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Enhancing soil management in cropping systems through agronomic, technological and agrostological interventions with case studies: A comprehensive review

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Abstract

Sustainable agricultural practices require efficient soil management in cropping systems to maintain ecological balance and maximum productivity while preserving soil health. The review examines current developments and case studies to clarify the efficacy of agronomic, technological and Agrostological interventions in fostering soil health and sustainability. The agronomic interventions implemented for soil management in cropping system has improved nutrient cycle, erosion management and soil structure. Farmers can optimize soil conditions, improve crop productivity and promote long term sustainability in agriculture. In technological advancement opportunities like remote sensing, Geographic Information System exist to improve soil health, increase production and reduce environmental impact that are critical for soil management. The synergistic benefits of Agrostological practices in promoting soil biodiversity and improving system sustainability. The case studies highlight the good effects on soil fertility, biodiversity and environmental resilience.

Keywords: Soil management, cropping system, agronomic interventions, technological interventions, agrostological interventions

Introduction

The word “Soil” is derived from the Latin word “Solum” means “Floor” or “Ground” (Mondal, 2021) ^[15]. According to USDA, Soil is the unconsolidated mineral or organic material that originates naturally on earth’s surface and acts as natural growing medium for terrestrial plants. It is a dynamic, intricate system that carries out essential tasks it maintains plant and animal life, control water flow, filter and absorb pollutants, cycle nutrients and offer support and stability physically.

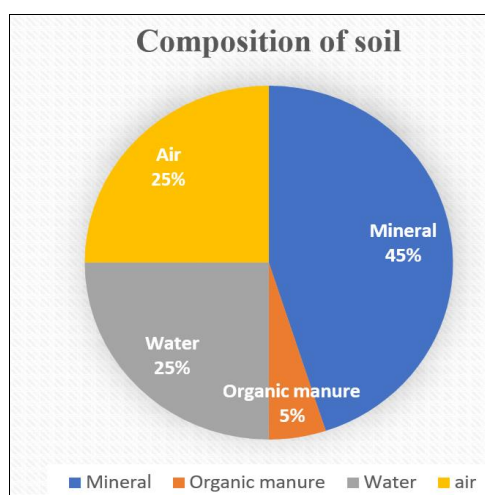


Fig 1: Volume composition of soil

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Soil has four major components such as soil air (25%), soil water (24%), mineral matter (45%) and organic matter (5%) on volume basis (Mondal, 2021)^[15], explained in figure 1.

Due to soil degradation, it has become crucial to manage the soil for good productivity of crop. Soil degradation is the loss of land's potential for production due to a decline in soil fertility, biodiversity and degradation (Maximillian *et al.*, 2019)^[10]. Soil degradation estimates 147 million hectares (Mha) of land in India area affected by soil degradation. Out of this, 94 million hectares are caused by water erosion, 16 million hectares by acidity, 14 million hectares by flooding, 9 million hectares by wind erosion, 6 million hectares by salt and 7 million hectares by a combination factors (Bhattacharyya *et al.*, 2015)^[3]. The main reason behind soil fertility depletion is improper management techniques used in field to increase the yield. Soil degradation refers to the decline in soil quality, often resulting from human activities such as improper land use, deforestation, overgrazing, urbanization and industrialization. It can lead to soil erosion, nutrient depletion, compaction, salinization, and desertification, posing significant environmental, economic, and social challenges (FAO, 2015)^[8],

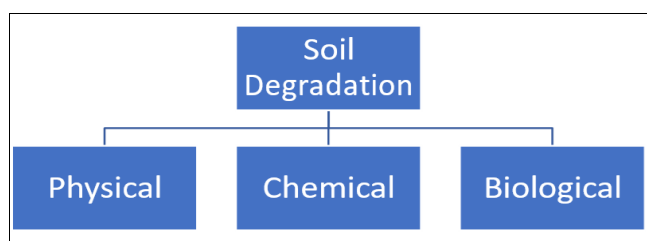


Fig 2: Soil degradation flow chart

Soil management plays crucial role on maintaining productive and sustainable crop production in cropping systems. Cropping system is the order in which the crops are cultivated on a piece of land over a fixed period (Rana *et al.*, 2011)^[21]. In the cropping system, sometimes a number of crops are grown together or they are grown together or separately at short intervals in the same field. Major objectives of cropping systems are (Rana *et al.*, 2011)^[21]:

- Efficient utilization of all resources.
- Maintaining stability in production.
- Obtaining higher returns.

The concept of soil management encompasses a wide array of strategies aimed at improving soil quality, enhancing nutrient availability, minimizing erosion, and mitigating environmental impacts associated with agricultural activities. These strategies range from traditional soil conservation practices to modern precision agriculture techniques tailored to specific agroecological contexts. It involves implementing practices that promote soil health and fertility, minimize tillage, and using appropriate fertilizers. Well-managed soils help lower pest pressure, optimize water use by plants, and improve overall crop yields. Contemporary soil management practices encompass a holistic approach that integrates agronomic, ecological and technological interventions to optimize soil health and productivity.

Agronomical interventions for effective soil management in cropping system

By adopting appropriate agronomic interventions, farmers can optimize soil conditions, improve crop productivity, and promote long-term sustainability in agriculture.

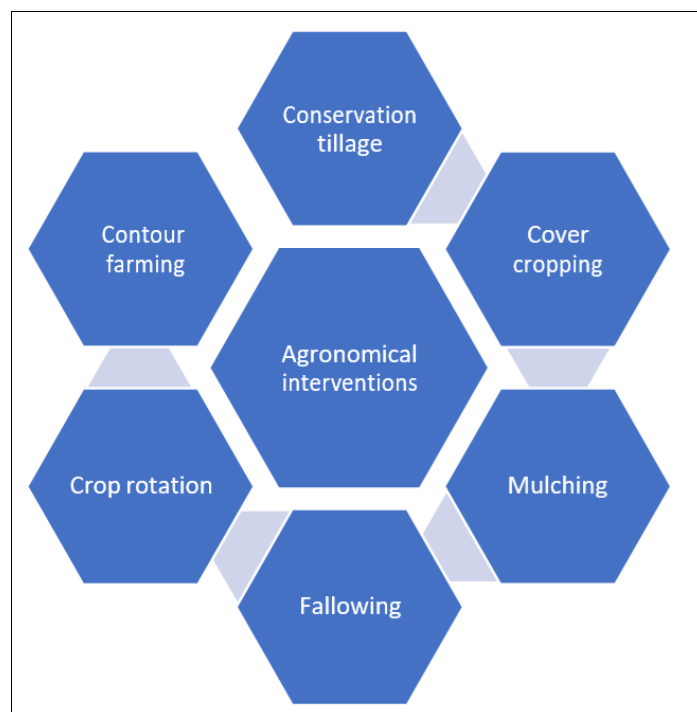


Fig 3: Agronomic interventions for soil management in cropping system

Conservation tillage: Conservation tillage practices, such as no-till and reduced tillage, minimize soil disturbance, and promote soil conservation. Conservation tillage in cropping system involves minimizing soil disturbance during planting and cultivation. Methods include no till, reduced tillage and strip till, which retain crop residues on the surface. By leaving crop residues on the soil surface, conservation tillage enhances soil structure, reduces erosion, and improve water retention capacity. Moreover, conservation tillage systems contribute to carbon sequestration, mitigating climate change impacts and enhancing soil health over time.

Case study: A study in north-eastern Tanzania reveals that the conservation tillage, a combination of ripping, mulch and manure application used to enhance soil health and perhaps stabilise yield levels in smallholder farming systems in semi-arid Sub-Saharan Africa. With a 17% cumulative increase in yield, the study discovers that the treatment only clearly increased yield during one of the six trial seasons. This study also emphasised the difficulties in modernising conventional farming practices and the possible long-term benefits of conservation tillage in terms of increased water availability in the crop root zone (Enfors E, *et al.*, 2011)^[7].

Cover cropping: Cover cropping involves planting temporary vegetative cover crops between main cash crops to protect the soil from erosion, suppress weeds, and improve soil fertility. Cover crops add organic matter to the soil, enhance microbial activity, and contribute to nutrient cycling. Additionally, deep-rooted cover crops help alleviate soil compaction and enhance water infiltration, thereby improving overall soil structure and health.

Case study: The study investigates the advantages of the long-term cover crop management in semi-arid locations. According to the study, the amount of soil organic carbon stocks rose by 0.14 mg ha⁻¹ year⁻¹ for every mg ha⁻¹ of added cover crop

residue between 2008 and 2012. However, despite the drought years in 2018, the amount of soil organic carbon remained unchanged. Additionally, the study discovered that cover crops increased soil aggregation more than fallow or peas, and that the advantage of cover crops for hay and simple cover crop combinations were comparable (Simon *et al.*, 2022) ^[25].

Mulching: Mulching involves covering the soil surface with materials such as plastic films, organic residues or living plants to achieve various benefits in cropping system, including moisture conservation, weed suppression, temperature moderation, erosion control, and improvement of soil health.

Case study: A study in North Eastern Hill region, Umiam, Meghalaya confirms residue mulching effectiveness in improving soil characteristics, high soil organic carbon content, retaining moisture, maximum maize equivalent yield and increasing crop and water productivity in Maize- French bean/black gram system (Ngangom B *et al.*, 2020) ^[17].

Fallowing: Fallowing is the practice of leaving agricultural land uncultivated or without crops for a specific period. This system provides some extent of stability, but in years of well distributed rainfall the chance of harvesting a good crop is lost. This intentional resting period helps in soil regeneration, weed control, moisture conservation, pest management, erosion prevention and promoting sustainable land use. During fallowing, farmers may implement soil conservation measures or plant cover crops to prevent erosion and maintain soil health. Fallowing is often used in rotation with cropping period.

Case study: The investigation practised on small farms near Santarem, Brazil, finding a prevalent multi- fallow cultivation system with rice, corn and bitter manioc. Five types of fallow vegetation are identified, each associated with specific relay-intercropping sequences. The selection of fallow length and cropping sequence is influenced by landscape productivity, ecological requirements, and economic factors (Scatena FN, 1996) ^[24].

Crop rotation: Crop rotation involves alternating the cultivation of different crops in a sequence on the same piece of land. Leguminous crops, such as peas and beans, are often included in crop rotations to fix atmospheric nitrogen, enriching the soil with this essential nutrient and reducing the need for synthetic fertilizers.

Case study: In Germany and Sweden, the study emphasis on the introduction of legumes in crop rotations which presents a fresh innovative approach for assessing and contrasting cropping systems. Cropping systems based on legumes have been found to have less detrimental effects on the environment as well as financial rewards. By highlighting the value of legume services and how they connect to farm economics, the framework promotes participatory design and highlights the possibility for increased agricultural sustainability using legumes (Reckling *et al.*, 2016) ^[22].

Precision nutrient management: Precision nutrient management entails applying fertilizers in precise amounts, timing and placement to optimize nutrient use requirements can be accurately determined, allowing for targeted fertilizer application. Additionally, precision nutrient management techniques, such as split applications and fertigation, ensure that

nutrients are available to crops when needed, reducing nutrient losses through leaching and runoff.

Case study: Three locations in Bangladesh have very different maize grain yields. When potassium was removed more frequently than phosphorus, Comilla experienced significant production losses, while Rajshahi and Rangpur sites experienced a decline maize yield. Because soil potassium is naturally low in these locations, production was lower in plots with no potassium or with less potassium. At Comilla, maize reacted more well to N and K treatments than P application. Districts and farmers' fields within a district differed greatly in terms of agronomic use efficiency for N, P and K in maize (Timsina *et al.*, 2012) ^[31].

Organic manure: Adding organic manure to soil, such as farm yard manure, compost and biochar, is a good way to improve soil fertility and structure, which in turn promotes microbial activity. These substances, which are distinguished by their high level of organic matter, improve soil moisture retention while providing essential nutrients to plants. Additionally, organic amendments improve soil health over time and support carbon sequestration, thereby reducing greenhouse gas emissions.

Case study: A field trial conducted on cotton farms in Xinjiang examined the hypothesis that crop yield can be increased by combining organic fertilizer with biochar additives. The results recorded showed that biochar and organic manure significantly changed the physiological and structural roots by increasing soil nutrients. A study found that adding 1% biochar and 6% organic manure improved the nutrient content and root physiology of the soil. This implies that in continuous cropping systems, the use of both biochar and organic manure can aid in enhancing root health (Zhang *et al.*, 2020) ^[35].

Contour farming: Contour farming, also known as contouring, is the practise of tilling and/or planting along a contour or horizontally across a slope, as opposed to vertically up and down. Furrows are ploughed perpendicular to the slope and not parallel to it. When contour farming proves inadequate to control erosion on exceptionally steep slopes, mitigation and installation of vegetation barriers across the slope become imperative. It performs best when combined with other tactics such as ally management, mulching, cover crops and residue management, mulching, cover cropping and residue management. Contour insulation is suitable for areas having 600mm of precipitation and slope of up to 6%, it is believed to work best on moderate slope between 2 and 7% (Gupta *et al.*, 2021) ^[9].

Case study: A field experiment conducted in 2019, during the Kharif season on Alfisols found that intercropping mung bean with pigeon pea was highly economical and productive. Contour farming yielded higher corn equivalent yield and conserved moisture than up- down farming. The combination of Mung bean + Pigeon Pea and contour farming significantly outperformed other methods in term of corn equivalent yield, soil moisture, nutrient uptake and agronomic efficiency (Ramanjaneyulu *et al.*, 2020) ^[20].

Technological/ Engineering interventions for effective soil management in cropping system

Optimizing soil management practices in cropping systems increasingly depends in technological interventions. By using technological innovations such as remote sensing, sensor-based

monitoring and precision agriculture, opportunities exist to improve soil health, increase production and reduce environmental impact. Precision farming, capture, terracing,

remote sensing, sensor-based monitoring, robotics and other engineering interventions are some of the methods used for soil management in cropping systems.

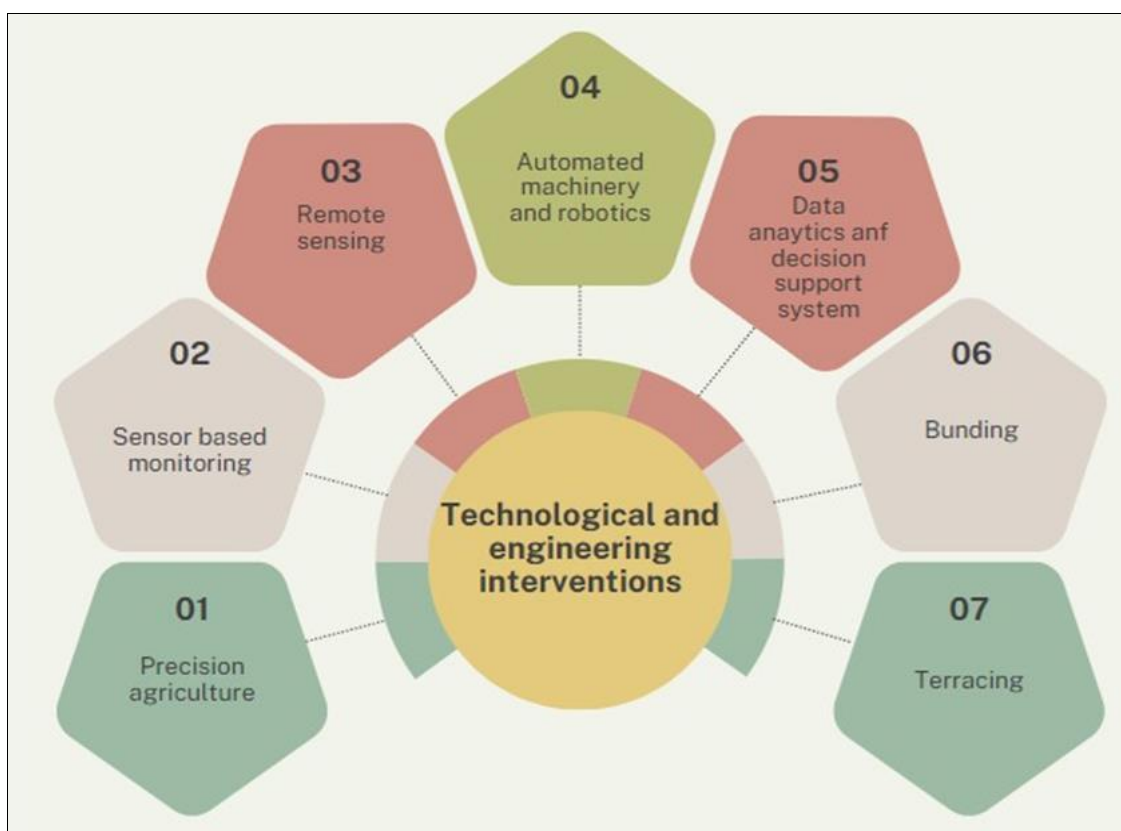


Fig 4: Technological/ Engineering interventions for soil management in cropping system

Precision agriculture: To enable site- specific control of agricultural inputs, precision agriculture makes use of technology like remote sensing, geographic information systems (GPS). With precision agriculture, farmers can accurately monitor crop performance, soil characteristics and variability across their entire field. The targeted use of water, herbicides and fertilizers increases resource efficiency and reduce environmental impact.

Case study: Precision agriculture addresses the problem of different soil properties by allowing the flexible use of substances such as fertilizers and pesticides. While its practical results and economic viability are subjects to debate. Its principles offer theoretical benefits, notably when considering factors like time and labor. A Brazilian study contrasting precision agriculture focus on P- fertilizer with optimized mechanical operations I sugar cane farming revealed efficiency improvements in mechanical processes but not in P- fertilizer use. Nonetheless, recent real- world applications in Brazilian sugar cane farming illustrate precision agricultures economic viability by enhancing efficiency without sacrificing materials and yields (Sparovek *et al.*, 2001) ^[27].

Sensor- based monitoring: Real time data on soil moisture, temperature, nutrient levels and other important characteristics are provided via sensor- based monitoring systems. These sensors can be incorporated into crop monitoring systems or placed directly in the ground. Farmers may increase soil health and crop output by timing irrigations, managing nutrients and controlling pests by regularly evaluating soil conditions and making well- informed decisions.

Case study: This study investigates how to precisely characterise the soil complexity by the integration of data from proximate soil sensors, which could enhance crop productivity and natural resource management. The study predicted soil organic matter, pH, lime buffer capacity and concentration of phosphorus, potassium, calcium, magnesium and aluminium using data from several proximate soil sensors, including topographical records, electrical conductivity and radioisotope content. In order to estimate soil parameters from individual sensors as well as various sensors as well as various sensor combinations, partial least square regressions were employed. Several data mining techniques were used to compare the predictive power, SVM produced superior predictions for soil organic manure, calcium, magnesium and aluminium. However, only MARS and PLSR could be used to make predictions on pH and LBC (Ji *et al.*, 2019) ^[11].

Remote sensing: Unmanned aerial vehicle (UAVs) and satellite photography are two examples of remote sensing technologies that provide important insights into crop health, soil qualities and environmental conditions over wide geographic areas. Data from remote sensing can be used to determine the amount of moisture in the soil, find nutrient shortages and pinpoint places where soil erosion or compaction is occurring.

Case study: The Hetao irrigation district in inner Mongolia, China, was the study's site for examining changes in soil salinity using historical remote sensing photographs. From 1973 until 2006, information was gathered from LANDSAT satellite pictures. According to the study, the total accuracy of remote

sensing in detecting soil salinity was 90.2%, while the accuracy in detecting planted areas was 98%. The study also discovered that lowering cropped land and installing drainage systems assisted in salt control (Wu *et al.*, 2008) ^[33].

Automated machinery and robotics: By enabling accurate and effective field operations, automated machinery and robotics are revolutionising soil management procedures. With GPS guidance systems installed, autonomous tractors can precisely carry out tillage, planting and harvesting operations, reducing soil compaction and increasing crop yields. Furthermore, quick assessment of soil fertility is made possible by robotics systems for soil sampling and analysis, which enables prompt modifications to nutrient management plans.

Case study: The study outlines the development of robotic system designed to collect soil samples autonomously and efficiently, utilizing both robotic technology and cloud-based software. It stresses the significance of precise soil sampling in soil fertility management and advocate for automation to enhance sampling frequency and quality. Adapted from an initial design by the Estonian University of Life Sciences, the robotic platform gathers and stores soil samples while concurrently measuring soil parameters. Operated through specialized software and remote server connection, the platform offers flexibility in function, telemetry monitoring and task scheduling. Through sensor fusion, the navigation software calculates optimal routes and avoids obstacles during operation. Furthermore, the paper explores integrating the system with a test area management platform to define test areas and allocate sample points effectively (Vaeljaots *et al.*, 2018) ^[32].

Data analytics and decision support systems: Large amount of agricultural data is analysed by data analytics and decision support system to produce insights that can be put into practice. They do this by using machine learning algorithms and predictive modelling approaches. To provide farmers advice on soil management techniques, these systems combine data from several sources, such as weather stations, crop monitoring platforms and soil sensors. Farmers may increase input efficiency, soil health and overall farm profitability by utilising data analytics.

Case study: In the context of the European LIFE+ project SOILCONSWEB, the system has undergone testing across a 20000-ha region in southern Italy. The paper presents findings from two specific applications: one focusing on agricultural aspects, particularly olive growth and the other on environmental concerns, especially the soil's capacity to safeguard groundwater. Developed collaborate with end users, the system is gradually being embarked by local communities. It represents a potential shift in the approach of soil and landscape scientists by offering a smart web-based platform that integrates geospatial data, thereby addressing the existing divide between researchers and end users (Terribile *et al.*, 2015) ^[29].

Bunding: Bunding involves creating low embankments or ridges along contour lines.

These structures effectively control water movement, preventing soil erosion and retaining valueable nutrients. By slowing down runoff, bunding encourages water infiltration, promoting optimal soil moisture levels for crop growth. Additionally, bunds serve as barriers against wind erosion and can facilitate efficient water management in areas prone to flooding or waterlogging, in essence, bunding contributes significantly to sustainable soil management and enhances crop resilience in agricultural settings.

Case study: Contour bunding is a widely used land and water management practice in rural Mali since the 1980s to improve agricultural productivity and erosion control. The influence of contour bunding technology on biophysical and socioeconomic advantages is assessed in this study. Data were gathered from sorghum, millet, peanut, maize and two agro-ecologies in southern Mali. The results indicated enhanced soil water retention and erosion rate along with increased crop yield and biomass when using contour bunding. In addition, contour bunding increased biomass and crop yield while reducing soil loss by 163%. The majority of farmers thought that contour bunding plots increased their income, which suggests their income, which suggests that contour bunding should be used across the terrain (Birhanu *et al.*, 2022) ^[4].

Trenching: Trenching is a soil management practice employed within cropping systems to regulate water movement and mitigate erosion. By digging narrow channels or trenches across fields, this technique facilitates water drainage, preventing waterlogging and soil saturation. Additionally, trenching aids in moisture retention by allowing water and infiltrate deeper into the soil profile, promoting optimal conditions for root development and crop growth.

Case study: An assessment of trenching as a method of determining soil autotrophic respiration was conducted in mountains. The experiment included breaking down fine roots and modifying microbial biomass and community structure. Although root degradation was sluggish, trench plots released less carbon dioxide than control plots. Fine root biomass dropped after 5 and 15 months, although autotrophic soil respiration rose to roughly 26% and 44% respectively. According to the study's findings, soil respirations autotrophic and heterotrophic components can be precisely estimated using trenching (Díaz-Pinés *et al.*, 2010) ^[5].

Agrostological interventions for effective soil management in cropping system

Grasses play crucial role in mitigating soil erosion through various mechanisms such as soil particle binding, rainwater absorption and canopy formation. Optimal erosion prevention is achieved through the cultivation of perennial plant species characterized by drought resistance and deep root systems. Additionally, grass legume associations prove beneficial in maintaining soil fertility due to the nitrogen-fixing ability of legumes, which enhances soil nutrient content. It helps to stabilize the surface of water ways, contour bunds, bench terraces etc. Further grasses improve, soil structure, porosity, infiltration and also add organic matter to the soil.



Fig 5: Agrostological interventions for soil management in cropping system

Pasture/ Grassland for shallow

The pasture involves planting and maintaining diverse grasses and legumes in cropping system. By incorporating perennial pasture, cover crops in rotation, and good grazing management, livestock producers can maintain species diversity, build soil health and increase soil carbon and nitrogen in the soil. incorporating forages and ruminants into regeneratively managed cropping systems can also elevate soil organic carbon and improve soil health, ecosystem function and reduce greenhouse gas emissions (Teague *et al.*, 2020) ^[28].

Case study: The study examined integrated crop- livestock systems under no- tillage. Finding that they promote carbon and nitrogen buildup in soil, contingent on pasture management and crop rotation. Two stocking methods and two sheep grazing intensities were evaluated over 14 years, alongside summer crop rotation, impacting crop yield and soil carbon and nitrogen stocks. Deeper soil layers showed lower carbon and nitrogen contents, while the surface layers exhibited higher stocks. Positive correlations were observed between carbon and nitrogen stocks and N inputs from pasture and summer crop residues. Low intensity grazing correlated with increased maize yield compared to moderate grazing, highlighting the significance of nitrogen inputs from soybean and winter pasture in soil carbon and nitrogen accumulation in integrated crop-livestock systems (Alves *et al.*, 2020) ^[1].

Ley farming

Ley farming involves strategic integration of temporary grasslands or fallow fields into crop rotations. This method is employed to enhance soil fertility, mitigate erosion, and manage weed population. The term “ley” denotes fallow and untilled land.

Case study: For Western Australian barren soils and low rainfall locations, perennial pasture legumes are essential for increasing sustainability and productivity. Since animals have fewer dietary preferences than people do. Perennial forage legumes offer more nutritional value as well as hydrological and biological nitrogen fixing benefits. It is difficult to find well-adapted plants, however findings species that yield a lot of hard

seed can help establish a perennial ley- farmings system. A shrub from south Africa’s Fynbos called *Lebeckia ambigua* exhibits characteristics that are necessary or domestication and may help create a permanent ley system (Edwards *et al.*, 2019) ^[6].

- Strip cropping with grasses**

Strip cropping is an agricultural practice where different crops are grown in alternating strips and bands across a field, with grasses typically included as one crop. This method is employed to prevent soil erosion, improve soil fertility and enhance overall crop yields.

When it comes to using grasses in strip cropping, they are often utilized as cover crops or buffer strips between rows of main crops to stabilized the soil and minimize erosion.

Case study: The Central arid zone research institute carried up a field experiment in 2006 and 2007 to investigate soil erosion and system productivity in hot, dry Western Rajasthan using grass-based strip cropping. *Cenchrus ciliaris* grown alone yielded the maximum productivity; strip cropping *C. ciliaris* + cluster beans came in second. Sole cropping resulted in higher rate of soil loss and a net loss of soil organic carbon (Rajasthan, 2013) ^[19].

Vegetation barrier

Vegetative barriers are ecological features composed of natural or planted vegetation, strategically positioned to control erosion, manage water flow and provide environmental benefits. These barriers typically consist of grasses, shrubs, trees or combination thereof planted along slopes, waterways, or vulnerable areas.

Case study: In the highlands of East Africa, the study evaluates he effectiveness of soil protection as well as immediate financial gains from vegetative barriers and low tillage. With the exception of Napier barriers, maize and soybean yields are higher when using vegetative obstacles. The majority of soil was protected by Napier barriers with regular tillage (72%), followed by Napier barriers with limited tillage (53%). The greatest positive marginal rate of returns was found in Leucaena barriers that were regularly tilted. Without barriers, minimum tillage proved ineffective especially after heavy rains. Leucaena barriers were less effective but more appealing commercially (S.N Gutoet *et al.*, 2011) ^[23].

Rotational grazing

Rotational grazing is a grazing management that involves periodical movement of livestock to new paddocks so that the pastures have time to regenerate before being grazed once more. Short- duration grazing, multiple pasture rotation and management intensive grazing are a few common rotational grazing methods (Beetz *et al.*, 1996) ^[2].

Case study: Within a semi- arid rangeland in South east Australia, the study investigates how commercial grazing and conservation could exist simultaneously. Understorey floristic diversity and composition are compared for three types of grazing management: continuous, rotational and protected region. Results reveal that area managed for conservation and those under rotational grazing exhibit greater diversity compared to continuously grazed area. This shows that managing rotational grazing outside of reserve systems can enhance biodiversity conservation (McDonald *et al.*, 2019) ^[13].

Future aspects of enhancing soil management in cropping system

- **Regenerative Agriculture:** Minimal tillage, cover crops and crop rotation are the techniques that highlights the ways to increase the soil health and production by reducing environmental effects (Lal R., 2015) ^[12].
- **Precision Agriculture:** It highlights on how cropping system can optimise inputs and reduce waste by using technologies like data analytics, remote sensing, robotics, which improves sustainability and productivity (Qin *et al.*, 2019).
- **Soil Health Monitoring:** It describes the effective methods for evaluating soil health metrics such as microbial activity and organic matter content for efficient soil management (Moebius-Clune *et al.*, 2016) ^[14].
- **Climate Resilience:** The agricultural systems can be made resilient by using techniques like carbon sequestration and better water management to prevent and adapt to the effects of climate changes on soil (Smith *et al.*, 2020) ^[26].
- **Soil Conservation:** The significance of agroforestry techniques and erosion control measures in preventing degradation of soil and maintaining soil quality for sustained crop production (Montgomery *et al.*, 2007) ^[16].
- **Integrated Systems Approach:** It supports all-encompassing strategies that incorporate soil management with other farming systems elements in order to enhance agricultural productions resilience and sustainability (Thorup-Kristensen *et al.*, 2013) ^[30].

Conclusion

Soil management in cropping systems is pivotal for sustaining agricultural productivity and environmental health. Soil, a complex and dynamic medium, faces significant challenges such as degradation due to erosion, nutrient depletion, and compaction. Effective soil management practices, including conservation tillage, cover cropping, and precision nutrient management, are crucial in mitigating these challenges and enhancing soil fertility and structure. Integrating agronomic, technological, and agrostological interventions offers a holistic approach to optimize soil health and productivity sustainably. Moving forward, adopting regenerative agriculture, precision techniques, and climate-resilient strategies will be essential for securing global food systems and preserving soil integrity for future generations.

References

1. Alves LA, de Oliveira Denardin LG, Martins AP, Bayer C, Veloso MG, Bremm C, *et al.* The effect of crop rotation and sheep grazing management on plant production and soil C and N stocks in a long-term integrated crop-livestock system in Southern Brazil. *Soil and Tillage Research*. 2020;203:104678.
2. Beetz AE, Rinehart L. Rotational grazing. *Attra*; c1996.
3. Bhattacharyya R, Ghosh B, Mishra PK, Mandal B, Srinivasrao C, Sarkar D, *et al.* Soil Degradation in India: Challenges and Potential Solutions. *Sustainability*; c2015.
4. Birhanu BZ, Traoré K, Sanogo K, Tabo R, Fischer G, Whitbread AM. Contour bunding technology-evidence and experience in the semiarid region of southern Mali. *Renewable Agriculture and Food Systems*. 2022;37(S1).
5. Díaz-Pinés E, Schindlbacher A, Pfeffer M, Jandl R, Zechmeister-Boltenstern S, Rubio A. Root trenching: a useful tool to estimate autotrophic soil respiration? A case study in an Austrian mountain forest. *European Journal of Forest Research*. 2010;129(1):101-109.
6. Edwards T, Howieson J, Nutt B, *et al.* A ley-farming system for marginal lands based upon a self-regenerating perennial pasture legume. *Agronomy for Sustainable Development*. 2019;39:13. Available from: <https://doi.org/10.1007/s13593-019-0558-2>
7. Enfors E, Barron J, Makurira H, Rockström J, Tumbo S. Yield and soil system changes from conservation tillage in dryland farming: A case study from North Eastern Tanzania. *Agricultural Water Management*. 2011;98(11):1687-1695.
8. Food and Agriculture Organization of the United Nations (FAO). Status of the World's Soil Resources; c2015. Available from: <http://www.fao.org/3/i5199e/i5199e.pdf>
9. Gupta N, Pradhan S, Jain A, Parel N. Sustainable Agriculture in India 2021: What We Know and How to Scale Up. New Delhi: Council on Energy, Environment and Water; c2021.
10. Maximillian J, Bruseau ML, Glenn EP, Matthias AD. Pollution and Environmental Perturbations in the Global System. In: Bruseau ML, Pepper IL, Gerba CP, editors. *Environmental and Pollution Science*. 3rd ed. Academic Press; 2019. p. 457-476.
11. Ji W, Adamchuk VI, Chen S, Su ASM, Ismail A, Gan Q, *et al.* Simultaneous measurement of multiple soil properties through proximal sensor data fusion: A case study. *Geoderma*. 2019;341:111-128.
12. Lal R. Restoring soil quality to mitigate soil degradation. *Sustainability*. 2015;7(5).
13. McDonald SE, Reid N, Smith R, Waters CM, Hunter J, Rader R. Rotational grazing management achieves similar plant diversity outcomes to areas managed for conservation in a semi-arid rangeland. *The Rangeland Journal*. 2019;41(2):135-145.
14. Moebius-Clune BN. Comprehensive assessment of soil health: The Cornell framework manual. Cornell University; 2016.
15. Mondal B. Concept and Approaches in Soil Science Study and Soils of India; c2021.
16. Montgomery DR. Soil erosion and agricultural sustainability. *Proceedings of the National Academy of Sciences of the United States of America*. 2007;104(33):13268-13272.
17. Ngangom B, Das A, Lal R, Idapuganti RG, Layek J, Basavaraj S, *et al.* Double mulching improves soil properties and productivity of maize-based cropping system in eastern Indian Himalayas. *International Soil and Water Conservation Research*. 2020;8(3):308-320.
18. Quintarelli V, Radicetti E, Allevato E, Stazi SR, Haider G, Abideen Z, *et al.* Cover crops for sustainable cropping systems: a review. *Agriculture*. 2022;12(12):2076.
19. Rajasthan SOHAW. Grass based strip cropping systems for controlling soil erosion and enhancing system productivity under drought situations of hot arid western Rajasthan. *International Journal of Agricultural Statistical Science*. 2013;9(2):685-692.
20. Ramanjaneyulu AV, Sainath N, Sravanthi D, Ramana MV. Contour farming improves soil moisture and dry land crop productivity on rainfed Alfisols. *International Research Journal of Pure and Applied Chemistry*. 2020;21(21):60-69.
21. Rana SS, Rana MC. Cropping system. Palampur: Department of Agronomy, College of Agriculture, CSK Himachal Pradesh Krishi Vishwavidyalaya; c2011. p. 80.
22. Reckling M, Hecker JM, Bergkvist G, Watson CA, Zander

- P, Schläfke N, *et al.* A cropping system assessment framework—evaluating effects of introducing legumes into crop rotations. *European Journal of Agronomy*. 2016;76:186-197.
23. Guto SN, Pypers P, Vanlauwe B, de Ridder N, Giller KE. Tillage and vegetative barrier effects on soil conservation and short-term economic benefits in the Central Kenya highlands. *Field Crops Research*. 2011;122(2):85-94.
24. Scatena FN, Walker RT, Homma AKO, de Conto AJ, Ferreira CAP, de Amorim Carvalho R, *et al.* Cropping and fallowing sequences of small farms in the “terra firme” landscape of the Brazilian Amazon: a case study from Santarem, Para. *Ecological Economics*. 1996;18(1):29-40.
25. Simon LM, Obour AK, Holman JD, Roozeboom KL. Long-term cover crop management effects on soil properties in dryland cropping systems. *Agriculture, Ecosystems & Environment*. 2022;328:107852.
26. Smith P, Soussana JF, Angers D, Schipper L, Chenu C, Rasse DP, *et al.* How to measure, report and verify soil carbon change to realize the potential of soil carbon sequestration for atmospheric greenhouse gas removal. *Global Change Biology*. 2020;26(1).
27. Sparovek G, Schnug E. Soil tillage and precision agriculture: A theoretical case study for soil erosion control in Brazilian sugar cane production. *Soil and Tillage Research*. 2001;61(1-2):47-54.
28. Teague R, Kreuter U. Managing grazing to restore soil health, ecosystem function, and ecosystem services. *Frontiers in Sustainable Food Systems*. 2020;4:534187.
29. Terribile F, Agrillo A, Bonfante A, Buscemi G, Colandrea M, D'Antonio A, *et al.* A Web-based spatial decision supporting system for land management and soil conservation. *Solid Earth*. 2015;6(3):903-928.
30. Thorup-Kristensen K, Magid J, Jensen LS. Catch crops and green manures as biological tools in nitrogen management in temperate zones; c2003.
31. Timsina J, Majumdar K. Improved nutrient management in rice-maize cropping systems: A case study. *Better Crops South Asia*. 2012;6(1):25-26.
32. Vaeljaots E, Lehist H, Kiik M, Leemet T. Soil sampling automation case-study using unmanned ground vehicle. *Engineering for Rural Development*. 2018;17:982-987.
33. Wu J, Vincent B, Yang J, Bouarfa S, Vidal A. Remote sensing monitoring of changes in soil salinity: a case study in Inner Mongolia, China. *Sensors*. 2008;8(11):7035-7049.
34. Zhang N, Wang M, Wang N. Precision agriculture—a worldwide overview. *Computers and Electronics in Agriculture*. 2002;36(2-3):113-132.
35. Zhang Z, Dong X, Wang S, Pu X. Benefits of organic manure combined with biochar amendments to cotton root growth and yield under continuous cropping systems in Xinjiang, China. *Scientific Reports*. 2020;10(1):4718.