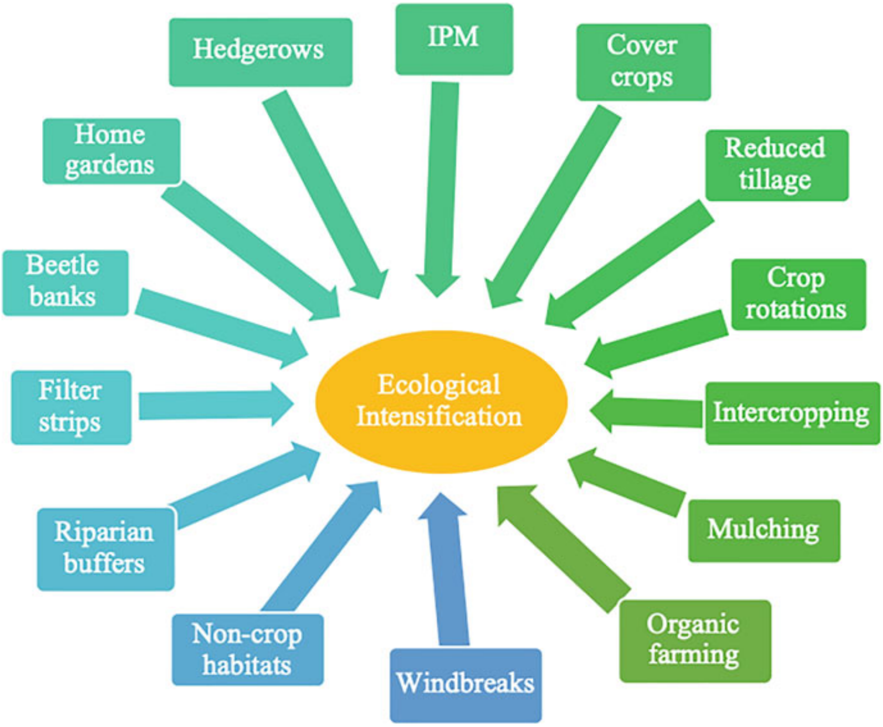

Fig. 3.2 Farming techniques that can intensify ecological processes in agricultural landscapes

Although farmers are slow in adopting the idea of ecological intensification, many scientists believe that maintaining high biodiversity in agricultural landscapes makes farming more sustainable. Biodiversity-friendly farming practices enhance the provision of ecosystem services (Bommarco et al. 2013; Singh and Jhariya 2016; Jhariya et al. 2015, 2018). There are several farming practices that can support farmland biodiversity including various eco-friendly practices (Fig. 3.2).

3.4 The Role of Biodiversity in Agricultural Landscapes

It has been suggested that wildlife-friendly farming practices make ecosystem service delivery more stable (Yachi and Loreau 1999; Isbell et al. 2017). In agro-ecosystems, biodiversity conservation is important in terms of ecological function and process like biogeochemical cycling, soil fertility, erosion and pest control, water quality, carbon sequestration, habitat provision for wildlife, wood and recreation (Table 3.1). There is a large pool of organisms hidden below-ground in soils (Wagg et al. 2014) whose diversity and abundance are altered by farming activities. Soil microorganisms help to maintain soil health and crucial to farming. The arthropod community is another group of wildlife that is beneficial to farmers for

Table 3.1 Examples of ecosystem services provided by biodiversity in agricultural landscapes (Source: Garibaldi et al. 2011; Garbach et al. 2014)

Ecosystem services	Definition	Examples
Regulating services	Ecosystem process regulation	•Erosion control •Flood control •Pollination •Pest control •Wildlife habitat •Water purification •Carbon sequestration •Habitat connectivity •Wind breaks •Microclimate
Provisioning services	Provisioning services relate to products obtained from the ecosystem	•Food •Fibre •Fuel •Forage •Medicines •Ornamental products •Genetic resources
Supporting	Supporting services mean aiding activity for smooth functioning of ecosystem	•Nitrogen fixation •Nutrient cycling •Soil formation and retention •Water cycling •Oxygen production
Cultural	Ecosystem's non-tangible benefits	•Aesthetic landscapes •Recreation •Shade •Sport (game hunting) •Sounds from birds •Scent from plants •Spiritual experience

their importance in nutrient cycling, seed dispersal, pest control, pollination and maintaining soil structure and fertility (Thorbek and Bilde 2004; Scudder 2009). Additionally, they are an important food source for other taxa including farmland birds.

Crop production is supported by ecological functions operating the ecosystem (Winfree et al. 2015; Kovács-Hostyánszki et al. 2017). Pollination services are special to farmers and a wide range of crops grown for human consumption are pollinator-dependent (Klein et al. 2007; Garibaldi et al. 2011; Deguines et al. 2014).

There are more than 100,000 species of pollinators which include bees, butterflies, beetles, birds, flies and bats. Garibaldi et al. (2011) conducted meta-analysis and found a decreasing in pollination services due to isolation from non-cropped habitats which clearly reveals the importance on farmlands.

It is estimated that globally pests damage 1/third of crop productivity yearly (Oerke 2006). This makes regulation of pest population as a significant ecological function in agro-ecosystem since it has the potential to reduce pesticides consumption. Enemies of natural pests are many and include birds, insects (e.g., ladybugs, parasitic wasps and flies), spiders, fungi, pathogens and many other types of organisms. Such biological controls help to reduce the costs of protecting crops and the need for pesticide use.

3.5 The Impact of Integrated Pest Management on Biodiversity and Ecosystem Services

Integrated Pest Management (IPM) aims to control pests, weeds and diseases by relying upon natural enemies rather than the extensive use of synthetic pesticides. Biological pest control is one of the IPM tactics that involves using natural enemies of crop pests such as insect predators, parasitoids or pathogens to suppress pest populations (Hokkanen 2015; Xu et al. 2017). IPM is designed to reduce the negative ecological impacts from over and improper use of synthetic pesticides which in turn helps to maintain or enhance biodiversity (Table 3.2). Although IPM emerged more than seven decades ago, adoption by farmers is still low (Parsa et al. 2014; Pretty and Bharucha 2015).

One interesting example of IPM is the 'push-pull' system which involves growing multiple crops on the piece of land (polyculture) for purposes of protecting crops from pest infestation (Xu et al. 2017; Hassanali et al. 2008). The said approach uses plants that repel insect pests ('push') and plants that attract the pests away from the crop ('pull'). As illustrated in Fig. 3.3, Napier grass (*Pennisetum purpureum*) is often planted by smallholder farmers in East Africa around the edges of crop fields to attract the moths, pulling them away from the main crop (Khan et al. 2011; Pickett

Table 3.2 Examples of IPM strategies that can intensify ecological processes on farmlands

IPM strategy	References
1. Substituting chemical pesticides with bio-pesticides	Pickett et al. (2014)
2. Controlling pesticide applications (e.g., targeted spraying)	Pretty and Bharucha (2015)
3. Breeding crops or livestock with traits that can resist attack by pests, parasites and pathogens	Pretty and Bharucha (2015)
4. Releasing natural enemies of pests (parasitoids and predators) to control pest populations	Hassanali et al. (2008), Khan et al. (2011)
5. Deploying sticky and pheromone compounds to trap pests	Xu et al. (2017)
6. Using crop rotations and crop diversity to limit pests and diseases	Pretty and Bharucha (2015)
7. Using the push-pull system to drive-off pests from crops	Hassanali et al. (2008)

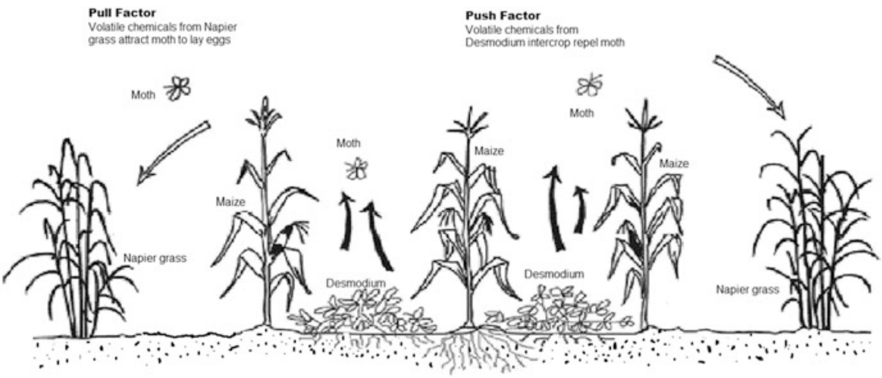

Fig. 3.3 The push-pull system (Adapted from Pickett et al. 2014)

et al. 2014). The farmers also intercrop legumes such as *Desmodium* with cereal crops (maize, millet and sorghum) to control pests as well as fixing nitrogen, which can be up to 100 kg N ha^{-1} $yr.^{-1}$ (Khan et al. 2011). *Desmodium* releases volatile chemicals that repel stem borer moths (push) and attract natural enemies of moths and parasitic wasps (pull). The push-pull system allows farmers to control pests and erosion, enhance soil fertility and reduce synthetic pesticide use. *Desmodium* can be used as fodder for livestock or can be sold to gain income (Hassanali et al. 2008).

3.6 The Impact of Organic Agriculture on Biodiversity and Ecosystem Services

Organic farming aims to increase soil health by nutrient use efficiency and other resources along with application of synthetic pesticides (IFOAM 2008; FAO 2015). Synthetic pesticides are substituted with bio-pesticides which include the use of microbes, entomophagous nematodes, plant-derived pesticides, antibiotics, insect pheromones, and fungal and viral attacks (Copping and Menn 2000). On organic farms, soil fertility is enhanced through the use of environmentally friendly farming systems such as crop rotation, intercropping, polyculture, covering crops and mulching. Weeds are controlled by employing a variety of techniques such as appropriate rotations, timing of seeding, mechanic cultivation, mulching, transplanting and flaming. Soil C concentrations are reported to be more elevated on organic than non-organic crop fields due to greater accumulation of soil organic matter from crop residues, cover crops, manure and compost (Gattinger et al. 2012). Organic farming is wildlife-friendly due to the non-use of chemical pesticides and fertilizers (Norton et al. 2009) and its wide uptake by farmers can benefit a range of taxa (Hole et al. 2005; Bengtsson et al. 2005; Gattinger et al. 2012; Tuck et al. 2014).

A meta-analysis conducted by Tuck et al. (2014) indicates that there is on average 30% higher species richness on organic farms than on conventional farms. Empirical evidence suggests that organic farming generally has a positive influence on richness and diversity of plants (Fuller et al. 2005; Gabriel et al. 2006), invertebrates (Holzschuh et al. 2008; Rundlöf et al. 2010), birds (Smith et al. 2010), soil microbes (Oehl et al. 2004; Verbruggen et al. 2010) and activity density of small mammals such as wood mouse, bank vole and common shrew (Wickramasinghe et al. 2003; Hole et al. 2005). Some studies have shown a higher abundance of birds on organic farms that on conventional farms, which could be attributed largely to an increase in the availability suitable habitats on organic farms (Santangeli et al. 2019; Hole et al. 2005). Plant diversity was also found to be higher in field margins (Rundlöf et al. 2010) and hedges (Aude et al. 2003) adjacent to organically managed crop fields compared to adjacent to conventionally managed crop fields. In conventional farming, the use of herbicides is known to reduce non-crop plant diversity in both arable lands (Winqvist et al. 2011; Schneider et al. 2014) and adjacent habitats (Aude et al. 2003; Rundlöf et al. 2010). Some studies have demonstrated that pollinating arthropods (e.g., bees, hoverflies and butterflies) and true bug communities have higher species richness on organic farms than on conventional farms (Holzschuh et al. 2008; Andersson et al. 2013; Birkhofer et al. 2015; Rundlöf et al. 2016). Furthermore, the presence of farmscape plantings (e.g., hedgerows, windbreaks and filter strips) and the absence of drifting pesticides and herbicides on organically managed farms attract new or re-colonizing species.

Although organic farming is beneficial to farmland biodiversity (Tuck et al. 2014), the major criticism is that it has lower productivity than conventional agriculture (Hodgson et al. 2010; Pickett 2013; Ponisio et al. 2015; Pittelkow et al. 2015; Röös et al. 2018). Studies by Seufert et al. (2012) and Ponisio et al. (2015) revealed that organic farms have on average 19.2% less yield compared to conventional farms. Recently, Knapp and van der Heijden (2018) found relative yield stability (temporal variation per unit yield produced) on organic farms to be significantly lower than on conventional farms. Opponents of organic farming have argued that it requires traditional practices for food production, and may threaten the world's natural habitats if adopted on large scales (Trewavas 2001, 2002; Avery 2006; Pickett 2013). Organic farming can result in reduced crop yields due to crop-weed competition, herbivory and diseases (Pittelkow et al. 2015; Knapp and van der Heijden 2018). Pest and weed control is a challenge in organic farming where agro-chemicals are not used. It is also a huge challenge in the absence of selection for traits such as resistance to diseases, enhanced interaction with plant symbionts and superior weed suppressing abilities (Knapp and van der Heijden 2018; Ponisio et al. 2015). On organic farms, pest control is achieved by using appropriate cropping techniques such as polyculture, natural pesticides and biological control. Weed control is managed by a wide range of techniques including rotations, timing for seeding, mechanic cultivation, mulching, transplanting and flaming (Gomiero et al. 2011).

3.7 The Impact of Agroforestry on Biodiversity and Ecosystem Services

Agroforestry, broadly defined as the integration of woody plants into farming systems is important for food insecurity, income generation and the conservation of biological diversity (Tscharntke et al. 2011; Kuyah et al. 2016; Barrios et al. 2018; Raj et al. 2019a, 2019b). Many smallholder farmers maintain or integrate trees into the farming system for the provision of fuelwood, food, fodder and shade (McNeely and Schroth 2006). The presence of trees on farmlands has been reported to decrease pest abundance (Guenat et al. 2019). Trees provide habitat for a variety of species including pollinators such as bees that would not be able to survive in a landscape with only annual crops (Ricketts et al. 2008; Pumariño et al. 2015). For peasant farmers who depend largely on the natural environment for inputs, more pollinators can increase mean yields (Garibaldi et al. 2016). Trees also provide favourable habitats for soil biota beneath their canopies through microclimate buffering and continuous supply of litterfall inputs which positively influence the activity of soil organisms (Kamau et al. 2017; Barrios et al. 2018).

Agroforestry practices maintain or increase landscape connectivity and heterogeneity, which is essential for the conservation of biological diversity. For example, smallholder farmers in Africa deliberately select and protect valuable indigenous trees located in their crop fields or set aside non-cropped areas that are managed as biodiversity conservation areas (Boffa 1999). Some authors have reported high levels of woody species diversity in agroforestry systems in Africa and Central America (Michon and de Foresta 1995; Khan and Arunachalam 2003; Schroth et al. 2004). Home gardens as a form of agroforestry are considered to be the richest in plant species diversity per unit area (Galluzzi et al. 2010; Kumar and Nair 2004). A home garden is a parcel of land set aside around a homestead where individual households grow a variety of plants including woody species for family consumption. These gardens are a source of many products including food, fodder, fuelwood, medicines, herbs, flowers, construction materials and income (Kumar and Nair 2004; Gbedomon et al. 2017). Due to their abundant litter and good plant cover, multistorey home gardens help to reduce soil erosion especially on sloppy areas (Kumar and Nair 2004; Agbogidi and Adolor 2013).

Estimates by Kim et al. (2016) show that trees in an agroforestry system have potential to sequester annually about 27.2 tons CO_2 eq per ha during the first decade of establishment. Trees in agricultural landscapes help to control soil erosion, floods and pests (Jose 2012; Mbow et al. 2014). The application of leguminous trees in agroforestry can increase crop yields (Branca et al. 2013) but if tree density is too high, crop yields can be affected negatively as crops compete with trees for nutrients, light and water. Empirical evidence shows that isolated trees in agroforestry systems can increase soil organic carbon and nitrogen beneath canopies (Pardon et al. 2017; Bayala et al. 2018), largely attributed to the ability of trees to retrieve nutrients from deeper soil horizons and deposit them on soil surface layers via litterfall inputs (Mlambo et al. 2005; Acharya and Kafle 2009). Trees in agroforestry systems have a positive impact on soil microbes that are responsible for litter decomposition and mineralization of organic matter. Agroforestry practices can support beekeeping (Hill and Webster 1995) which in turn can enhance pollination service that is required to increase crop yield and profitability (Alam et al. 2014).

Farmscape plantings (e.g., hedgerows, windbreaks and woodlots) are common in many agricultural landscapes. Since these plantings are less disturbed than cropped areas, they provide favourable habitats for a variety of wildlife, including natural enemies of crop pests and pollinators (Hannon and Sisk 2009; Morandin and Kremen 2013; Sardiñas and Kremen 2015). Hedgerows planted along field edges protect insects that are sensitive to pesticide drift from neighbouring crop fields (Kjaer et al. 2014). Farmscape plantings create natural places for birds and beneficial insects, and can provide valuable corridors for a wide variety of wildlife. Some studies have reported that birds can be effective on farms in controlling pest insects and in eating significant amounts of weed seeds (Railsback and Johnson 2014). Farmscape plantings also control erosion and water run-off from agricultural fields, which help to reduce the amount of nutrients, pesticides and sediments washed from agricultural land to waterways (Philips et al. 2014). Some farmers plant beetle banks (perennial bunchgrass plantings within fields or on field edges) to provide shelter for crop damaging enemies (Macleod et al. 2004). Beetle banks are important refugia for predacious ground beetles that prey upon multiple crop pests including caterpillars, slugs and snails.

3.8 The Impact of Conservation Agriculture on Biodiversity and Ecosystem Services

Conservation agriculture aims to increase crop yield and profits while preserving the environment (Corsi et al. 2012). Conservation tillage, permanent covering of the soil surface by crop residues or cover crops and crop rotations are the key components of conservation agriculture (Pittelkow et al. 2015; Busari et al. 2015; Knapp and van der Heijden 2018). Cover crops are crops planted to enrich the soil and capture inorganic N. Conservation tillage leaves at least 30% of the soil surface covered with crop residues after planting to reduce soil erosion (Busari et al. 2015). The protection of soil from erosion is important because soil contains a wealth of biodiversity which can exceed 1000 species m^{-2} of soil surface. There are several conservation tillage practices which include no-tillage, reduced tillage and mulch tillage. No-tillage means cultivating land with little or no soil disturbance, the only disturbance being during planting. In reduced tillage, ploughing is done by primary implements to reduce the level of soil manipulation. Mulch tillage involves leaving plant residues permanently in the field during land preparation or planting to cover soil surface.

A number of studies indicate that conservation farming enhances soil quality, natural pest control, soil carbon sequestration and supports a range of soil biodiversity (Hobbs et al. 2008; Pittelkow et al. 2015; Briones and Schmidt 2017). Conservation tillage systems minimize crop residue disturbances and soil loss by wind and water. Crop residues remaining on the soil surface in zero or reduced tillage systems provide a protective environment and food to a wide range of wildlife (Morris et al.

2010). Reduced tillage provides better wildlife habitats because fewer nests are destroyed by farm machinery. Soil tillage can cause disturbances to organisms by injuring, killing, forcing them to migrate, or exposing them to predation (Roger-Estrade et al. 2010). Generally, earthworms are more abundant in reduced tillage systems than under deep inversion tillage (Boatman et al. 2007) because the later buries earthworm food sources and destroys burrows. Jiang et al. (2011) mentioned that deep inversion tillage generally reduces total soil microbial biomass including fungal biomass which is affected by the destruction of fungal hyphal networks. Least tillage enhances organic materials into the soil and the activity of soil organisms in the uppermost soil layer (Gattinger et al. 2012; Mäder and Berner 2012; Cooper et al. 2016; Puerta et al. 2018). This may increase water infiltration rates, aggregate soil stability and soil nutrient cycling (Bender and Van Der Heijden 2014). In a study conducted by Wang et al. (2016) in the dryland of northern China, conservation tillage increased the abundance and diversity of soil bacteria of the genus *Bacillus*. Natural pest control is reported to be higher in reduced tillage than in conventional tillage systems due to higher abundance of pest predators in the former than in the later (Tamburini et al. 2016).

A major drawback of zero or reduced tillage practices is a potential reduction in crop productivity. Cooper et al. (2016) showed decreased crop productivity by an average of 7.6% in reduced till organic systems compared to conventional tillage systems. Zikeli and Gruber (2017) reported 67% reduction of winter wheat yields in organic reduced tillage system compared to organic inversion tillage system due to reduced mineralization and increased weed pressure. Although reduced tillage farming is biodiversity-friendly, uptake by farmers has been low due to concerns about increased weed pressure and low crop productivity (Mäder and Berner 2012; Zikeli and Gruber 2017). While zero or reduced tillage can save farmers' tilling costs, it requires more herbicide use (Soane et al. 2012). Empirical evidence shows that weed pressure is greater in reduced than in deep inversion tillage system (Légère et al. 2011). Cover crop application in no-till or reduced tillage systems provides cover, nesting areas and food to wildlife. Cover crops can suppress weeds through competition for light and soil resources. In the American Upper Midwest, Silva (2014) reported a significant reduction in weed pressure following the use of rye cover crop in organic no-till crop production system. Although cover crops can reduce annual weed growth in the subsequent crop, the control of perennial weeds remains a challenge. Some studies have reported lack of positive effect as shown by reduction in weed infestation (Blanco-Canqui et al. 2015; Batary et al. 2015; Venter et al. 2016). Although cover crops can improve soil structure and reduce soil erosion, they have a disadvantage of competing with the primary crop for resources.

On organic farms, where use of synthetic herbicides is forbidden, diversified crop rotations may be used in combination with reduced tillage to suppress weeds (Cooper et al. 2016). Crop rotation is the sequential planting of individual crops through time, reducing the reliance on chemical fertilizers, pesticides and herbicides. Diversified crop rotations and appropriate timing of management interventions can disrupt life cycles of many weed species and pests (Bàrberi 2002; Smith et al. 2008; Tiemann et al. 2015). Growing different kinds of crops in recurrent succession on the same land can increase soil fertility particularly when nitrogen fixing plants are used in rotations (Smith et al. 2008; Tiemann et al. 2015). Diversified crop rotations produce a diversity of plant litter, which in turn can support a greater diversity of decomposers. In a meta-analysis of 122 studies conducted by McDaniel et al. (2014), crop rotations increased microbial biomass by an average of 21%, which may be attributed to increased plant diversity, ground cover and organic materials in soil (Zak et al. 2003; Venter et al. 2016). Microbial decomposers play an important role in the formation of soil organic matter, which is a source of nutrients for plants. Soil organic matter binds the soil into clumps, preventing soil erosion and improving soil structure and water storage capacity.

3.9 The Impact of Intercropping on Biodiversity and Ecosystem Services

Intercropping involves the growing of two or more crop species on the same piece of land, and the species have to coexist for some time. Although intercropping is often placed on the fringes of conventional agriculture, it has potential to increase yield stability, reduce pests and weed pressure as well as maintain or increase soil fertility (Letourneau et al. 2011; Beizhou et al. 2012; Boudreau 2013). Previous studies have reported that the frequency of disease occurrences in intercrop systems is reduced by 30–40% compared with crop monocultures (Finch and Collier 2012; Brooker et al. 2015; Bybee-Finley and Ryan 2018). A review of more than 200 studies by Boudreau (2013) found that disease incidences were reduced on average by 73% in intercropped systems compared to their respective monocultures. Another review study by Letourneau et al. (2011) revealed that intercrop systems can support greater abundance of natural enemies of pests compared to monocultures, which may help to reduce crop damage in the former. In a recent meta-analysis, weed biomass was found to be 56% higher in non-weeded monoculture fields than in non-weeded intercropped fields (Verret et al. 2017).

3.10 Ecological Intensification and Its Role towards Management of Terrestrial Landscape

Nearly one-third of terrestrial land is under cropland and planted pastures. Field size enlargement and the removal of natural or semi-natural habitats as well as the use of agrochemical inputs in farming landscapes caused significant reduction of bio-resources and ecological functions (Redlich et al. 2018). On farmlands, amount of non-cropped habitats (e.g., hedgerows, woodlands, and permanent grasslands and pasture) is often used as a surrogate measure of landscape heterogeneity or complexity (Tscharntke et al. 2005). The major role of ecological intensification in the terrestrial landscape is to maintain or restore natural or semi-natural habitats, enhance habitat quantity and quality, species diversity and soil health as well as protect water resources (Table 3.3). Empirical evidence shows that in

Table 3.3 Ecological roles of non-cropped habitats on farmlands

Ecological roles	References
Maintain terrestrial landscape diversity	Tscharntke et al. (2005)
Reduce pesticide use: Exploit pest predators and parasitoids	Holland et al. (2017)
Reduce soil erosion	Zuazo and Pleguezuelo (2008)
Buffer agrochemical drift	Kjaer et al. (2014); Earnshaw (2018)
Reduce fertilizer and other pollutant movement, especially in surface run-off	Philips et al. (2014); Garibaldi et al. (2019)
Act as a refuge or corridor for wildlife	Jose (2012)

Table 3.4 Examples of ecosystem services that can be enhanced through ecological intensification and associated benefits at landscape level (Adapted from Garbach et al. 2014)

Ecosystem service	Description	Benefits at the landscape level
Erosion protection	Reducing soil loss caused by wind or water	Reduction of sedimentation in downstream water bodies
Water flow regulation	Reducing water loss (e.g., increasing water infiltration into soils and aquifers, reducing run-off)	Mitigation of flooding to downstream areas and groundwater recharging
Water purification	Mechanical removal of physical impurities in water (e.g., filtration, sedimentation and precipitation)	Clean water available to downstream users
Pollination	Transferring pollen to the stigma of a flower to allow fertilization	Necessary for outcrossing in non-cultivated flowering plants
Pest control	Controlling pests through the use of natural enemies of pests	Reduced use of chemical pesticides minimizes damage to non-target species, contamination of water bodies and risk to human health.
Weed control	Suppressing weeds through intercropping and the use of cover crops	Reduced use of herbicides, enhance biodiversity
Carbon sequestration	Removal of CO_2 from the atmosphere (e.g., by green plants) and storing it as carbon in biomass and soils	Climate change mitigation

agro-ecosystems, landscape heterogeneity supports a greater number of species than crop diversity (Redlich et al. 2018). Wildlife species that rely on forests for nesting and foraging (e.g., birds and bees) can benefit from the presence of non-cropped habitats due to improved resources or habitat availability. Vegetation in non-cropped habitats intercepts nutrients leached out of the crop fields, thus reducing the negative impact of diffuse pollution on aquatic life and potentially improving the quality of drinking water (Table 3.3). For example, Borin et al. (2010) found that vegetation buffer strips can decrease phosphorus and nitrogen in polluted run-off by 60–98% and 70–95%, respectively. Table 3.4 shows that there are many benefits associated with transitioning to ecological intensification that can be realized at landscape level.

Ecological intensification approaches such as organic farming limit the use of chemically synthesized inputs which help reduce nutrient pollution, eutrophication and pesticide residue contamination in water bodies. Non-cropped habitats and farmscape plantings support air and water purification, carbon sequestration and storage (Khan et al. 2020a, 2020b).

3.11 Future Perspectives

Despite the potentiality of ecological intensification in boosting crop productivity while maintaining or enhancing biodiversity and associated ecosystem services, policies promote its adoption among farming community (Kleijn et al. 2018; Garibaldi et al. 2019). A widespread adoption would require a robust evidence base that demonstrates the net agronomic or economic benefits associated with a transition to ecological intensification of mainstream farming. This would require scientists to focus on the costs and benefits of ecological intensification. Such studies should include costs of establishing and maintaining farmscape plantings as well as loss of production on land used for landscape plantings. The benefits should extend beyond crop yields to incorporate the values of ecosystem services. Future studies should also distinguish between benefits delivered by ecological intensification to individual farmers and the public such as increased carbon sequestration, improved human health due to reduced pesticide use and wildlife conservation.

3.12 Conclusion

Conventional agriculture is one of the major causes of biodiversity loss due to unsustainable farming practices such as natural habitat fragmentation, field size enlargement and the use of agrochemicals. Such practices have multiple detrimental impacts on biodiversity, quality of the environment and threaten the sustainability of food production. The environmental damage associated with conventional agriculture implies the existence of huge external or social costs which can be internalized by governments through a variety of mechanisms such as compulsory practices that support biodiversity or introducing charges for the production and use of agrochemicals. Policies that promote nature-based farm management and make external inputs more expensive have potential to make ecological intensification more attractive to farmers, financially. A growing body of literature shows that practices that constitute ecological intensification have potential to reduce or replace the use of external inputs without compromising on crop yield and profitability if properly planned.

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