Regenerative Agriculture: Integrating Soil Health, Carbon Management, and Socio-Ecological Outcomes

Abstract

Regenerative agriculture is a revolutionary farming method that aims to address the many issues raised by current agricultural practices by balancing soil health, carbon management, and socio-ecological results. This all-encompassing framework incorporates ideas to improve and restore soil ecosystem health, store carbon in the atmosphere, and build resilient rural communities. Regenerative agriculture prioritizes soil health by emphasizing techniques like cover crops, decreased tillage, and diverse cropping systems, which together strengthen soil structure, increase microbial activity, and accelerate nutrient cycling. Through their substantial contribution to carbon sequestration, these techniques help to stabilize the climate by reducing greenhouse gas emissions. Simultaneously, regenerative agriculture supports structures that foster socio-ecological resilience, such as fair resource distribution, farmer welfare, and community involvement. This strategy strives to improve ecological integrity and reconstruct rural livelihoods in addition to raising farm productivity and profitability. The combination of these components highlights a comprehensive vision in which agricultural methods are in line with social and ecological goals, offering a sustainable route forward for food systems in the future. In addition to providing insights into regenerative agriculture's potential to address global sustainability issues, this abstract highlights the fundamental concepts, advantages, and potential drawbacks of the practice. It also advances ecological and community health. Findings demonstrate convergence with respect to goals that improve the environment and emphasize the significance of socioeconomic factors that support food security.

Keywords: Regenerative agriculture, soil health, soil carbon, climate mitigation, farming systems.

INTRODUCTION

“Regenerative agriculture (RA) is a farming approach that preserves or increases farm profitability by utilizing natural processes to boost soil health, improve nutrient cycling, raise biological activity, restore landscape function, and produce food and fiber. In order to increase production and restore landscape functionality, practitioners of the strategy employ a range of strategies that integrate biological and ecological processes. These tactics are founded on a set of guiding principles”(Gosnell *et al.*, 2020a).

“The main goals of (RA) are to maintain soil cover, reduce soil disturbance, maintain living roots in the soil throughout the year, diversify species, integrate livestock, and use as little as possible synthetic substances (fertilizers and herbicides)”[Gosnell *et al*., 2019].

“The conventional farming approach has frequently resulted in increasing greenhouse gas emissions, diminished biodiversity, and degraded soil. Regenerative agriculture is a paradigm that has arisen in reaction to these trends, emphasizing ecological restoration and resilience above all else”[Sherren*et al*., 2012]. “The present review offers a thorough exposition of regenerative agriculture, with a particular focus on its fundamental constituents: soil health, carbon management, and socio-ecological effects. Regenerative agriculture (RA) is a farming approach that preserves or increases farm profitability by utilizing natural processes to boost soil health, improve nutrient cycling, raise biological activity, restore landscape function, and produce food and fiber. In order to increase production and restore landscape functionality, practitioners of the strategy employ a range of strategies that integrate biological and ecological processesapproach” (Hruska*et al*., 2017).“These tactics are founded on a set of guiding principles. Traditional farming methods can cause productivity to drop and soil to deteriorate. Advocates claim that regenerative agriculture (RA), which emphasizes soil health and carbon sequestration, is the answer to these problems.. Rejuvenating the land and soil as well as benefiting the larger community's ecology, economy, and society are the main goals. Even with the alleged advantages of RA, most producers are hesitant to implement these techniques because there is insufficient actual data to support the benefits and In specific climatic zones and soil types, the research indicates that agricultural methods including low 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 overuse of manmade chemicals. Raising cattle in the same setting as agriculture and agroforestry can boost soil carbon and have a number of additional benefits. The advantages of RA techniques, however, can fluctuate amongst various agro-ecosystems and might not always hold true for various agro-ecological zones”(Gordon *et al*., 2021). “The advice is to conduct thorough, long-term agricultural system trials that contrast conventional and RA techniques in order to increase our understanding of the advantages and working mechanisms of RA at the regional level” (Massy, 2017). "An approach to farming that uses soil conservation as the entry point to regenerate and contribute to multiple provisioning, regulating, and supporting services, with the objective that this will enhance not only the environmental, but also the social and economic dimensions of sustainable food production," was proposed as the temporary definition of regenerative agriculture (RA).

Need of Regenerative agriculture

Losses are ongoing and soil deterioration is a result of the current intensive agricultural system. According to international scientists, there could not be enough soil to feed everyone on the planet in the next fifty years. Globally, there is a decline in biodiversity and soil fertility. By increasing soil organic matter, biodiversity, and biota, regenerative agriculture enhances soil health. Moreover, improving water-holding capacity and carbon sequestration are its goals. As a result, our food crops and plants ended up being of poor quality due to a decrease in soil fertility. It is vital to boost healthy soils in our agroecosystem and raise crop production (yields) of affordable, nutrient-dense, and culturally suitable food crops as the world's population grows every day. Healthy soil is the foundation for agriculture, crop productivity, and human security in the future, according to recent research and discoveries. Research suggests that "alternative" farming methods could help address problems related to soil and water deterioration (FAO, 2019).**"**These practices are adopted to promote healthier soils and can result in increasing crop productivity, greater economic viability, and increased local food security. Major emphasis is placed on 'regenerative agriculture' and 'bio-stimulation' as conservation and alternative approaches/management practices improve soil health and agricultural productivity. This paper presents a review and an assessment of regenerative agriculture and plant bio-stimulation and their potential benefits to soil health and agricultural production. It will summarize and communicate the benefits of these two innovative alternative practices to agriculturists, government officials, and farmers. Maintaining our soils and empowering farmers to accelerate the transition to global food security require alternative agriculture systems that enhance the health of our ecosystem and are deemed both economically and ecologically sustainable. Organic farming, conservation farming, "zero-till" farming, bio-stimulation, and bioremediation are just a few of the several methods and production systems that fall under the umbrella of alternative agriculture. In order to attain high agricultural yield, these techniques have been proposed to improve soil management's sustainability" (FAO, 2019). "According to definitions, soil health is the capacity of the soil to carry on as an essential living system within ecological and land-use boundaries, supporting biological productivity, preserving the quality of the air and water, and enhancing the health of people, animals, and plants" [Doran *et al*., 2013 and 2014]. In a more modern definition, soil health was described as "the ability of the soil to sustain the productivity, diversity, and environmental services of terrestrial ecosystems" [16] by the

Intergovernmental Technical Panel on Soils (ITPS) (ITPS 2020). The favourablephysical (texture, water-holding capacity), chemical (pH, soil organic matter; SOM), and biological (microbial diversity, N mineralization, and soil respiration) characteristics of healthy, productive crops are what are considered to be the hallmarks of healthy soil. Considered a living, dynamic ecosystem, soil is home to a diverse range of micro- and macro-biota that control its characteristics. “Modern technology-induced agricultural intensification has reduced soil's ability to sustain its functions, which has an impact on long-term production and results in the loss of ecosystem services” [Bender *et al*., 2016 and Wagg *et al*., 2016]. The main goal of RA is to improve soil health by raising organic matter levels and enhancing soil fertility and productivity.

- ✓ It facilitates soil aggregation, water infiltration, retention and nutrient cycling.
- ✓ Regenerative agriculture also reduces erosion, provides habitat and food for diverse species and is beyond sustainability.

Proponents and implementers of regenerative agriculture (RA) contend that these techniques will stop soil erosion and depletion, actively improve soil, supply crop nutrients with minimal outside help, create high-yielding, healthy crops with few weeds and pests, reduce greenhouse gas emissions, boost farmers' profits, and enhance human health (Figure 1).

Fig 1: Regenerative agriculture

Principles of Regenerative agriculture

Five principles that guide the approach are as follows:

- ✓ Minimize soil disturbance
- ✓ Keep the soil covered year-round
- ✓ Keep live plants and roots in the soil for as long as possible
- ✓ Incorporate biodiversity
- ✓ Integrate animals.

Regenerative agriculture (RA)

The theory behind regenerative agriculture (RA) aims to create sustainable food systems. Varied actors have varied perspectives about RA, and there isn't a consensus definition from science. In order to identify similarities and differences between the goals and actions that characterize RA, findings demonstrate convergence with respect to goals that improve the environment and emphasize the significance of socioeconomic factors that support food security. However, the goals of RA concerning socio-economic aspects are vague and do not have a structure for execution. Based on our research, we provide a tentative description of RA as a farming strategy that starts with soil protection and uses it to regenerate and support a variety of ecosystem services.Regenerative agriculture (RA) is an outcome-based approach of food production that improves agricultural productivity and profitability while preserving biodiversity, the climate, and water resources proponents and practitioners assert that their methods will lower greenhouse gas emissions, halt soil erosion and depletion, actively rebuild soil, supply sufficient crop nutrients with little external inputs, generate high-yielding, healthy crops with few weeds and pests, enhance human health, and more.

- ✓ Biological and ecological systems are combined in a number of ways used by RA practitioners to improve production and restore the function of the landscape. The primary goal is to reap the benefits of natural processes, which may be accomplished by doing the following actions: soil carbon is collected by photosynthesis in plants with high biomass.
- ✓ Improving symbiotic soil micro biota plant interactions.
- ✓ Using biological systems to enhance soil structure and water retention.
- ✓ Including livestock, with an anticipated positive impact on ecosystem services.

It is necessary to tailor these strategies to the specific farming and environmental conditions in which they are employed, as there is no one strategy that fits all circumstances. Variables including precipitation, temperature, soil type, agricultural enterprise mix, markets, and human preferences must be considered while implementing a RA system. Furthermore, RA is not a rigid agricultural method nor an organic farming practise. Rather, it is based on basic principles that enable individuals to apply various techniques to their properties to get the desired outcomes. Many of the techniques used by RA farmers are well-known "good farming" techniques that conventional farmers also use. Other forms of sustainable agriculture, such as carbon farming, low-input farming, organic farming, climate wise agriculture, and low-input farming, also employ certain RA techniques.

Benefits of Regenerative agriculture

Numerous advantages are provided by regenerative agriculture in terms of the environment, economy, and society. Here's a closer look at these benefits:
Benefits to the Environment:

- Enhanced Soil Health

  I. Improved Soil Structure: Regenerative techniques like cover crops and less tillage increase the aggregation and structure of the soil, which promotes better water infiltration and less erosion.

  II. Increased Organic Matter: The addition of compost and green manures to the soil increases its organic matter content, which enhances microbial activity and soil fertility.

  III. Improved Microbial Diversity: A rich soil micro biome that supports nutrient cycling and plant health is fostered by a variety of cropping methods and less soil disturbance.

- Carbon Sequestration:

  I. Increased Soil Carbon Storage: By capturing and storing atmospheric carbon in the soil, regenerative farming techniques including agroforestry, cover crops, and no-till farming assist to slow down global warming.

  II. Decreased Greenhouse Gas Emissions: Regenerative agriculture can reduce emissions of methane and nitrous oxide by enhancing soil health and minimizing the need of synthetic fertilizers.

- Water Resources Management:

  I. Increased Water Retention: Robust soils with a high level of organic matter have the capacity to hold onto more water, which lowers the likelihood of drought and increases resistance to dry spells.

II. Decreased Runoff and Erosion: Techniques such as decreased tillage and cover crops help to clean up streams and lakes by reducing surface runoff and soil erosion.

- Conservation of Biodiversity:

I. Creation of Habitats: Agroforestry and diverse cropping systems support greater biodiversity above and below ground by creating habitats for a wide range of species.

II. Pollinator Support: By giving pollinators resources, flowering cover crops and a variety of plantings promote healthier ecosystems and improved crop pollination.

- Financial Gains Cost Reductions:

I. Lower Input Costs: Farmers' total input costs are generally reduced by using regenerative practices, which frequently eliminate the need for synthetic pesticides and fertilizers.

II. Enhanced Resilience: Diverse cropping strategies and healthier soils can result in more consistent yields and less susceptibility to pests and illnesses, which can lower financial risks.

- Enhanced Output:

I. Enhanced Soil Fertility: Increased crop yields and more effective nutrient use can be brought about by healthier soil, which raises total production.

II. Sustainability over Time: Regenerative methods gradually increase soil fertility, promoting agricultural productivity throughout the long term and lowering the need for expensive soil additives. All these practices are well defined in below:

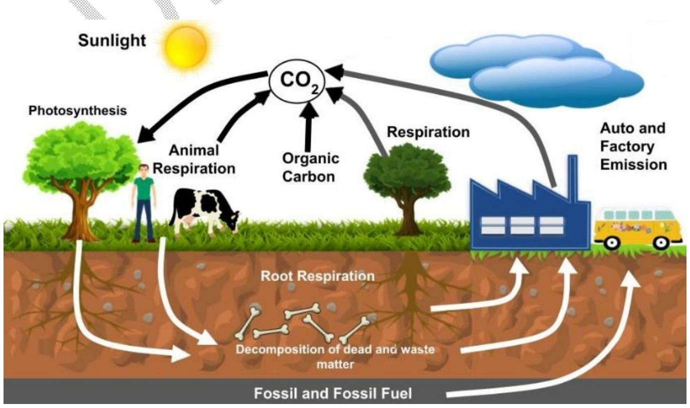

Fig 2:Benefits of Regenerative agriculture

- **Increased soil carbon**

Because soil can hold three times as much carbon as the atmosphere, it is regarded as an active carbon storage pool. The loss of soil organic carbon (SOC) is one of the main factors contributing to soil degradation. It has been demonstrated that SOC enhances soil fertility, aeration, water infiltration, structure, nutrient availability, and water-holding capacity [(Reeves *et al*., 1997]. In order to maximize soil carbon sequestration, air carbon dioxide removal must be minimized. All of the soil organic carbon that is sequestered must come from the atmospheric carbon pool and be absorbed by plants, plant residues, microbial residues, and other organic solids in order for soil carbon sequestration to take place [Olson *et al*.,2014]. Although it varies greatly, roughly 50% of soil organic matter is made up of soil organic carbon [Robertson *et al*., 2015]. The depletion of SOC supplies in terrestrial ecosystems is a key factor contributing to lower agricultural yield. In order to optimize agricultural output, it is recommended to employ management strategies that increase SOC. It has been shown that raising SOC by up to 2% increases maize and wheat yields, which may reduce the demand for N fertilizer (Oldfield *et al*., 2019 and Kane *et al*., 2021). While soil carbon build-up is influenced by regional climate and management practices (Hoyle *et al*., 2016), SOC is believed to be lost as a result of events such erosion, fire, land use conversion, and deforestation. In particular, land cultivation removes topsoil, breaks down the structure of soil aggregates, and exposes SOC to oxidation, all of which change the physical properties of the soil and the availability of nutrients.

The following section discusses a number of cropping techniques used to preserve or raise SOC:

- **Minimum/No tillage**

RA farmers prioritize little to no tillage in order to minimize soil disturbance. The strategy aims to lessen soil disturbance while also encouraging the formation of fungal hyphae, which will enhance the soil's nitrogen cycle. Soil disturbance resulting from intense tillage is the cause of carbon dioxide (CO2) fluxes to the atmosphere and water resources (Sapkota*et al*., 2015). In many countries, regions at danger of soil and water erosion benefit from limited or no tillage in addition to economic savings. Apart from these benefits, experts believe that conservation tillage methods can increase carbon sequestration, lessening the impact of global warming (Yang *et al*., 2013). Tillage and ploughing cause significant soil deterioration and emissions of carbon dioxide into the atmosphere. Minimal or no tillage is a crucial technique employed by RA farmers to reduce soil disturbance. One of the additional advantages of minimizing soil disturbance is that it promotes the growth of fungal hyphae, which improves soil nutrient cycling. Carbon dioxide (CO2) fluxes to the atmosphere and water resources are caused by soil disturbance brought on by intensive tillage [Sapkota*et al.,* 2015]. Some nations have widely embraced minimum or no tillage not just as a cost-saving strategy but also to offer advantages in regions vulnerable to soil and water erosion risk. In addition to these advantages, some specialists think that conservation tillage techniques can improve carbon sequestration, which will lessen the effects of global warming [Yang *et al.,* 2013]. To increase SOC stocks in croplands, the most promising management technique is to combine little tillage with residue retention in a double-cropping system [Li *et al.,* 2020]. In addition to supporting more productive soil with higher biological activity, increased SOC stock or concentration in the topsoil also fosters resilience to adverse weather conditions. One suggestion is to use no-till (NT) farming to enhance the biological qualities of the soil. When Martinez et al. (2013) [46] investigated specific soil parameters in irrigated Mediterranean no-till and conventional tillage (CT) systems, they found that soil chemical fertility increased under NT, with greater levels of N, P, and K. In contrast to traditional tillage, no-till retained more C. Under NT as opposed to CT, increased SOC led to higher biological activity.

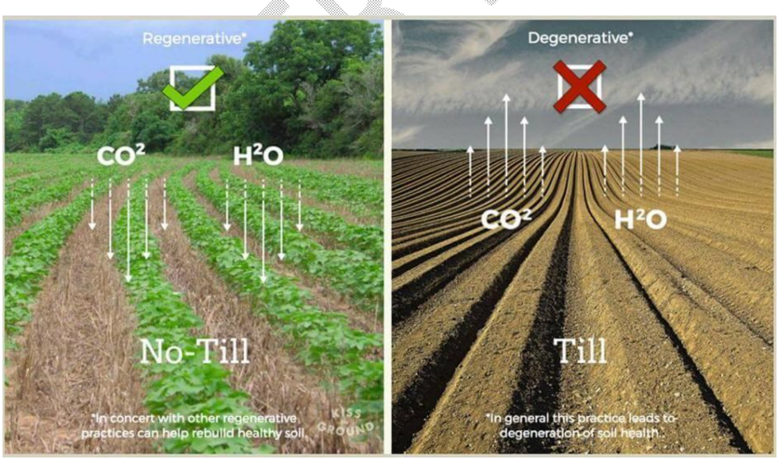

Fig 3: Comparison of regenerative and degenerative agriculture

Based on a global met analysis, Haddaway*et al*. (2017) estimated the increased C stock under no tillage versus high tillage in the upper soil (0–30 cm) to be roughly 4.6 Mg/ha (0.78–8.43 Mg/ha, 95% CI) over approximately 10 years, while no influence was found in the complete soil profile (Deen*et al*., 2003). On the other hand, it was found that slow SOC accumulation could be achieved by adding perennial pastures on a rotational basis to continuous cropping in a warm, semi-arid temperate or subtropical climate with zero tillage (Chan *et al*., 2003 and Young *et al*., 2009). Conservation tillage's capacity to raise SOC is contingent upon several factors, such as soil depth, crop yield, rainfall, stubble retention, and rate of decomposition. The practice of no-till (NT) farming has been advocated as a way to improve the biological properties of soil.Martinez *et al*. (2013) observed that soil chemical fertility rose under NT, with larger levels of N, P, and K. They assessed particular soil parameters in irrigated Mediterranean no-till and conventional tillage (CT) systems. Compared to conventional tillage, no-till yielded increased carbon dioxide storage. Greater SOC under NT compared to CT resulted in greater biological activity. No-till farming improves soil quality, although Powson*et al*. (2014) argue that its significance in mitigating climate change is greatly exaggerated. They also support the enhanced productivity of NT soil with respect to its chemical composition.

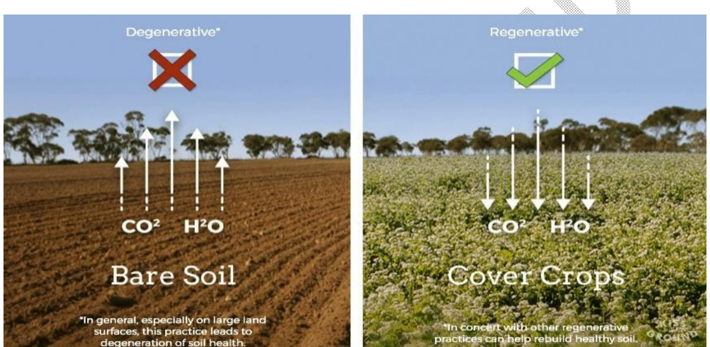

Fig 4: Comparison of bare and cover soil

- **Cover crop**

The second and third RA principles demand that soil cover and live roots remain in the soil for the whole year. One option is to incorporate cover crops into the farming system. Cover crops are often planted between main crops in order to cover the soil and keep live plants there during non-cash farming seasons. This is accomplished by sowing cover crops following harvest or by underseeding cash crops (often grains) with perennial plants that will develop and maintain soil cover for the duration of the subsequent growing season.

Cover crops can be single species or mixtures of several species. While a single species can be managed easily, a combination of species can provide all the benefits of each species in the mixture (Finney *et al*., 2017). Legumes are one of the multi-species cover crops that are thought to improve ecosystem processes like biological nitrogen fixation, microbial variety, reduced compaction, attraction of beneficial insects, suppression of weeds, temperature regulation of the soil, and increased water infiltration.Expanding the use of cover crops might improve soil fertility and aid in carbon sequestration while reducing agricultural Greenhouse Gasesemissions by 10%, which is equivalent to using no-till or other cropping techniques (Kaye *et al*., 2017). Increasing the quantity of soil organic matter in the soil allows cover crops to boost microbial biomass, which is one of their main benefits (McDaniel *et al*., 2014). However, a significant rise in soil carbon can take a few years. Ghimire*et al*. (2018); Poeplau*et al*. (2015). There have been recorded reactions of cover crops to SOC build-up in a variety of agroclimatic regions worldwide. In a temperate, humid region of North America, it has been shown that applying cover crops six times in eight years improves SOC surface storage; however, profitability relies on the type of production system used (Chahal*et al*., 2020).Soil carbon acquisition using cover crops has been linked to soil texture, with clay soils having a greater chance of accumulating soil carbon. Studies carried out in Argentina indicate that the absorption of soil carbon is enhanced by the planting of cover crops on soils with both fine and coarse textures (Alvarez *et al*., 2017). The benefits of no tillage are more evident because residue decomposition proceeds more slowly than it does with conventional tillage, even if cover crops can help eroded soils with low carbon content accumulate more carbon (Hassink*et al*., 1997; Berhe*et al*., 2007). (Olson *et al*., 2014).

Fig 5: Cover crop

- **Stubble retention**

Leaving the stubble on the field after harvest has several advantages, including lessening water runoff and soil erosion, restocking the soil with nutrients, and enhancing water infiltration and carbon input (Packer et al., 1992). Generally speaking, stubble retention affects C build-up more when combined with other management strategies (Saffigna*et al*., 1989). Plant variety influences how above- and below-ground plant litters decompose and change, which in turn influences how SOC is produced and accumulates (Cotrufo*et al*., 2015). Furthermore, the amount of carbon sequestered (C:N ratio) depends on the quality of the residual C intake. Manure with a higher C:N ratio breaks down more slowly, releasing more carbon into the soil, and vice versa. According to Pandey *et al*. (2019), burning stubble results in greenhouse gas emissions, physical, chemical, and biological damage, and a decrease in SOM. Another way to improve soil biodiversity and SOC is to use garbage as a surface mulch (Tomar*et al*., 1992). The capability for sequestering carbon may be significantly or negligibly impacted by stubble addition, depending on the kind of soil. Clay soils with integrated stubble sequester more carbon than sandy soils do. Numerous studies have shown that when stubble retention and no tillage were coupled, crop yield and SOC stocks significantly increased (Xia *et al*., 2018 and Shi *et al*., 2022).

Although keeping stubble in place has been suggested as a way to enhance soil health, it can also pose a risk for the spread of diseases that are carried by stubble and impact crop output. However, the negative impacts can be lessened by implementing integrated disease management measures.

Fig 6: Crop rotation

- **Crop rotation**

Crop rotation, sometimes referred to as diversification, is a centuries-old technique that breaks the cycle of pests, diseases, and weeds while improving production and profit. But around the middle of the 20th century, crop rotation as a technique went back to monoculture because of increased dependence on artificial fertilizers and pesticides, better crop types, and occasionally, financial concerns. In the end, all of these led to SOM loss and land degradation (Di Bene *et al*., 2016). The potential of crop rotation to enhance soil quality is getting more and more attention (Jarecki*et al*., 2003). SOC and N may be greatly increased by farming techniques that include crop rotation with high residue-producing crops, keeping surface residue cover, and minimizing tillage (Havlin*et al*., 1990). However, in WA's rich soil, crop rotation had little effect on SOC. Pulse crops have a major role in the biological fixation of nitrogen, which increases SOC. The yield benefit of rotating wheat and pulse crops, however, depends more on the kind of pulse crop in rotation than SOC as certain pulse crops generate far less biomass and residual inputs than others.

Fig 7: Grazing practices

- **Well managed grazing practice**

Even though raising livestock is sometimes blamed for contributing to methane emissions, integrating animals is another popular RA strategy that enhances soil health and broadens the source of income. In order to improve soil health and elevate SOC, rotational grazing is recommended over continuous grazing. They enhance the total productivity of pastures and grazing areas, as well as plant growth and soil carbon deposits. Additionally, they improve soil carbon sequestration, variety of plants and insects, and soil fertility. These activities improve dietary omega balances and the availability of micronutrients, which is advantageous for the environment, animal health, and human health. Feed lots and restricted animal feeding practices significantly contribute to-

- Un-healthy monoculture production systems,
- low nutrient density forage,
- increased water pollution,

- antibiotic use and resistance
- CO_2 and methane emissions

All of which combine to produce unreliable food production systems that are bad for the environment. One of the most important elements of the many techniques for raising organic livestock is rotational grazing, which involves transferring cattle over pastures on a regular basis to enhance the health of the soil, plants, and animals. Animal welfare must come first in order to satisfy the needs of the animals and keep them healthy without using hormones or antibiotics.

- **Pest, Pathogen, and Weed Control/Suppression**

Crop viruses, pests, and weeds cause significant production losses and financial losses on a global scale. Certain diseases and pests—especially those that prefer warmer climates—are expected to become more common and severe as a result of climate change. Certain environmental conditions, such elevated temperature, CO2, humidity, and nutritional status, can affect plant immune responses. One agricultural practice that promotes disease and pests is monoculture. To lessen the resulting losses, integrated disease and pest control is frequently suggested. Using fungicides and insecticides for traditional plant disease and pest management is one of the recommended approaches, but it has a lot of disadvantages.

In addition to pollution and negative effects on soil microbiota, pesticide consumption in recent years has led to the emergence of pesticide resistance. Consequently, there is a global desire among specialists to develop sustainable and environmentally safe disease control solutions.

Numerous microorganisms present in soil have been recognized as agents that inhibit pests and illnesses. Microbial biological control agents protect crops from diseases by several mechanisms, such as competition, hyper parasitism, and antibiosis. Numerous beneficial soil fungi, viruses, bacteria, and microfauna have been noted as potential candidates for biological control and the restoration of ecological balance (Ruiu*et al*., 2018). Weeds are a big problem in WA farming systems, and chemical weed control is frequently used. It will be extremely difficult to manage weeds in no-till and other regenerative farming practices without the quick development of novel non-chemical strategies. Chemical weed control is not only costly, but it also presents serious issues since certain weed species breed to produce resistant populations. Integrated weed management (IWM), which combines physical, cultural, genetic, biological, and chemical strategies, is the way of the future for long-term weed control. Allopathy is another tactic to reduce the usage of weedicides. Soil microorganisms, including nematodes, bacteria, viruses, and fungus, help reduce weed seed banks. A major drawback is that most of the microorganisms employed to control weeds are diseases that affect both weeds and agricultural plants.

- **Climate Mitigation**

According to RA practitioners, one of the extra advantages of RA is decreased greenhouse gas emissions. Australia's annual greenhouse gas emissions are made up of methane and nitrous oxide, which are produced by the enteric fermentation of crops and livestock/animals, respectively. A 10% to 20% decrease in agricultural productivity can result from a loss in SOC brought on by rising temperatures and likely soil erosion (Delgado *et al*.,2011).

The potential of agricultural methods to mitigate climate change stems from the sequestration of SOC in soil through photosynthesis. The greatest capacity for sequestration is found in crops, grazing/range lands, degraded/deserted lands, and irrigated soils. These areas have the ability to offset emissions from fossil fuels by 5–15% each year. Increased C sequestration in soil may be achieved by a variety of management strategies, such as the use of perennial fodder crops, the removal of bare fallows, the development of biofuel crops, improved nutrient management, less tillage, and the creation of high residues (Paustial*et al*., 1997).

Regenerative agriculture in India

In India, regenerative agriculture is becoming more popular as a workable way to solve problems with degraded soil, limited water supplies, and falling agricultural yields that plague the country's traditional farming systems. This strategy fits in nicely with the many agro-ecological zones and customs of farming in India. The Union government of India is pushing regenerative agriculture in an effort to save input costs and lessen the use of chemical pesticides and fertilizers. States that have launched programs to promote it include Gujarat, Uttarakhand, Himachal Pradesh, Andhra Pradesh, and Sikkim.

An outline of regenerative agriculture in India is provided below:

- **ParamparagatKrishiVikasYojana (PKVY)**

This program, which was introduced in 2015, attempts to enhance the quality of organic products, expand the area under organic farming, and generate jobs in the organic industry. It encourages farmers to employ organic fertilizers, conventional farming techniques, and crop rotation. It also promotes organic farming practices and certification. The program also offers funding for capacity building and organic certification.

- **The National Project on Organic Farming** is the country’s longest experiment on the practice, ongoing since 2004 and conducted by ICAR-Indian Institute of Farming System Research to promote organic farming.

- **Zero-budget natural farming**

Zero-budget natural farming, often referred to as SubhashPalekar Natural Farming, places a strong emphasis on preparing and utilizing inputs derived from a variety of materials, including fruits, cow dung and urine, and crop residue. According to the findings, natural farming uses less energy and less irrigation over time.

- In India, natural farming is encouraged by the BhartiyaPrakritikKrishiPaddhati Programme (BPKP), a centrally supported initiative known as the ParamparagatKrishiVikasYojana (PKVY). The goal of BPKP is to promote traditional indigenous lifestyles that decrease reliance on outside resources. In cooperation with the Ministries of Agriculture and Farmers Welfare, NITI Aayog organized a number of high-level discussions on natural farming methods with experts from outside. In India, regenerative agriculture is already practiced by over 2.5 million farmers. Twenty lakh hectares of organic farming, including natural farming, are expected to be planted in the next five years; twelve lakh of those hectares are expected to come under the BPKP. It is thought to be a profitable farming technique with the potential to boost employment and rural development.
- Sustainable farming: agriculture must cooperate with nature rather than fight it if it is to continue feeding the 224.5 million undernourished people in the nation, according to the UN's State of Food Security and Nutrition in the World, 2022.
- Chemical-free farming: Using natural inputs and cultivation techniques like crop rotation and diversification, which are grouped under the larger heading of regenerative agriculture, farmers, activists, and agricultural research organisations worldwide are creating chemical-free farming methods.

Conclusion

Regenerative agriculture unites soil health, carbon management, and socio-ecological outcomes into a unified framework that offers Indian agriculture a transformative chance. In India, regenerative techniques provide workable answers to urgent problems such soil degradation, water scarcity, and biodiversity loss caused by traditional farming practices. Regenerative agriculture may improve ecosystem resilience, restore soil fertility, and sequester carbon by emphasising techniques like organic farming, agroforestry, and effective water management. It may also strengthen rural communities, encourage biodiversity, and provide farmers more financial stability. A more sustainable, fruitful, and just agricultural system could result from the effective adoption of regenerative practices throughout India, even while obstacles like knowledge gaps and the requirement for supportive policies still exist. Adopting this all-encompassing strategy is in line with India's objectives for sustainable development and environmental stewardship, opening the door for a robust and prosperous agriculture industry. A farmer who uses regenerative practices and doesn't disturb the soil reduces the impact of climate change by cultivating organic matter. Furthermore, the more organic matter there is in the soil. Regenerative agriculture techniques help farmers deal with the immediate effects of climate change by increasing their farms' resilience and adaptability to external events.

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