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Regenerative Agriculture: Techniques and Long-Term Impact on Soil Fertility

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Traditional farming methods might result in decreased output and degraded soil. Regenerative agriculture (RA), which emphasizes soil health and carbon sequestration, is promoted as a remedy for these problems. Maintaining soil cover, minimizing soil disturbance, preserving living roots in the soil throughout the year, enhancing species variety, integrating livestock, and reducing or doing away with the use of synthetic substances (such as fertilizers and herbicides) are the core tenets of RA. Restoring the land and soil, as well as benefiting the larger community on an economic, social, and environmental level, are the main goals. Despite the alleged advantages of RA, the great majority of growers are hesitant to implement these techniques because there is insufficient empirical support for their profitability and stated benefits. In some climatic zones and soil types, the research indicates that agricultural methods, including limited tillage, residue retention, and cover cropping, can enhance soil carbon, crop productivity, and soil health. Degradation of ecosystems and loss of biodiversity can result from the overuse of manmade chemicals. Combining livestock with cropping and agroforestry in the same landscape can increase soil carbon and provide several co-benefits. The advantages of RA practices, however, can vary among different agroecosystems and may not always hold for various agroecological zones. To increase understanding of the advantages and ecosystem experiments that compare conventional and RA approaches. This will provide producers and decision-makers with a solid foundation of data to inform their decisions on whether to adopt RA practices, thereby reaping the social and economic benefits and building resilience to climate change.

Keywords: *microbial function, regenerative agriculture, soil carbon, soil health*

Introduction

Regenerative agriculture (RA) utilizes natural processes to boost biological activity, improve soil health, improve nutrient cycling, restore landscape function, and produce food and fiber, all while maintaining or improving farm profitability. Regenerative agriculture is a comprehensive agricultural method that aims to actively enhance ecosystem health, especially soil health, rather than just maintain it. To increase production and restore landscape functionality, practitioners employ a range of strategies that integrate biological and ecological processes, all of which are founded on a set of guiding principles.

The goal of RA is to use natural ecological processes within an agricultural system to enhance the health of the farming system, not to restore the biological function and ecology of the pre-agricultural state. This strategy improves the soil's biological activity and structural integrity by combining practices like crop diversification, agroforestry, composting, conservation tillage, cover crops, and managed grazing (Schreefel et al., 2020). Regenerative agriculture's long-term effects on soil fertility are becoming more widely acknowledged. Rebuilding soil organic carbon, enhancing soil aggregation, and promoting microbial communities—all of which are essential for nutrient cycling and plant health—are all made possible by practices that lessen disturbance and boost organic inputs (Gattinger et al., 2012). Additionally, these techniques improve resilience to drought and climate variability, decrease erosion, and increase water retention capacity (Rhodes, 2017). The combined impacts eventually result in farming systems that are more sustainable and productive and depend less on chemical fertilizers.

Table 1. RA (Regenerative Agriculture) principles, practices, and purported benefits and mechanisms to improve soil health

RA Practices	RA Benefits	RA Principles	Microbial Mechanism
➢ No minimum tillage ➢ Stubble retention ➢ Diverse crop rotations ➢ Multispecies cover crops ➢ Intercropping ➢ Composting and using biostimulants	➢ Improved soil health through ➢ Increased soil carbon, ➢ Improved microbial functions and associated nutrient cycling ➢ Improved soil moisture ➢ Improved resilience to pests and diseases	➢ Minimise soil ➢ Disturbance ➢ Keep soils covered. ➢ Keep living roots in the soil year-round ➢ Encourage diversity ➢ Integrate livestock	➢ Liquid carbon pathway ➢ Improved uptake of water and minerals ➢ Enhanced soil aggregation, plant growth, and photosynthesis

Potential Benefits of RA for Soil Health

The ecological benefits of regenerative agriculture (RA) are numerous, but one of the most important and quantifiable results is improved soil health. The primary goal of RA is to enhance the soil's biological, physical, and chemical properties, thereby creating an agroecosystem that is more resilient and productive.

1. **Improved Soil Organic Carbon and Carbon Sequestration:** The substantial increase in soil organic carbon (SOC) brought about by RA techniques like cover crops, reduced tillage, and organic amendments is one of its main advantages. These methods improve fertility and slow down climate change by storing atmospheric carbon in the soil (Lal, 2020). Improved SOC promotes improved soil aggregation and lowers bulk density, which promotes water transport and root development (Gattinger et al., 2012).
2. **Enhanced Soil Structure and Water Retention:** Improved water penetration and retention result from techniques including mulching, minimizing soil disturbance, and adding compost, which raise soil porosity and aggregate stability. This decreases the chance of erosion, drought stress, and runoff (Schreefel et al., 2020). The establishment of a varied soil biota is supported by healthy soil structure, and this further aids in soil regeneration.
3. **Increased Microbial Diversity and Activity:** Regenerative methods increase organic inputs and reduce synthetic chemical use to support a healthy soil microbiota. Plant productivity and health are improved by diverse microbial communities, which also promote nutrient cycling and inhibit pathogens (LaCanne & Lundgren, 2018). Beneficial fungi and bacteria that promote decomposition and nutrient availability are activated by biofertilizers, compost, and cover crops.

Pest, Pathogen, and Weed Control/Suppression

Worldwide, crop diseases, pests, and weeds result in large output and financial losses. Certain illnesses and pests, especially those that flourish in warmer areas, are predicted to become more common and severe as a result of climate change. Plant immune responses are affected by elevated temperature, CO2, humidity, and nutritional condition. Some agricultural methods, including monocultures, encourage disease and pests. To minimize further losses, coordinated disease and pest management is often advised. Using fungicides and insecticides to control plant diseases and pests is one of the suggested methods, but it has several drawbacks. Pesticide overuse in recent years has resulted in pesticide resistance, in addition to pollution and negative effects on soil microbiota. Consequently, there is worldwide interest among researchers in developing environmentally safe and sustainable disease control solutions. Beneficial organism populations, such as predatory insects and parasitoids that naturally regulate pest numbers, are promoted by diverse crop rotations, intercropping, and habitat management techniques like hedgerows and flowering strips (Nicholls et al., 2016).In addition to supporting more resilient agroecosystems, this integrated approach minimizes adverse effects on non-target species, including pollinators and soil fauna, and lowers the likelihood of resistance development (Pretty & Bharucha, 2015). Finally, regenerative agriculture provides a comprehensive and sustainable substitute for chemical-based approaches to managing weeds, diseases, and pests.

Effect of Management Practices on Microbial Activity

Agricultural production is decreased by agricultural intensification because it compromises soil functions and decreases the functional groups of soil biota (Schreefel et al,.2020). Conservation agriculture techniques that control microbial communities, such as crop rotation, manuring, decreased tillage, and cover crops, enhance or preserve soil quality for sustainable crop production (Tsiafouli et al.,2014). But across croplands, nutrient management and extended crop rotations may directly affect community structure and related ecosystem services. Long-term benefits to agroecosystems are achieved by crop rotations that include cover crops and organic amendments, which increase C, N, and microbial biomass and improve soil fertility. The loss of biodiversity is one of the most detrimental effects of less crop rotation. Crop rotation considerably raised the soil microbial biomass by 20.7 and 26.1%, respectively, according to a meta-analysis of 122 studies on the impact of crop rotation on soil biological properties. Diversified crop rotation increases microbial functions, which enhances plant resource use efficiency, according to some research.

Nutrient-Dense Food

RA practitioners assert that using RA principles can enhance the nutritional quality of food and that increased yields lead to a drop in nutrients in plants. Dietary quality may suffer as a result of climate change, especially increased CO2. Nutritional security is critical to global food production and is inextricably linked to human health. The fertility and quality of the soil significantly influence nutrient levels in food crops. Depletion of micronutrients and macronutrients in the soil has been connected to poor nutrient content in food. According to reports, the mineral content of soil has decreased by up to 85% in several countries over the past century. It has been discovered that the mineral elements in fruits and vegetables have drastically decreased.

Climate Mitigation

Reduction of greenhouse gas emissions is one of the co-benefits of RA, according to RA practitioners. Methane and nitrous oxide from the enteric fermentation of crops and livestock/animals make up 14.6% of annual greenhouse gas emissions from Australian agriculture. Due to SOC loss, elevated temperatures, and possible soil erosion, agricultural yield is reduced by 10% to 20%. Agricultural soils are believed to be a significant carbon sink, with 1.1–2.2 Pg of carbon sequestered during the next 50 years. Agricultural practices' capacity to slow down climate change is ascribed to the sequestration of SOC in soil through photosynthesis. The potential for carbon sequestration to reduce fossil fuel emissions by 5–

15% annually is largest in croplands, grazing/range areas, degraded/deserted regions, and irrigated soils. Management techniques such as the utilization of perennial forage crops, the removal of barren fallows, the production of biofuel crops, better nutrient management, decreased tillage, and the generation of large amounts of residues.

Conclusion

As climate change and growing input costs present obstacles, RA is becoming more popular. It is suggested that RA and other climate-smart agriculture techniques be implemented to lessen the effects of extreme weather events and fight greenhouse gas emissions. Restoring soil health is the main objective of RA, which is not a whole novel farming method but rather integrates elements of well-established sustainable agricultural systems to revitalize degraded land and provide social, economic, and environmental advantages to a wider community. Additionally, if the suggested management practices are implemented, the system may aid in carbon sequestration. A revolutionary method of farming, regenerative agriculture emphasizes long-term soil health, ecological balance, and sustainable yield. Regenerative methods actively repair deteriorated soils rather than just maintaining them by combining practices including cover crops, limited tillage, organic amendments, crop variety, and the use of biofertilizers. These techniques raise the amount of organic matter in the soil, boost microbial activity, improve soil structure, and encourage effective nutrient cycling, all of which eventually lead to increased soil fertility. RA creates resilient agroecosystems that can support both environmental and economic sustainability, in contrast to conventional methods that frequently result in soil deterioration, nutrient depletion, and growing reliance on synthetic inputs.

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