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# Regenerative agriculture: A pathway to restoring soil quality and improving crop performance

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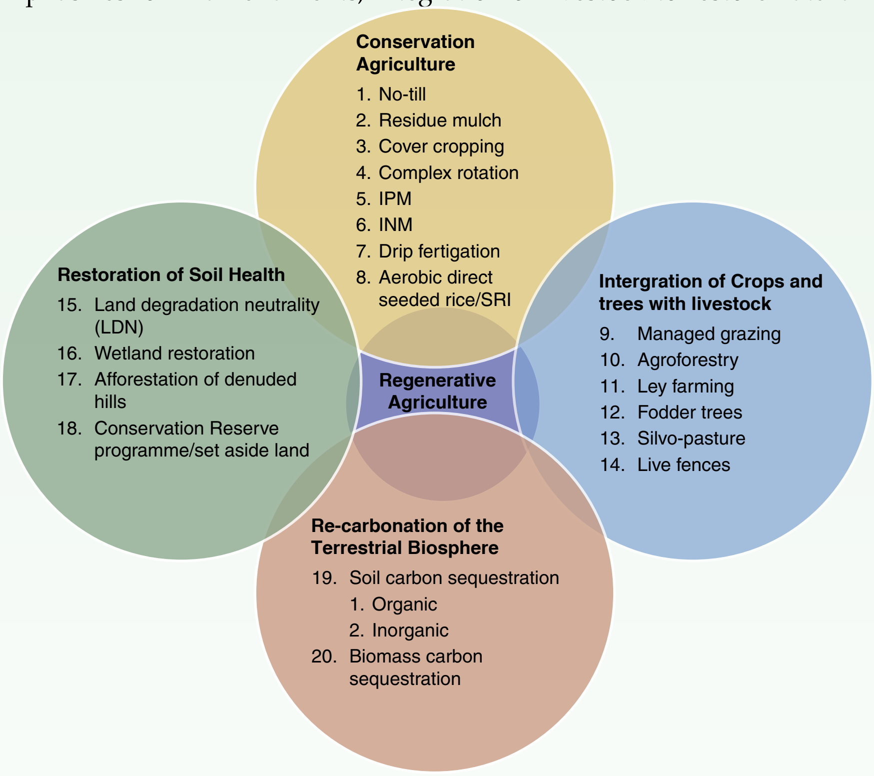
*Regenerative agriculture offers a sustainable pathway to restore soil quality, and improve crop performance by integration of diverse practices i.e. no-tillage, crop diversification, cover crop, agro-forestry and organic amendments. These practices enhance soil structure, water retention, infiltration, nutrient cycling and microbial activity leading to resilient cropping systems with stable yields. Scientific evidences from different land use systems revealed its role in decreasing input dependency, mitigating climate change through C sequestration and strengthening ecosystem services. Thus, it provides a holistic approach for long-term agricultural productivity and environmental sustainability.*

**Keywords:** Cover crop, Crop diversification, Regenerative agriculture, Soil quality, Sustainability

REGENERATIVE agriculture (RA) is an ecologically grounded farming strategy that emphasizes on improving biodiversity, rebuilding soil health, increasing ecosystem resilience, improving nutrient cycling, sustaining crop yield, and restoring landscape functions while preserving or enhancing farm profitability. The approach of RA is based on sets of guiding principles and objectives where practitioners of RA uses various tactics that integrate ecological and biological processes with the aim of increasing agricultural production and restoring soil quality and landscape functionality. The objective of RA is not to restore the native pre-agriculture biology and ecology functions, but to leverage ecological processes in nature with the agriculture systems to enhance farming system health. Unlike the conventional practices that degrade soil fertility and structure through intensive tillage, injudicious use of fertilizers and other agro-chemicals, mono-cropping and faulty irrigation practices, RA employs agricultural practices such as conservation agriculture (CA), crop diversification, cover cropping, use of organic amendments, integration of livestock to restore natural




Basic tenets of regenerative agriculture designed to draw $CO_2$ from the atmosphere (*Source*: Lal 2020).

soil processes. The term "regenerative agriculture" was coined by Gabel in 1979, then Rodale further developed the concept of RA organic farming to include various options that encompass a holistic approach with a focus on social and environmental improvements without the use of synthetic fertilizers and other agro-chemicals. Since then, scientific studies have demonstrated that RA can significantly enhance soil physico-chemical and biological attributes. According to Food and Agricultural Organization (FAO), RA practices have adopted the practices to go beyond the "do no harm" principles of sustainable agriculture.

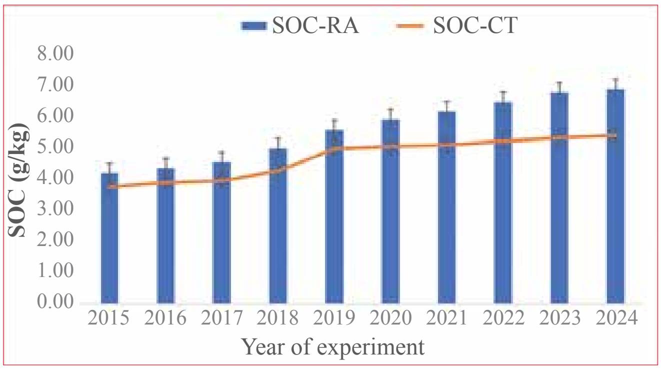
**Table 1.** Regenerative agriculture's principles, practices and purported benefits and mechanisms to improve soil health

| RA Principles | RA Practices | RA Benefits | Microbial Mechanisms |
|---|---|---|---|
| • Minimum soil disturbance<br>• Keep living roots in soil year round<br>• Limited use of chemicals<br>• Keep soils covered<br>• Integrate livestock<br>• Encourage diversity | • No/minimum tillage<br>• Diverse crop rotation<br>• Stubble retention<br>• Multispecies cover<br>• Composting and use of biostimulants<br>• Intercropping<br>• Rotational grazing<br>• Reduce synthetic inputs | ➢ Improved soil health through<br>• Improved microbial functions<br>• Increased soil carbon<br>• Improved soil moisture<br>• Improved resilience to pest and disease<br>➢ Nutrient rich food<br>➢ Reduced greenhouse gas emissions | • Liquid carbon pathway<br>• Enhanced soil aggregation, plant growth and photosynthesis<br>• Improved uptake of water and minerals |

The six principles of RA help in preventions of soil erosion and depletion, provide appropriate nutrients to the crops with minimum external inputs, actively build the soil, produce healthy, high yielding crops with limited weeds and pests' incidences, increase farmers financial returns, minimize the greenhouse gas emissions from agriculture, and improve the human health. The major goal of RA is to capitalize on natural processes through, capturing environmental carbon dioxide ($CO_2$) through photosynthesis, improved symbiotic soil-plant-microbial interaction, enhancing soil structure and water retention through biological means, integration of livestock with positive impact on ecosystem services. For better results and long-term sustainability, RA practices should align with climatic, social and environmental factors i.e. temperature, precipitation, soil type, markets, farm enterprise mix, and individual preferences.

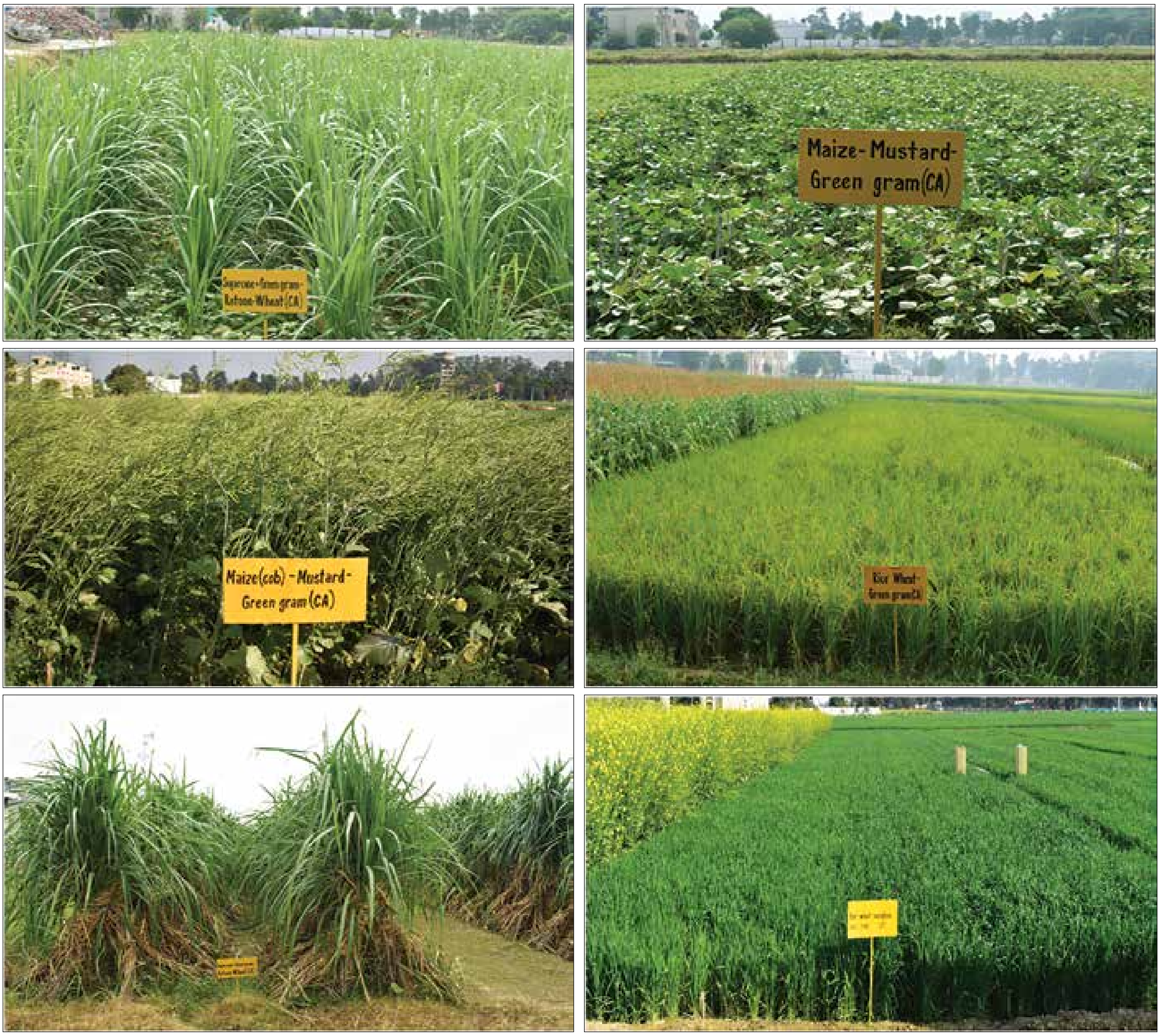
## RA practices for improving soil health/quality

Soil quality/health is defined as the ability of soil to continue function as a vital living system within ecosystem and land-use boundaries, while sustaining biological productivity, maintaining water and air quality, and promoting plant, animal and human health. The soil health is attributed to its desirable soil physico-chemical and biological attributes that supports healthy productive crops. The RA practices primarily focuses on improving soil organic matter and boosting its fertility and productivity. Soil organic carbon (SOC) is crucial for improved soil structure, fertility, aeration, nutrient availability, water holding capacity and water infiltration, solution for mitigating climate change. The RA practices such as no-tillage combined with multi-species cover crops, can improve SOC by 0.3–1.0 Mg C/ha/yr and enhance water retention by 15–20%. Further, an annual improvement of 0.4% SOC in 30–40 cm soil layer in all land uses can significantly absorb $CO_2$ emitted from human activities, while providing co-benefits of improved food security and soil health. Long-term adoption of RA practices can offset 33 Pg SOC losses in different land use systems. In India, trials under Consortium Research Platform on Conservation Agriculture (CRP CA) have shown that integrating no-till/reduce tillage and legumes in different cropping systems increased SOC by 23–29% over a decade. The CA practices i.e. zero tillage, permanent cover and crop diversification which are an integral part of RA, significantly improve the C stock, C-accumulation, and C-sequestration compared to conventional practices. Minimum tillage, a key practice in RA, aims to promote microbial proliferation, thus enhancing nutrient cycling in the soil. Minimum or no-till coupled with residue retention in different cropping systems is a promising management strategy to improve SOC stock, increased biological activity and resilience to harsh weather conditions. Long-term adoption of no-tillage in different landuse systems could improve the C stock around 4.6 Mg/ha in 0–30 cm soil layer over a period of 10 years.



Changes in soil organic carbon over the years in RA and CT practices

Further, long-term adoption of no-till/zero-tillage (NT/ZT) in various land use systems across the Indo-Gangetic Plain of India has shown an improvement of 12–20% in SOC content in the top 0–10 cm soil layer. In addition to SOC enhancement, NT promotes soil aggregation (30–40% improvement) by minimizing soil disturbance. This improved soil aggregation further protects soil organic matter within the soil aggregates.




Performance of different crops in RA based management practices

Soil moisture and infiltration are significantly improved under the NT system due to maintenance of continuous pore networks. NT system reported to increase infiltration rates by 30–50% and soil moisture retention by 25–32% compared to conventional tillage. A long-term study in the Upper Indo-Gangetic Plain (UIGP) demonstrated that adoption of NT practices saved 15–20% irrigation water in the rice-wheat system compared to CT. In addition to SOC improvement, enhanced root proliferation in the NT improves nutrient uptake. Furthermore, NT coupled with crop residue retention improves the available nitrogen, phosphorus, potassium and sulphur by 10–26% in 0–15cm soil layer. Soil biological activity is significantly improved by NT including soil microbes, fungi, actinomycetes, extracellular enzymes and earthworms. A long-term study of 11 years in UIGP showed 40–60% higher soil microbial biomass C and N in NT systems compared to CT. Agroforestry, a key component of RA other than CA practices, plays significant role in improving soil SOM, water retention, nutrient cycling and reducing soil erosion, thus ensure long-term agricultural sustainability and ecosystem functions. Livestock have been an integral part of agriculture since ancient time. Integration on livestock with crops/grazing cover crops have shown a significant improvement in soil health. Studies conducted across the different agro-ecosystems recorded an improvement of soil health index (up to 0.58–0.66 m layer) with crop-livestock integration both in pasture and other land use systems. Likewise, long-term studies (>15 years) for organic manures and their role in regenerative agriculture under different types of soils in India and globe improved SOC by 9.1–11.0%, N (4.0-16.4%), K (9.9-20.3%) and crop phosphorus by 3.56 kg/ha. Crop and soil management approaches i.e. cover cropping and green manuring, crop diversification and rotations, contour farming, terracing and buffer strips are other nature-based approaches which are crucial for sustainability of RA practices. Studies on these practices recorded 0.1–0.3% per year improvement in SOC, and 40–70% reduction in soil erosion.

### RA practices and crop performance

The RA practices have shown a significant positive impact on crop yields and profitability, although the extent of benefits depends on local agro-climatic conditions, crop and soil factors. The RA practices generally lead to enhancement in crop yields and performances, primarily through improved soil health and increased climate resilience. The RA practices build SOM, improving soil nutrient and water retention, enhanced microbial activity, all which benefits the crops during the adverse conditions. The RA practices i.e. NT in conjunction with cover crops/residue retention and crop diversification has potential benefits on crop performance through enhancement in the long-term C sequestration, soil quality, greater resilience to production system to climate change related aberrations, mitigation in greenhouse gas emissions and improved environmental sustainability. Additionally, these practices reduce weed incidences, enhance nutrient and water use efficiency, and prevent crop residue burning. Long-term studies in IGP have shown significant improvement by 20%, 17.7%, 16.6% and 21.4% in maize, mustard, wheat and greengram yield, respectively under RA-NT/ZT systems compared to conventional system. Residue management, crop diversification with inclusion of summer greengram in rice-wheat system can enhance the system productivity by 0.5–1.2 Mg/ha/yr under RA practices. Thus, as a result of its potential to mitigate climate change and improvement in crop yield, regenerative agriculture is recommended as an effective climate-smart agriculture management practice. Scientific evidences from different land use systems across the globe has proven that RA practices promote crop diversification, through inclusion of legumes and agroforestry which stabilize crop yields under climatic stress and it can deliver up to 19% higher crop yields under the drought conditions as compared to monoculture. In south Asia, even replacing rice with maize or pulses under RA system can improve the system productivity by 20–25%.

### SUMMARY

Regenerative agriculture is an ecological approach to restore soil health, biodiversity, and crop performance. Practices such as no-tillage, crop diversification, cover cropping, organic amendments, and agroforestry improve soil organic matter, water retention, and nutrient cycling. These methods reduce erosion, enhance microbial activity, and increase resilience against climate stresses. Scientific studies from the IGP and other regions show yield stability and higher input-use efficiency under regenerative practices compared to conventional farming. By sequestering carbon and enhancing ecosystem services, regenerative agriculture not only boosts farm productivity but also contributes to climate change mitigation and long-term sustainability. Thus, regenerative agriculture serves as a sustainable pathway to maintain soil quality, ensure food security, and support long-term farm profitability.

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