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Restoring Agroecosystem Biodiversity: The Role of Regenerative Agriculture in Reversing Monoculture-Induced Declines

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Abstract

The modern global food system is increasingly fragile, a consequence of the sweeping agricultural transformations initiated during the Green Revolution of the 1940s. While the Green Revolution introduced high-yielding crop varieties (HYVs), chemical fertilizers, pesticides, and intensive irrigation, these advancements came at a cost: a significant loss of crop biodiversity, soil degradation, and increased vulnerability of food systems to climate change and disease outbreaks. The Food and Agriculture Organization (FAO) estimates that 75% of global crop diversity was lost between 1900 and 2000. This paper examines the unintended consequences of the Green Revolution on food security and biodiversity while exploring regenerative agriculture as a viable solution to correct these damages. Regenerative farming practices, including crop diversification, organic soil amendments, reduced chemical inputs, and agroecological approaches, have demonstrated potential in restoring soil fertility and increasing ecosystem resilience. By transitioning from an extractive, yield-maximizing agricultural model to a regenerative one, it is possible to address food production challenges in a sustainable manner. This paper also highlights the need for policy shifts, economic incentives, and scientific research to support the widespread adoption of regenerative agriculture, ensuring a resilient global food system for the future.

Keywords: *Green Revolution, regenerative agriculture, crop biodiversity, food security, nutrient density, industrial agriculture, sustainability, malnutrition.*

1.0 Introduction

Biodiversity refers to all species of plants, animals and micro-organisms existing and interacting within an ecosystem (Vandermeer and Perfecto, 1995). Natural biodiversity has provided the foundation for all agricultural plants and animals. The entire range of the domestic crops used in world agriculture is derived from wild species that have been modified through domestication, selective breeding and hybridization. Most remaining world centers of diversity contain populations of variable and adaptable landraces as well as wild and weedy relatives of crops, all of which provide valuable genetic resources for crop improvement (Harlan, 1975).

According to Clergue (2005), biodiversity is a very complex issue. In agroecosystems, it serves three basic functions: genetic, agricultural, and ecological functions. The first function of biodiversity involves maintaining species gene pool, in particular, the endangered ones. The second function, connected with agricultural activity, contains increasing the resistance of agroecosystems to abiotic and biotic stresses, as well as maintaining their productive role. Biodiversity has also ecological functions, for example, creating habitats with different flora and fauna species that have specific significance in agroecosystems. The issue of widespread species decline and ecosystem degradation was formally highlighted in 1992 with the creation of the Convention on Biological Diversity (CBD) during the inaugural Earth Summit held by the United Nations in Rio de Janeiro, Brazil.

The loss of biological diversity is one of the most important problems of the world and a threat to our civilization. The destruction of primary ecosystems, intensive farming, urbanization, and also infrastructure development cause depletion and weakening of the stability of ecosystems. Agroecosystems are the most at risk of losing biological diversity (TEEB, 2008). During the last decades, worldwide losses of biodiversity have occurred at an unprecedented scale and agricultural intensification has been a major driver of this global change (Matson *et al*., 1997).

Since the 1900s, some 75-percent of plant genetic diversity has been lost as farmers worldwide have left their multiple local varieties and landraces for genetically uniform, high-yielding varieties. 30-percent of livestock breeds are at risk of extinction; six breeds are lost each month. Today, 75-percent of the world's food is generated from only 12 plants and five animal species. Of the 4-percent of the 250-000 to 300-000 known edible plant species, only 150 to 200 are used by humans. Only three-rice, maize and wheat - contribute nearly 60-percent of calories and proteins obtained by humans from plants. Animals provide some 30-percent of human requirements for food and agriculture and 12-percent of the world's population live almost entirely on products from ruminants (FAO, 1999).

The net result of biodiversity simplification for agricultural purposes is an artificial ecosystem that requires constant human intervention, whereas in natural ecosystems the internal regulation of function is a product of plant biodiversity through flows of energy and nutrients, and this form of control is progressively lost under agricultural intensification (Swift and Anderson, 1993). Commercial seed-bed preparation and mechanized planting replace natural methods of seed dispersal; chemical pesticides replace natural controls on populations of weeds, insects, and pathogens; and genetic manipulation replaces natural processes of plant evolution and selection. Even decomposition is altered because plant growth is harvested and soil fertility maintained, not through nutrient recycling, but with fertilizers (Cox and Atkins, 1979).

Thus, modern agricultural systems have become productive but only by being highly dependent on external inputs. A growing number of scientists, farmers and the general public fear for the long-term sustainability of such highly input-dependent and ecologically simplified food production systems. Questions are being raised about the growing dependence of modern farming on non-renewable resources, the loss of biodiversity, the loss of land through soil erosion and the heavy reliance on chemical fertilizers and pesticides. Farm chemicals are questioned on grounds of cost but their widespread use also has implications for human and animal health, food quality and safety and environmental quality. The commercial agricultural sectors of developing countries suffer from similar problems but the greater challenge for them is to determine new ways to increase small farm productivity that not only benefit the rural poor under marginal agricultural conditions (hillsides, rainfed and marginal soils), but also conserve and regenerate the resource base (Altieri, 1995).

The significant decline in agroecosystem biodiversity can be largely attributed to the Green Revolution, which catalyzed the widespread adoption of high-yielding crop varieties and intensive monoculture farming systems. This transformation prioritized productivity and uniformity over ecological diversity, leading to habitat simplification, reduction in genetic variability, and disruption of ecological interactions essential for resilient agroecosystems. Promoting functional biodiversity within agroecosystems represents a fundamental ecological approach to achieving sustainable agricultural production. To illustrate this concept, this paper examines how regenerative farming practices can help counteract the negative impacts caused by monoculture-driven biodiversity loss.

2.0 Monoculture, Ecological Impact and Agroecosystem Decline

Monoculture/solely crop production farms are the farming types by which farmers grow only crops, both annual crops/trees and field crops, such as wheat, corn, rice, rapeseed, sugar cane, and cotton. Monoculture is widely used in industrial farming systems, including conventional and organic farming, and has allowed increased efficiency in planting and harvest. Continuous monoculture, or "monocropping" where the same species is grown year after year, can lead to unsustainable environments such as building up disease pressure and reducing particular nutrients in the soil. Under certain circumstances, monocropping can lead to deforestation. The practice has also been criticized for its environmental impacts, one of the major being soil degradation due to non-rotational cropping. Crop rotation is the practice of changing the types of crops in a farmland from year to year, which improves soil health and quality, whereas monocropping has been implicated in the loss of nutrients from the soil (Bennett *et al*., 2012).

Monoculture is the annual production of the same plant species on a farm, for one or more years (Andres *et al*., 2016; Utomo *et al*., 2016). It is a commercial mode of production that has been predominant in recent decades and has largely integrated food market systems, as it is mass-produced (Woźniak, 2020).

From an economic viewpoint, larger or single-component production with mechanical- or technological-dependent system seems more practical. By cultivating the same species in a huge land area, farmers can maximize their profit by mass production via a single operation through unique growing/farming practices including planting, maintaining (including pest control), and harvesting with similar resources. This helps result in a greater yield at a lower cost. In addition, farmers can pick the best monoculture crops to grow considering the local climate and soil conditions. Further, it is much easier and straightforward to cultivate one kind of crop or breed one type of livestock in terms of the knowledge and experience needed to do it successfully (Salaheen & Biswas, 2019).

Monoculture farming has several disadvantages due to the ability to produce a larger volume of affordable products with less investment. Monoculture farming cultivates a single crop in an intensive manner and on a very large scale, such as current practices in the United States in which corn, wheat, soybeans, cotton, and rice are commonly grown. However, growing the same crops year after year can deplete the soil of appropriate nutrients or humus that play key roles in soil fertility. In some cases, monocultures are more susceptible to certain weeds and pests, which means that farmers will depend vastly on pesticides to save their crops, which may have environmental impacts (Salaheen & Biswas, 2019).

For example, Zhao *et al*. (2018) have currently showed that coffee monoculture, in the long term, decreased soil pH and organic matter content, while it increased soil salinity, which severely inhibited the growth of coffee plants and therefore affected its yield. The richness of soil bacteria and of fungal communities also declined with continued coffee cultivation (Zhao *et al*., 2018). Similarly, Xiong *et al*. (2015) have demonstrated that continuous and long-term cultivation of black pepper resulted in a significant decrease in organic matter content, soil pH, and enzyme activities. These led to a decline in the abundance of soil bacteria, hence 454 pyrosequencing analyzes of 16S rRNA genes revealed that acidobacteria and proteobacteria were the major phyla that dominated 73% of the soil around black pepper plants. Similarly, the relative abundance of the Bacteroides and firmicutes phyla was depleted with continuous cultivation, and at the genus level, the abundance of Pseudomonas decreased significantly after 21 years of monoculture (Xiong, Li, *et al*., 2015).

Further, Liu *et al*. (2014) also confirmed this finding and have revealed that soil bacterial communities formed by potato monoculture have increased soil incidence of Fusarium wilt disease which impacted the performance of this crop. When a crop is grown as a monoculture, the microbial community is instantly exposed to the roots of that plant, selecting certain groups of microorganisms, namely soil pathogens, which are responsible for debilitating the yield of that crop (Cook, 2006).

Several studies on the monoculture of soybeans (Bai *et al*., 2015), melon (Soriano-Martín *et al*., 2006), bananas (Chen *et al*., 2013), and apples (Mazzola & Manici, 2012). With regard to yield and plant biomass, it turned out that the latter dropped significantly, in monoculture. This was supported by the study conducted by Zhao *et al*. (2018), which showed that shoots and dry weight of coffee decreased significantly with increasing years of monoculture. Similarly, Strom *et al*. (2020) found that soybean did not have a high yield after planting it directly after five years of continuous maize cultivation.

Further, continuous cultivation of black pepper severely inhibits its growth (Xiong *et al*., 2015). Continuous cultivation or monoculture can lead to an unhealthy and unsustainable environment, easily developing diseases and draining the soil from its nutrients, which is responsible for debilitating yields (Salaheen & Biswas, 2019).

The crops grown in the genetically homogeneous monocultures that characterize industrial farming are neither able to feed the world’s expanding population nor resilient to the more frequent and destructive climate extremes (Altieri *et al*., 2015; Reza & Sabau, 2022). For instance, Wright *et al*. (2017) found that crop species grown in plots with higher biodiversity were, on average, less adversely affected by flooding, and the plants with higher system leaf area and higher root system performed better.

Furthermore, plots with mixed crops had higher soil porosity, which positively impacted plant performance. The negative impact of flooding on the performance of monocrops is primarily due to limited gas exchange due to slower gas diffusion in water compared to air, and low light intensity in turbid floodwaters, thereby causing an energy and carbohydrate deficit (Sasidharan & Voesenek, 2015), inhibiting plant growth, and eventually its survival (Mommer & Visser, 2005; Nguyen *et al*., 2018; Zhou *et al*., 2020). According to the survey carried out by Reza & Sabau (2022), it has been shown that monocropping has a negative impact on soil depletion and contributed to a decrease in soil nutrient diversity.

Although this cropping system is commercially efficient and profitable, it provides an unbuffered niche for parasitic species, increasing the crop's vulnerability to opportunistic insects, plants, and microorganisms (Blary *et al*., 2021; Dolezal *et al*., 2019; Suarez *et al*., 2023). Because a single crop is more vulnerable to a particular pathogen or pest, it accelerates the spread of diseases and pest outbreaks (Biber-Freudenberger *et al*., 2016; Cui *et al*., 2023; Kaur *et al*., 2021), increasing farmers’ intensive reliance on pesticides and fertilizers, which affects water quality, human health, and wildlife population (Rahman, 2023). Increased use of chemical fertilizers and synthetic pesticides will ultimately increase emissions of greenhouse gases such as N2O (Reza & Sabau, 2022).

Compared to monocultures, intercropping contains more water, biomass, root system, and litter and can supply habitat for more organisms and contribute to flood mitigation, soil conservation, habitat quality, and carbon storage (Li *et al*., 2020; Ma *et al*., 2022; Sun *et al*., 2021). Climate change will increase the likelihood and severity of droughts into the future in many worldwide locations (Abdelmajid *et al*., 2021; Altieri *et al*., 2015; Chien *et al*., 2023; Leal Filho *et al*., 2023; Moldavan *et al*., 2023; Mutengwa *et al*., 2023; Shukla *et al*., 2019).

Natarajan & Willey (1986) studied the effect of drought on improved yields with multicropping by manipulating water stress on intercrops of sorghum and peanut, millet and peanut, and sorghum and millet. All the intercrops overyielded consistently at five levels of moisture availability, ranging from 297 to 584 mm of water applied over the growing season. Finn *et al*. (2018) found that grassland monocrop with experimental drought, decreased strongly the yield by 66%, in contrast, mixtures increased yield by 33% compared to the average of monocultures. Altieri *et al*. (2015) attested that multicropping has been shown to have higher yield stability and less productivity loss during drought than monocropping. The effects of drought on yield depend on environmental conditions, including agricultural intensity (Sun *et al*., 2021; Vogel *et al*., 2012; Zwicke *et al*., 2013), as well as pre-drought conditions and soil type, in particular, soil moisture retention properties (Hofer *et al*., 2016). Extreme weather events last longer, droughts become longer, moisture deficits during plant development during vegetation increase, soil moisture declines, and new pests and plant diseases appear (Cui *et al*., 2023; Moldavan *et al*., 2023) that agroecological farms are better able to counteract through the use of genetically diverse varieties of cultivated plants (Chien *et al*., 2023; Cui *et al*., 2023; Ma *et al*., 2022; Moldavan *et al*., 2023). Pathogen development and survival are most likely to be impacted by projected climate changes (Elad & Pertot, 2014). It is projected that a crop will become more vulnerable to numerous pests, diseases, and weeds as a result of changes in an area's climate or weather pattern. While yields are predicted to decline at lower latitudes, they are forecast to increase in countries with high and middle latitudes (Rosenzweig *et al*., 2001). However, estimates indicate that a one-degree increase in temperature will result in a 10–25% increase in losses from insect pest infestation (Deutsch *et al*., 2018; Shrestha, 2019).

Nowhere are the consequences of biodiversity reduction more evident than in the realm of agricultural pest management. The instability of agroecosystems, which is manifested as the worsening of most insect pest problems, is increasingly linked to the expansion of crop monocultures at the expense of the natural vegetation, thereby decreasing local habitat diversity (Altieri and Letourneau, 1982). Plant communities that are modified to meet the special needs of humans become subject to heavy pest damage and generally the more intensely such communities are modified, the more abundant and serious the pests. The inherent self-regulation characteristics of natural communities are lost when humans modify such communities through the shattering of the fragile thread of community interactions. Agroecologists maintain that this breakdown can be repaired by restoring the shattered elements of community homeostasis through the addition or enhancement of biodiversity (Altieri, 1994).

For years, ecologists have debated the assumption that increased diversity fosters stability. Critical theoretical reviews on this subject are abundant in the literature, as well as reviews that use agricultural examples to bolster the theory (Andow, 1991). Most studies conclude that by mixing certain plant species with the primary host of a specialized herbivore gives a fairly consistent result: specialized species usually exhibit higher abundance in monocultures than in polycultures. In a recent review, Andow (1991) identified 209 published studies that deal with the effects of vegetation diversity in agroecosystems on herbivorus arthropod species. Fifty-two percent of the 287 total herbivore species examined in these studies were found to be less abundant in diversified systems than in monocultures, while only 15.3% (44 species) exhibited higher densities in polycultures.

Monoculture relies heavily on the use of chemical fertilizers and pesticides. The intensive use of chemical fertilizers can also affect soil properties and those of microbial communities and their functions (Pahalvi *et al*., 2021; van der Bom *et al*., 2018). Excessive use of nitrogen fertilizers can leach nitrates into water bodies, causing eutrophication and affecting aquatic life and drinking water quality (Khan *et al*., 2018). Phosphate is adsorbed on soil particles and transported to water bodies by soil erosion. Long-term excessive fertilizer use causes soil acidification, with long-term effects on soil productivity and soil protection (Mandal *et al*., 2020). In recent decades, the use of fertilizers and pesticides has increased the exposure of farmers, farm workers and the general population to these chemicals (Gupta, 2008). Dhankhar & Kumar (2023) attested that when fertilizers are applied to croplands, they are either directly or indirectly distributed into grains and vegetables, harming human health and lowering the nutrient density of the dominant plants. For instance, the nitrates and nitrites in fertilizers have been linked to cancer, birth defects, and other health issues like intoxications (Guo *et al*., 2020; Savci, 2012).

Furthermore, lead and cadmium-based fertilizers can be hazardous to both humans and animals, resulting in health difficulties such organ damage, neurological abnormalities, and developmental problems (Dhankhar & Kumar, (2023). Furthermore, Sharma (2017) reported that according to the U.S Environmental Protection Agency EPA's Office of Pesticide Programs, most of the pesticides contain ingredients that are cancerogenic to humans. The continued use of fertilizers hardens the soil, and can even modify its pH by increasing its acidification. For example, Pan *et al*. (2021) found that P addition slowed the process of nitrification in urea-treated soils, where a high N:P ratio appeared to be a major barrier. Ammonia-oxidizing bacteria's (AOB) response, which was more responsive to P addition than ammonia-oxidizing archaea's (AOA's) response, further corroborated this. The findings of this study indicated that the nitrification process in soil amended with urea was slowed by the application of P fertilizer, indicating that a synergistic feature of N and P nutrient management should be further investigated to slow N losses from agricultural systems.

Furthermore, the most frequently form of nitrogen or sulfur fertilizer in soil is nitrates or sulfate (S) (Brito *et al*., 2007; Vandenberghe *et al*., 2012), which is likely to exacerbate secondary salinization in the soil layer (Lu *et al*., 2019; Shen *et al*., 2016). Increased secondary salinization may lead to a reduction in soil fertilizer availability, which would reduce the productivity of crops, like cotton (Osanai *et al*., 2017; Tian *et al*., 2018), sunflower (Aziz *et al*., 2019), and maize (Lu *et al*., 2019; Rajeshwar & Khan, 2010). These will contribute to a drop in the content of organic matter in the soil, humus and the useful microbial load, relating to the decrease in quality of agricultural land, stunted plant growth, which is responsible for greenhouse gas emissions (Pahalvi *et al*., 2021). On the other hand, the excessive and long-term application of the chemical inputs is confirmed to contaminate the soil by heavy metals, including arsenic, mercury, and cadmium which are present either in the raw materials of the fertilizers (Atafar *et al*., 2010; Pogrzeba *et al*., 2018). Some heavy metals are required for plant development, such as, Fe, Cu, Mn, Mo and Zn, although they can be toxic to plants when present in excess. In addition, there are other Heavy Metals (Cd, Hg, Pb) that are irrelevant to plant development and can damage plants (Pogrzeba *et al*., 2018). The infiltration of these constituents, during the production processes, cannot be fully absorbed by the crops, and penetrates into the groundwater which causes their contamination (Chen *et al*., 2021). Nitrogen (N), phosphorus (P) and potassium (K) are the main macronutrients frequently required by crops to maximize their productivity (Gautam *et al*., 2020; Maathuis, 2009). Global nitrogen use, which is the single most important determinant of crop yield, is expected to increase by 1.6% per year until 2018, while phosphate use is expected to increase by

2.2% and potash 2.6%. In comparison, supplies of these three essentials are expected to grow by 3.7%, 2.7% and 4.2% per year, respectively (Nations, 2015).

The intensive use of nitrogen fertilizers causes emissions of ammonia and nitrogen oxide into the atmosphere and therefore has the effect of harming the ozone layer, its overuse can lead to an accumulation of nitrates in soils, leading to their acidification and salinization (Chen *et al*., 2021). In addition, the phenomenon of acidification accelerates the leaching process of calcium and magnesium, this can contribute to the reduction of the saturation of soils in nutrients and possibly their fertility (Chen *et al*., 2021; Pahalvi *et al*., 2021). These are suggested to influence the biodiversity and sustainability of soil. Consequently, it has become essential to protect and maintain soil productivity in the long term without resorting to destructive and unbalanced practices, in particular the irrational application of chemical inputs which leads to a degradation of soil quality and water (Abebe *et al*., 2022; Gautam *et al*., 2020; NING *et al*., 2017; Wu *et al*., 2021).

The Green Revolution may not be the only reason for biodiversity decline. But it's definitely a major factor. According to the FAO's State of the World's Biodiversity for Food and Agriculture (2019), while more than 6 000 plant species have been cultivated for food, fewer than 200 make substantial contributions to global food output, with only nine accounting for 66 percent of total crop production in 2014. Although it is not possible to make definitive statements about global trends in the erosion of on-farm crop diversity, evidence suggests that, overall, the diversity present in farmers' fields has declined and that threats to diversity are getting stronger (FAO, 2019). Biodiversity serves as a foundational component of natural ecosystems and the global food system. Its ongoing decline poses significant risks to ecological stability and the continuity of life-supporting processes. Without urgent and effective intervention to halt and reverse this trend, the trajectory points toward an uncertain and potentially destabilizing future for human societies and the planet at large.

3.0 Regenerative Agriculture: Principles and Practices

The Green Revolution in the 1950s and 1960s led to a significant increase in productivity through modern machinery, artificial fertilisers and highly bred crop varieties (Evenson & Gollin, 2003). At the same time, the impact on the environment, including on soils, water quality and biodiversity, has often been neglected. As the world's population and the demand for agricultural products is growing further, the environmental impacts are not only becoming more acute, but also have long-term implications for food security itself. Global food systems will remain highly dependent on ecosystem services and abiotic factors, some of which are also changing for the worse, most notably climate (Foley *et al*., 2005; Wheeler & von Braun, 2013).

To overcome the negative consequences of conventional farming, alternative approaches have arisen in recent decades. These are often subsumed under the term sustainable agriculture, defined by the Food and Agriculture Organization (FAO) as " ... the management and conservation of the natural resource base and the orientation of technological and institutional change in such a manner as to ensure the attainment and continued satisfaction of human needs for present and future generations. Such sustainable development ... conserves land, water, plant and animal genetic resources, is environmentally non-degrading, technically appropriate, economically viable and socially acceptable" (FAO, 1989).

Various approaches have been developed and implemented to achieve this transformation (Oberč & Arroyo Schnell, 2020). One established approach is conservation agriculture (CA), which has its roots in conservation tillage as a solution that emerged from the "Dust Bowl" that affected US and Canadian prairies in the 1930s (Hobbs, 2007). In the 1970s and 1980s, this approach was complemented by the practice of intercropping and crop rotations and has been employed widely under the label CA since the 1990s. The FAO highlights three key principles of CA: minimisation of soil disturbances, enhancement or maintenance of a protective organic cover, cultivation of a wide range of plant species (FAO, 2011).

Conservation agriculture is the basis of regenerative agriculture. The concept of a regenerative agriculture can be traced back to the cusp of the 1980s discussions of sustainability (Gabel, 1979; Sampson, 1982; Rodale, 1983). Regenerative agriculture adopts the principles of conservation agriculture that's meant to maintain soil health. Where regenerative agriculture diverges is its broader focus on increasing biodiversity in general and creating a closed nutrient cycle in combination with livestock management at farm level. It includes additional approaches such as manure composting, rotational grazing and silvopasture in grassland management (Smith *et al*., 2021).

In practice, regenerative agriculture and conservation agriculture involve similar cropping systems and the terms are often used interchangeably. Some scholars and practitioners additionally ascribe a social dimension to RA (Müller, 2020). Some of the more holistic regenerative approaches transcend soil regeneration and additionally aim at "regenerating" the social aspects related to agriculture. For example, in terms of good livelihoods, social relationships and stable incomes (LaCanne & Lundgren, 2018), future perspectives, and (re) building human–nature relationships (Gordon *et al*., 2022; Hes & Rose, 2019).

Newton *et al*. (2020), in their comprehensive meta-analysis, are the only researchers to date who have explicitly categorized regenerative agricultural practices based on a thorough review of the literature. Drawing from 229 peer-reviewed journal articles, they identified the five most frequently cited practices. These include: using no or low external inputs while maximizing on-farm inputs (26.4%), integrating livestock into farming systems (19.0%), avoiding synthetic pesticides (12.4%), avoiding synthetic fertilizers (12.4%), and reducing tillage (11.6%). This list reflects the academic emphasis on minimizing synthetic inputs and enhancing self-sufficiency within farm ecosystems. In contrast, when examining 25 practitioner websites, Newton *et al*. found a slightly different prioritization of regenerative practices. The most commonly mentioned were reducing tillage and integrating livestock, both cited by 40.9% of sources. These were followed by the use of cover crops (36.4%), crop rotations (31.8%), and minimizing external inputs in favor of on-farm resources (31.8%). This practitioner-focused perspective highlights a more operational and practical orientation toward soil health and system resilience, indicating both overlap and divergence between academic and on-the-ground understandings of regenerative agriculture.

Conclusively, regenerative practices contribute significantly to biodiversity by creating diverse, resilient agroecosystems that support a wide range of organisms. Reducing or eliminating synthetic inputs like pesticides and fertilizers helps preserve beneficial insects, soil microbes, and pollinators, which are often harmed by chemical exposure. Integrating livestock and using cover crops and crop rotations introduce a variety of plant and animal species into the farming system, breaking pest and disease cycles and enriching habitat complexity. Additionally, reducing tillage protects soil structure and fosters underground biodiversity, including fungi, earthworms, and microbial communities. Altogether, these practices enhance both above- and below-ground biodiversity, promoting ecosystem balance and long-term sustainability.

4.0 Evidence of Biodiversity Recovery in Regenerative Agriculture

Biodiversity loss is a critical global concern, driven largely by conventional agricultural practices that simplify ecosystems and rely heavily on synthetic inputs. In response, regenerative farming has emerged as a holistic approach aimed at restoring ecological balance through methods that enhance soil health, reduce chemical dependence, and increase biodiversity. A growing body of research suggests that regenerative practices—such as cover cropping, crop rotation, livestock integration, and minimal tillage—not only sustain productivity but also foster the recovery of biodiversity at multiple trophic levels. Regenerative agriculture restores soil biodiversity by reversing the degradative effects of monoculture, which typically depletes soil life through uniform cropping, heavy tillage, and chemical input use. It promotes a heterogeneous and nutrient-rich soil environment that supports diverse microbial communities, fungi, earthworms, and other soil organisms.

Microorganisms, for example, are crucial to soil biodiversity and ecosystem functioning. They decompose organic matter, releasing nutrients essential for plant growth. Bacteria and fungi work in tandem to break down complex organic materials, converting them into forms that plants can readily absorb. For instance, mycorrhizal fungi form symbiotic relationships with plant roots, facilitating the uptake of water and nutrients, especially phosphorus, which is crucial for plant health (Smith & Read, 2008). Fungi, particularly mycorrhizal species, are essential for maintaining soil biodiversity. They create extensive networks that connect plant roots, allowing for nutrient exchange not only between plants but also with soil microorganisms. This network improves the overallhealth of the soil ecosystem, enhances plant resilience, and facilitates the transfer of water and nutrients over long distances (van der Heijden *et al*.,2008). In summary, regenerative systems foster the recovery and proliferation of soil biodiversity that monoculture systems often diminish or destroy.

Plant diversity is a cornerstone of agroecosystem resilience. Increasing cropping diversity in field has been shown to lead to increased crop and forage yield in some contexts (Smith *et al*., 2008). This is achieved through the establishment of diverse plant species that have complementary nutrient requirements and support beneficial interactions (Beillouin *et al*., 2021). Crop diversity can also improve yield stability by reducing the risks associated with monocultures and susceptibility to pests, diseases and climate shocks (Raseduzzaman and Jensen, 2017).

Furthermore, increased on-farm biodiversity can provide a greater range of habitats to support pollinators, crucial for the success of some crops and fruit trees (Nicholls and Altieri, 2013; Pywell *et al*., 2015). Increased biodiversity promotes natural pest suppression, as a diverse range of predators and beneficial organisms helps regulate pest populations (Gurr *et al*., 2003; He *et al*., 2019; Nicholls and Altieri, 2013). Increased crop diversity or the use of cover crops can also suppress weed pressure, as diverse plant communities compete with and inhibit weed growth (Isbell *et al*., 2017). Increased diversity in grassland has been shown to be associated with higher levels of soil carbon and nitrogen, and invertebrate abundance in soils (Norton *et al*., 2022). On-farm diversification of crops is known to enhance biodiversity and a range of ecosystem services such as supporting pollinators, pest control, nutrient cycling, soil fertility and water regulation, without compromising crop yields (Brooker *et al*., 2015; Tamburini *et al*., 2020).

The results of a meta-analysis of 53 individual European studies on the effects of agroforestry on ecosystem services showed a strong positive effect of agroforestry on biodiversity, with the effect size varying depending on the taxa and systems studied; the strongest positive effects were seen for birds and silvo-arable systems (Torralba *et al*., 2016).

RizomaAgro is developing regenerative agriculture in three farms in Brazil, which have a size of over 2,000 hectares. In 2022, it reported a significant improvement in environmental indicators related to carbon sequestration, biodiversity and water retention. According to the report, it tripled the number of species of pollinators and natural enemies of pests (RizomaAgro, 2022).

Regenerative agriculture can reduce on-farm herbicide and pesticide use. Besides supporting pollinators, cover and companion crops support a broad spectrum of beneficial insects through creation of habitats during the growth and senescence phases of the crop. Furthermore, companion crops can be used to divert insect pests away from the main cash crop and could also act as barriers against fungal pathogen spread throughout the cash crop (Huss *et al*., 2022). There is potential to reduce herbicide and pesticide use if weeds, pests and diseases are successfully suppressed through companion cropping (Osipitan *et al*., 2019). Potential benefits from mixed crops include the maintenance of crop yields with reduced inputs, such as herbicides and pesticides and greater resilience to environmental variability such as summer droughts (Weih *et al*., 2022). By reducing the reliance on chemical pesticides and fostering a diverse insect community, regenerative agriculture creates a more resilient system capable of self-regulation (Benton *et al*., 2003). Studies have shown that farms with higher plant diversity can significantly boost pollinator visitation rates, leading to improved crop yields and ecosystem health (Klein *et al*., 2007).

In conclusion, the evidence presented underscores that regenerative agriculture offers a viable and ecologically sound alternative to conventional practices, with significant benefits for soil health, biodiversity restoration, ecosystem services, and long-term farm productivity, ultimately contributing to a more resilient and sustainable agricultural system.

5.0 Conclusion

The health of an ecosystem is measured by the degree of its diversity. This paper has demonstrated that regenerative agriculture offers a powerful framework for reversing biodiversity loss driven by conventional farming practices. Through practices such as cover cropping, crop rotation, livestock integration, and minimal tillage, regenerative systems foster rich and resilient ecosystems both above and below ground. The restoration of soil microbial communities, enhancement of plant diversity, support for pollinators, and natural pest regulation all contribute to healthier, more self-sustaining agroecosystems.

Despite these promising outcomes, the widespread adoption of regenerative practices faces several challenges—including economic and policy barriers, limited farmer training, and insufficient market incentives. There may also be trade-offs, particularly between yield stability and biodiversity gains, that require context-specific evaluation and management.

To fully realize the potential of regenerative agriculture, long-term biodiversity monitoring must be prioritized, alongside efforts to integrate these practices into national and international agricultural policies. Scaling biodiversity-friendly farming will require coordinated research, cross-sectoral collaboration, and financial frameworks that reward ecological stewardship.

In conclusion, regenerative agriculture stands out as a viable pathway to restore biodiversity while sustaining agricultural productivity. This calls for deeper interdisciplinary research and robust policy support to overcome barriers and ensure its benefits are accessible, scalable, and lasting as the world moves toward sustainability.

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