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Impact of *in-situ* green manuring on soil properties and fertility under regenerative farming: A case study of Akshayakalpa farm in Tiptur, India

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Abstract
Regenerative farming is a way of farming that focuses on soil health. When soil is healthy, it produces more food and nutrition, stores more carbon, and increases biodiversity – the variety of species. A teaspoon of soil contains up to 6 billion microorganisms. Healthy soil supports other water, land and air environments and ecosystems through natural processes including water drainage and pollination. This study explores the progress of soil physico-chemical and biological properties, fertility, nutrient supply to succeeding crops, checking erosion and plant protection due to green manuring under regenerative farming system. The green undecomposed material used as manure is called green manure. It is obtained in two ways: by growing green manure crops or by collecting green leaves (along with twigs) from plants grown in wastelands, field bunds and forests. The green manuring is growing in the field plants usually belonging to leguminous family and incorporating into the soil after sufficient growth. The plants that are grown for green manure are known as green manure crops. The green manure crops sowed at the farm are Sun-hemp, Dhaincha, Bajra and Horse gram and this was done for 65 acres. The soil test reports were collected before and after green manuring. The average of all the soil samples showing the improvement in the soil parameters and nutrient level is as follows, the soil pH from 6.96 to 7.22, EC from 0.215 to 0.117, OC from 0.403 to 0.595, Copper from 0.85 to 0.84, Zinc from 1.35 to 0.98, Iron from 4.89 to 6.05, Manganese from 2.09 to 0.58, Nitrogen from 266.77 to 658.51, Phosphorous from 23.77 to 32.96 and Potassium from 295.29 to 296.51.

Keywords: Regenerative farming, green manure, Soil properties, soil nutrients, biomass, organic carbon (OC), electrical conductivity (EC)

Introduction

Agriculture today, including the use of heavy machinery, fertilizers, and pesticides to maximize food production, is contributing to soil degradation and loss. Within 50 years, there may not be enough soil left to feed the world, according to regenerative farming organization Regeneration International. Intensive farming also churns up CO_2 naturally stored in soil and releases it into the atmosphere. This contributes to global warming that is driving climate change. Agriculture accounts for over a third of greenhouse gas emissions globally, according to the United Nations (UN).

Regenerative farming methods include minimizing the ploughing of land, explains Regeneration International. This keeps CO_2 in the soil, improves its water absorbency and leaves vital fungal communities in the earth undisturbed. Rotating crops to vary the types of crops planted improves biodiversity, while using animal manure and compost helps to return nutrients to the soil. Continuously grazing animals on the same piece of land can also degrade soil, explains the Regenerative farming in Europe report from the European Academies' Science Advisory Council. So regenerative agriculture methods include moving grazing animals to different pastures. While damaged soil and eroded land can make environments more vulnerable to extreme weather events like flooding, which are increasing in frequency and intensity as the Earth warms.

In regenerative farming systems to enhance the soil nutrient levels and to maintain the ideal soil parameters green manuring is found to be the best option.

The green manuring crops are beneficial for increasing nitrogen uptake by plants and improving fodder yield. The primary purpose of green manure crops is to increase the nitrogen supply for succeeding crops through biological nitrogen fixation (Irin and Biswas 2021) [1]. The green manuring crops provide multiple benefits in enhancing soil fertility and crop productivity (Nelson *et al*., 2010) [8]. These benefits include increased organic matter content, improved soil structure, enhanced nutrient availability, reduced erosion, and disease suppression. The use of green manure crops in agriculture has become increasingly important to enhance soil fertility and promote sustainable crop production Overall, the addition of green manuring crops to agricultural practices is crucial for maintaining and enhancing soil fertility (Chandrasoorian *et al*., 2020) [3]. Green manure crops, such as Sesbania aculeate and cluster beans, have been found to increase soil organic matter content, nutrient availability, and soil fertility by improving the physical, chemical, and biological properties of the soil (Li *et al*., 2021) [6]. The use of green manure crops can also help mitigate the limitations of inorganic fertilizers, such as scarcity, high cost, nutrient imbalance, and soil acidity (Isah *et al*., 2014) [4]. Green manure crops offer a low-cost opportunity for maintaining soil fertility by supplying nutrients during decomposition with slow release, which can be better timed with plant uptake while reducing nutrient losses. In addition to enhancing soil fertility and nutrient availability, green manure crops also contribute to sustainable agriculture practices by reducing erosion and suppressing diseases (Ansa and Wiro 2020) [2]. Green manuring is a field operation that involves in-situ raising and incorporation of legume crops in the soil to supply nitrogen through biological nitrogen fixation (Kaur *et al*., 2019) [5]. Additionally, the use of green manure crops also promotes biodiversity and helps in weed control by providing competition against unwanted plant species. Overall, the adoption of green manuring crops is a crucial step towards enhancing soil fertility and overall plant and soil health. The integration of agricultural manure and green manure in combination with mineral fertilizers has been proven to significantly increase crop yields, indicating the potential of these biofertilizers to promote sustainable agriculture and enhance crop productivity (Lorraine *et al*., 2015) [7]. In this paper, we explore the potential role of green manuring in improvement of soil properties, soil nutrients and soil fertility under regenerative farming system.

Materials and Methods

The study was conducted at Akshayakalpas' Devarakadu Research and Development, which is located near Tiptur, Tumkur district of Karnataka. The Sixty-five (65) acres of land was selected for the study. The land was covered with coconut plantations, fruit crops like mango, sapota and Guava, Papaya, Jackfruit, Timber crops like Neem, Rosewood, Sandalwood, Malabar Neem, Subabul, Teak, and Mahagony etc.

Descriptive research design has been employed; the primary data has been collected by researchers. The data on soil pH, OC, EC, Macro-nutrients, and Micro-nutrients status were tested before and after green manuring through soil test at local Krishi Vigyan Kendra (Farm science Center- ICAR KVK, Konehalli, Tumkur-1). Using descriptive statistics, the data has been analyzed with statistical tools such as frequency and percentage. The results are summarized below.

Results and Discussion

A total of 34,988 Kgs of fresh in-situ biomass was generated in 65 acres of land and added to soil. Total dry biomass was found to be 21,084 kgs.

Table 1: Table representing the biomass of in-situ green manuring added into the soil.

Sample Areas	Total Fresh Biomass (Kgs)	Total Dry Biomass (Kgs)
1	7180	4708
2	3992	2332
3	7288	4036
4	5484	2956
5	6808	4356
6	4236	2696
Total	34,988	21,084

A total of 34,988 kg of fresh in-situ green manure biomass was added to the soil with round of rotavator by using tractor, the 60 days of post-addition of fresh biomass to the soil, the soil parameters and soil nutrients were re-examined and compared to previous/baseline data.

The post incorporation of in-situ green manures the soil pH, EC and OC in sampling area has been changed as follows. In sampling area-1, pH from 7.27 to 7.40, EC from 0.22 to 0.129 and OC from 0.33% to 0.58%. In sampling area-2, pH from 7.40 to 7.2, EC from 0.20 to 0.094 and OC from 0.58% to 0.68%. In sampling area-3, pH from 6.41 to 7.39, EC from 0.19 to 0.098 and OC from 0.39% to 0.61%.

Table 2: Table representing the soil pH, EC, and OC - before and after green manuring.

Sample plot	Stage of Study	pH (6.5-8.4)	Electrical conductivity (<0.25)	Organic Carbon (0.50-0.75)
1	Before	7.27	0.22	0.33
	After	7.40	0.129	0.58
2	Before	7.40	0.20	0.58
	After	7.20	0.094	0.68
3	Before	6.41	0.19	0.39
	After	7.39	0.098	0.61
4	Before	6.62	0.28	0.44
	After	7.36	0.158	0.56
5	Before	6.60	0.26	0.35
	After	6.20	0.094	0.53
6	Before	7.47	0.14	0.33
	After	7.78	0.132	0.61
Average value	Before	6.96	0.215	0.403
	After	7.22	0.117	0.595

In sampling area-4, pH from 6.62 to 7.36, EC from 0.28 to 0.158 and OC from 0.44% to 0.56%. In sampling area-5, pH from 6.60 to 6.20, EC from 0.26 to 0.094 and OC from 0.35% to 0.53%. In sampling area-6, pH from 7.47 to 7.78 EC from 0.14 to 0.132 and OC from 0.33% to 0.61%

Post in-situ leaf manuring leads to an increase in the soil organic carbon and maintained the PH and EC within the limits. Organic matter is one of the most important components of soil that plays an important role in improving the chemical, physical and biological properties of the soil (Fenton *et al*., 2008; Roman *et al*., 2015). In Indonesia, most of the agricultural land (73%) has low organic matter content (<2%) (Pringadi, 2009) [9]. Whereas the organic matter content of the soil in 89% of the agricultural lands in Turkey varies from less than 1% (very low level) and around 1-2% (low level) (Ünver, 2013; Gezgin, 2018) [11]. Soil organic matter from crop reduces in the range of 2-5% per year (Rosenfeld and Rayns, 2011) [10]. To provide sustainability and the availability of organic matter and other nutrients of the soil, the amendment of organic matter into the soil needs to be done. One of the basic sources of organic amendment into the soils is

green manuring. It also maintains the pH and EC within the recommendable range.
The macronutrients level was also examined in the soil and the results are as follows, the nitrogen, phosphorus, potassium in different samples is found to be changed.

In sampling area 1: The N, P, K was changed from 246.49 kg/ha, 21.98 kg/ha and 277.40 kg/ha to 689.90 kg/ha, 37.38 kg/ha and 308.31 kg/ha respectively. In sampling area 2, the N, P, K were changed from 259.90 kg/ha, 21.52 kg/ha and 309.25 kg/ha to 685.50 kg/ha, 33.25 kg/ha and 294.87 kg/ha respectively.

In sampling area 2: The N, P, K were changed from 259.90 kg/ha, 21.52 kg/ha and 309.25 kg/ha to 685.50 kg/ha, 33.25 kg/ha and 294.87 kg/ha respectively.

In sampling area 3: The N, P, K was changed from 287.26 kg/ha, 24.50 kg/ha and 308.31 kg/ha to 685.50 kg/ha, 29.54 kg/ha and 289.50 kg/ha respectively. In sampling area 4, the N, P, K were changed from 250.88 kg/ha, 27.02 kg/ha and 291.24 kg/ha to 595.80 kg/ha, 50.40 kg/ha and 294.60 kg/ha respectively.

In sampling area 4: The N, P, K were changed from 250.88 kg/ha, 27.02 kg/ha and 291.24 kg/ha to 595.80 kg/ha, 50.40 kg/ha and 294.60 kg/ha respectively.

In sampling area 5: The N, P, K was changed from 270.95 kg/ha, 25.41 kg/ha and 281.70 kg/ha to 627.20 kg/ha, 47.04 kg/ha and 302.80 kg/ha respectively. And

In sampling area 6: The N, P, K was changed from 286.00 kg/ha, 22.21 kg/ha and 303.88 kg/ha to 721.20 kg/ha, 0.13 kg/ha and 288.96 kg/ha respectively.

The green manuring is a sustainable agricultural practice that significantly improves the fertility of soil through various mechanisms. Here are detailed explanations of how green manuring enhances soil fertility.

a) Nutrient Accumulation and Recycling: Green manure crops actively absorb nutrients, including nitrogen, phosphorus, and potassium, from the lower layers of the soil through their root systems. When these crops are ploughed back into the soil as organic matter, they release these nutrients, making them available to subsequent crops. This nutrient recycling helps maintain soil fertility by ensuring that essential elements are continuously cycled within the ecosystem.

b) Nutrient Retention: Green manure crops, with their dense root systems, help prevent the leaching of nutrients from the soil. Leaching occurs when rainfall or irrigation water carries nutrients downward into deeper soil layers or groundwater, making them unavailable to plants. Green manure crops act as a barrier, reducing nutrient loss and ensuring that valuable nutrients remain in the upper soil profile where plants can access them.

c) Nitrogen Fixation: Many green manure crops, particularly legumes, have a symbiotic relationship with nitrogen-fixing bacteria called rhizobia. These bacteria reside in the root nodules of legumes and have the remarkable ability to convert atmospheric nitrogen gas (N_2) into ammonia (NH_3) and other nitrogen compounds that plants can use for growth. This biological nitrogen fixation not only provides a direct source of nitrogen for the green manure crop but also enriches the soil with nitrogen when the crop is incorporated, benefiting subsequent crops.

d) Increased Nutrient Solubility: Green manure crops, as well as the organic matter they add to the soil, promote the activity of soil microorganisms. These microorganisms break down organic matter and produce organic acids during decomposition. These organic acids enhance the solubility of essential nutrients such as lime, phosphate, and various trace elements. As a result, these nutrients become more accessible to plants, supporting their growth and overall health.

e) Improved Soil Structure: The addition of green manure to the soil enhances its physical properties. The organic matter from green manure helps create better soil structure, increasing its water-holding capacity, aeration, and overall tilth. Improved soil structure allows plant roots to penetrate more easily, access nutrients, and grows more vigorously.

Tabel 3: Tabel representing the status of macro nutrients before and after green manuring.

Sample plot	Stage of Study	Nitrogen (N) (280-560Kg/Ha)	Phosphorous (P) (22.5-55Kg/Ha)	Potassium (K) (144-336Kg/Ha)
1	Before	246.49	21.98	277.4
	After	689.9	37.38	308.31
2	Before	259.03	21.52	309.25
	After	658.5	33.32	294.87
3	Before	287.26	24.50	308.31
	After	658.5	29.54	289.50
4	Before	250.88	27.02	291.24
	After	595.80	50.40	294.60
5	Before	270.95	25.41	281.7
	After	627.2	47.04	302.80
6	Before	286.00	22.21	303.88
	After	721.2	0.13	288.96
Average value	Before	266.77	23.77	295.29
	After	658.51	32.96	296.51

The micro-nutrients level was also examined in the soil and the results are as follows, the copper, zinc, iron, and manganese in different samples is found to be changed.

In sampling area 1: The Cu, Zn, Fe and Mn were changed from 0.58 ppm to 1.001 ppm, 0.78 ppm to 1.14 ppm, 4.67 ppm to 5.837 ppm and 1.51 ppm to 0.82 ppm respectively.

In sampling area 2: The Cu, Zn, Fe and Mn were changed from 0.88 ppm to 0.513 ppm, 1.11 ppm to 1.06 ppm, 3.20 ppm to 1.198 ppm and 2.11 ppm to 0.46 ppm respectively.

Tabel 4: Tabel representing the status of micronutrients before and after green manuring.

Sample	Stage	Copper (0.2-2.0ppm)	Zinc (0.6-1.2)	Iron (4.5-9.0ppm)	Manganese (2-4ppm)
1	Before	0.58	0.78	4.67	1.51
	After	1.001	1.14	5.837	0.82
2	Before	0.88	1.11	3.20	2.11
	After	0.513	1.06	1.198	0.46
3	Before	0.77	1.42	5.21	2.11
	After	0.917	0.94	6.009	0.74
4	Before	0.81	1.58	5.22	2.11
	After	0.638	0.8	6.294	0.49
5	Before	1.29	1.44	6.72	2.45
	After	0.89	1.12	5.591	0.42
6	Before	0.82	1.77	4.32	2.23
	After	1.132	0.82	11.295	0.56
Average Value	Before	0.85	1.35	4.89	2.09
	After	0.84	0.98	6.05	0.58

In sampling area 3: The Cu, Zn, Fe and Mn were changed from 0.77 ppm to 0.917 ppm, 1.42 ppm to 0.94 ppm, 5.21 ppm to 6.294 ppm and 2.11 ppm to 0.74 ppm respectively.

In sampling area 4: The Cu, Zn, Fe and Mn were changed from 0.81 ppm to 0.638 ppm, 1.58 ppm to 0.80 ppm, 5.22 ppm to 6.294 ppm and 2.11 ppm to 0.49 ppm respectively.

In sampling area 5: The Cu, Zn, Fe and Mn were changed from 1.29 ppm to 0.89 ppm, 1.44 ppm to 1.12 ppm, 6.72 ppm to 5.591 ppm and 2.45 ppm to 0.42 ppm respectively and

In sampling area 6: The Cu, Zn, Fe and Mn were changed from 0.82 ppm to 1.132 ppm, 1.77 ppm to 0.82 ppm, 4.32 ppm to 11.295 ppm and 2.23 ppm to 0.56 ppm respectively.
The green manuring is a multifaceted approach to improving soil fertility. It enriches the soil with nutrients, prevents nutrient loss through leaching, harnesses nitrogen-fixing bacteria, and enhances nutrient solubility while also benefiting soil structure. This sustainable practice not only boosts crop productivity but also promotes long-term soil health and reduces the need for synthetic fertilizers and chemical inputs, making it an essential component of sustainable and environmentally friendly agriculture.

Conclusion
Regenerative farming can improve crop yields – the volume of crops produced – by improving the health of soil and its ability to retain water, as well as reducing soil erosion. Also, organic matter is one of the most important components of the soil. The Soil organic matter is the source of nitrogen, as well as all nutrients. The application of green manure plants improves the physical, chemical, and biological properties of soil by basically increasing the amount of organic matter. According to several previous studies and current studies, the incorporation of several green manure crops significantly improved the chemical, physical and biological properties of the soil. In addition, green manure also potentially contributes to disease, pest, and weed control as well as increased soil erosion. The green manure is very important for environmental sustainability by reducing chemical fertilizers and pesticides, improving soil properties, controlling soil erosion, and preventing the leaching of nitrate and other chemical inputs into surface and groundwater.

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