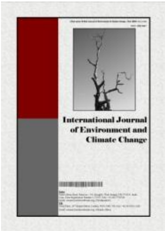

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Long Term Benefits of Legume Based Cropping Systems on Soil Health and Productivity. An Overview

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Increasing land-use pressure and monoculture coupled with inadequate restorative practices pose threat to sustainability, nutrient uptake of crops often exceeds replenishment causing fertility deterioration. Imbalanced and indiscriminate use of fertilizers deteriorates soil health and factor productivity. Long-term impacts on soil nutrient stocks influence the sustainability of crop production are major gains of regular inclusions of legume in a cropping system. Inclusion of green gram in potato cultivation increased organic carbon and nutrients than non-legume based potato cropping systems. Legume-based cropping systems increased soil C and N stock than only cereal based cropping system. Maize intercropped with velvet-bean recorded higher productivity compared with pure maize and pure maize with mineral fertilizers. Bulk density of soil in glyricidia + maize system was lower compared to sole maize and maize grass fallow. Intercropping

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with glyricidia, glyricidia pruning incorporated into the soil optimized the cation exchange capacity in soil than sole maize system. Higher grain yield of finger millet and sustainable yield index were observed in green leaf manuring. Due to socioeconomic and environmental benefits, legumes could be introduced in cropping systems to reduce external inputs and increase crop diversity. They also found to perform well in conservation systems, intercropping systems, which are very important in developing nations. Legumes fix nitrogen from the atmosphere and aid in the cycle of soil nutrients and water retention. Because of their many uses, legumes have a lot of potential for conservation agriculture, as they can be used as a growing crop or as crop residue.

Keywords: Cropping system; legumes; soil health; sustainability.

1. INTRODUCTION

Large regional disparities distinguish crop production systems around the world. They are still evolving in response to rising land demands, crop introductions, and new technology. Land becoming greatly limiting due to ever increasing population and land pressures. Soil being an important component of the earth's biosphere and its proper maintenance is essential in sustaining the production of food, fiber and environmental quality. Improper land use and poor soil management accelerate soil degradation, affecting adversely the environment and jeopardize productivity. Use of Inorganic fertilizer needs an economic shift involving very high investments in the local manufacture. Otherwise, they remain expensive and beyond the reach of farmers. Premised on their nitrogen fixing characteristics, intensive and sufficient quantities incorporation of legumes in cropping systems should lower the amounts of inorganic nitrogen applied. Legumes have long been prescribed as the missing ingredient for conserving soil resources, yet farmer production of legumes is minimal. In addition to increasing soil physical status, this should lower the cost of N fertilizer input and the danger of water pollution. Carbon (C)-adding soil systems have been discovered as having the potential to store N and make it available for future crop use while reducing the danger of contamination. Food insecure farmers rely on cereal-dominated cropping systems, which poses a long-term sustainability concern for cropping systems in developing nations. Legumes recycle nutrients from deep in the subsoil. Furthermore, legumes have the ability to emit root chemicals that allow them to reach phosphorus (P) pools that would otherwise be inaccessible. Legumes not only flourish in low-fertility areas, but they also produce nutrient-dense meals, such as high-protein grain and leaves. These are significant advantages, however there are numerous obstacles to increasing legume use in smallholder agricultural s ystems.

2. LEGUME IN CROPPING SYSTEMS

The use of various food, herbaceous (green manure), and forage legumes in systems to improve soil fertility, either as intercrops or in rotations with other crops, is a well-known technique in the tropics. The use of various food, herbaceous (green manure), and forage legumes in systems to improve soil fertility, either as intercrops or in rotations with other crops, is a well-known technique in the tropics. Dual-purpose legumes that produce food and feed [e.g. cowpea (*Vigna unguiculata* L. Walp.); groundnut (*Arachis hypogea* L.); pigeonpea (*Cajanus cajan* L. Millsp.] and forage legumes (e.g. *Stylosanthes* spp., *Trifolium* spp. *Vicia* spp.) are attractive particularly to small scale farmers who practice mixed crop/livestock systems. These legumes boost the yields of succeeding cereal crops planted in rotation by enhancing the soil chemical, physical, and biological qualities, in addition to providing economic income to farmers through the sale of grain and/or livestock products (milk, meat, and manure). The legume you choose will have a big impact on the benefits of diversification. When compared to short-duration legumes, long-season legumes are biologically superior in fixing considerable amounts of nitrogen, increasing P availability and yields of future cereal crops. Short-duration cultivars, on the other hand, have the best yield potential while delivering fewer nutrients for soil development. Access to both types of legumes may be appealing to farmers. Genotypes that are short-duration and early yielding are often grown to address market niches (e.g. groundnut), whereas long-duration types (e.g. pigeonpea) fit into relay intercrops and subsistence production systems. Cowpea, pigeonpea, mucuna, and soybean cultivars have low-competition growth habits, such as late-season branching patterns and deep taproots, which reduce intra-row competition. By establishing the secondary crop after the first crop has been planted, relay planting reduces competition. The presence of parasitic weeds and soil-borne pests is reduced in rotational systems.

Perennial tree legumes may have more potential to replace soil fertility than annual grain legumes due to their ability to use leftover water and subsoil nutrients that crops are unable to consume, as well as their ability to tolerate drought and thus generate more biomass. Because of their year-round growth, they may be able to repair more biological nitrogen. Other benefits of perennial legumes include the lack of repeated setup costs, the ability to plant multiple crops without surrendering area, enhanced soil physical conditions, and increased water infiltration due to their root activity. If the species is edible, some or all of the several harvests throughout the year can be given to livestock to boost productivity and manure recycled to the fields to keep soil fertility. However, if not maintained appropriately, most tree legumes could be fierce competitors for growth resources with crops. Perennial legume competition can be reduced by cutting them low and/or frequently, or by choosing species with slow coppice growth.

The legume–cereal ratio, the duration of legume biomass production, and residue management all influence the soil fertility benefits of legume diversity. The leaves of edible legumes are frequently removed and utilized as a vegetable or pasture, limiting nutrient input to the soil. N inputs are predicted to rise as a result of residue management approaches. To reduce the need for external nutrient input, a better understanding of soil building qualities, farmer tolerance, and residual management is critical.

3. LEGUME AND SOIL HEALTH

Physical, chemical, and biological factors all contribute to soil health. Because it affects many of the other soil qualities and processes necessary for soil quality, the buildup of soil organic matter or soil organic carbon is central to the effects of diverse cropping systems on soil quality. Increased aggregate stability, cation exchange capacity, nutrient cycling, and biological activity can all help to improve soil quality by reducing bulk density, surface sealing, and crust formation, as well as increasing aggregate stability, cation exchange capacity, nutrient cycling, and biological activity. The amount and type of carbon input from crop biomass and manure, as well as tillage methods that impact the rate of decomposition and stratification of soil organic matter, can all affect soil organic matter [1].

Nitrogen Fixation: The ability of legumes to fix nitrogen from the atmosphere is possibly the most noteworthy feature that distinguishes them from other plants. Legumes that have been inoculated with the right strain of Rhizobia bacteria can provide up to 90% of their own nitrogen (N) [2]. The bacteria that feed non-carbohydrates produced by the above-ground plant during photosynthesis bind nitrogen gas in the soil air. Ammonia (NH_3) is produced by bacteria using hydrogen from the plant's carbohydrates and nitrogen from the air. The ammonia then acts as a nitrogen source for the plant to thrive. When soil microorganisms die, they breakdown the nitrogen-rich organic material and release the nitrogen into the soil. After a legume in a rotation, around two-thirds of the nitrogen fixed by the crop becomes accessible the next growing season.

Soil Organic Matter: Most crop residues contain much more carbon than nitrogen, and bacteria in the soil need both carbon and nitrogen. Legumes are high in protein, and therefore, nitrogen rich. Legumes provide nitrogen, which aids in the decomposition of crop leftovers and their conversion to soil-building organic matter.

Soil Porosity: Several legumes develop vigorous taproots that stretch 6 to 8 feet deep and have a half-inch diameter, opening deep into the earth. Earthworms are attracted to nitrogen-rich legume wastes. Root channels and earthworm tunnels promote soil porosity, allowing air and water to percolate deep into the soil.

Recycle Nutrients: Perennial and biennial legumes have the ability to recycle agricultural nutrients that are deep in the soil profile because they root deeply in the soil. This leads in more efficient fertilizer application and prevents nutrients (especially nitrate nitrogen) from being lost below the root zone of shallower-rooted crops in the cycle due to leaching.

Improve Soil Structure: In both the United States and Canada, research has shown that legumes increase soil physical qualities. Increases in more stable soil aggregates are credited with the improvements. Glomalin, a protein found symbiotically in the roots of legumes and other plants, acts as a "glue" that holds soil aggregates together. Because of the increased pore space and tilth, soil erodibility and crusting are reduced.

Lower Soil pH*:* Because inoculated, legumes get their nitrogen from the air as diatomic N rather than the soil as nitrate, the pH of the soil is lowered. Alfalfa and soybeans dropped the pH of clay loam soil by one entire pH unit in greenhouse trials. On soils with a pH above the range for optimum crop growth and development, legumes could lower the pH and encourage greater plant-soil-microbial action.

Biological Diversity: Legumes help to improve the diversity of soil flora and fauna, which helps to stabilise the soil's overall vitality. By providing additional nitrogen, legumes also encourage the formation of more total biomass in the soil. Microbes in the soil use the extra nitrogen to break down carbon-rich residues from crops like wheat and corn.

Break Pest Cycles: Legumes are a great way to break up a crop rotation and decrease the buildup of grassy weeds, insects, and diseases. A three-year gap between crops of the same type (grassy, broadleaf, cool season, warm season) is usually enough to minimize weed, insect, and disease pressure significantly.

3.1 Legume in Indian Context

In India, about 60% area comes under rainfed lands [3]. The so-called grey patches, which were not affected by the Green Revolution, play an important role in Indian agriculture. They are frequently more hungry than thirsty, contributing to the low output. Organic matter loss, whether due to erosion or high temperatures, depletes soil resources for various elements required for plant growth. A decrease in organic matter increases nutrient deficits; a two-thirds reduction in organic matter represents a significant reduction in nutrient availability. Furthermore, fertilizer usage is quite low. Thirty-five percent of the total 464 districts use less than 50 kg ha^{-1} of fertilizer, which is one of the reasons for low productivity in this rainfed area due to excessive nutrient mining.

Arable land per capita in India is progressively disappearing, and fundamentally sustainable practises and indigenous technical knowledge (ITK) used prior to the Green Revolution have been systematically replaced. For example, pre-chemical subsistence agriculture successfully maintained soil N status by maintaining a balance between N lost in grain harvest and N acquired in biological N fixation. Less intensive farming, reasonable crop rotations, and intercropping with legumes made this possible. Modern agriculture focuses on maximal output while neglecting input efficiency. There is mounting evidence that fertilizers alone cannot sustain yields for long periods of time because crops only use about 30% to 40% of the applied fertilizer nutrient, with the remainder being lost through various pathways such as leaching, surface runoff, volatilization, denitrification, soil erosion, and soil fixation.

Due to the lack of organic manures and indiscriminate fertilizer application, nutrient-related stress is becoming more common in many soils, resulting in low productivity. In this setting, legumes play a critical role in maintaining soil fertility in high-productivity agricultural systems. In reality, legumes are a natural mini-nitrogen manufacturing plant in the field, and farmers may play a critical role in enhancing indigenous nitrogen production by producing these crops. In addition to enhancing soil fertility, some legumes, such as chickpea and pigeon pea, have the ability to solubilize occluded P and very insoluble calcium-bound P through their root exudates. Legumes aid in disease and pest control by enhancing the physical environment of the soil, increasing microbial activity and organic matter restoration, and aiding in disease and pest control. Furthermore, legumes have a weed-smothering action, and some legumes appear to lower nitrate levels in the soil profile.

Table 1. Changes in bulk density in long term cropping sequences

Treatment	Bulk density (g/cc)
Initial value	1.46
Cropping system	
Potato-greengram-rice	1.38
Potato-maize-rice	1.40
Potato-onion-rice	1.42
SEm ±	0.01
CD (0.05)	0.01

Singh and Lal, [4]

3.2 Long Term Effects of Legume Crop Rotations on Soil Health and Productivity

Crop rotation is the practice of planting different crops in succession on the same piece of land, with the goal of preserving the soil's productive capacity. Growing a short-duration grain legume such as green gramme, black gramme, or cowpea and putting the residues into the soil after harvesting the grains/pods is recommended not only to boost system production but also to save money on chemical fertilizer.

3.3 Long Term Legume-based Crop Rotations on Soil Physical Properties

Among three cropping sequences in rotation potato-greengram-rice recorded significantly lower bulk density. This was mainly due to greengram crop residues were incorporated into the soil during puddling of rice, which after decomposition increased the organic matter content in soil. Since organic matter having higher surface area with lesser weight reduced the bulk density in long run.

Biederbeck et al. [5] revealed that black lentil-wheat rotation significantly increased the wet aggregate stability (WAS) and dry aggregate stability (DAS) compared to continuous wheat and fallow-wheat rotation. The size distribution of dry aggregate can be used to predict resistance to abrasion and wind erosion, whereas wet aggregate stability indicates how well a soil can withstand raindrop impact and water erosion. This was also noticed that in all legume rotations WAS and DAS were high. Soil aggregate stability depends on the quality of organic inputs as well as the quantity, which was found high in legume rotation. Due to the presence of stable aggregates wind erodible fractions were less in all legume based rotations.

Table 2. Physical properties influenced by legume green manure (11 years rotation)

Cropping systems	WAS (g kg^{-1})	WEF (g kg^{-1})	DAS (g kg^{-1})
Fallow-wheat	240	325	252
Fielddpea-wheat	305	302	307
Black lentil-wheat	341	287	333
Taniger flatpea- wheat	320	284	323
Chickling vetch– wheat	310	285	301
Continuous wheat	278	531	299
LSD (P < 0.05)	61	30	33

WAS: Wet aggregate stability, WEF: Wind erodible fraction, DAS: Dry aggregate stability.
Biederbeck et al. *[5]*

Table 3. Soil physical properties at the end of 12 years of various crop sequences

Crop rotation	Macro-aggregation (%)	Aggregate stability (%)	Dispersion coefficient (%)
Watermelon-wheat	20.2	29.5	3.5
Fallow-wheat	20.5	30.8	3.4
Wheat-wheat	14.4	22.1	4.2
Chickpea-wheat	24.9	33.1	3.1
Lentil-wheat	26.7	35	2.7
Vetch-wheat	25.9	37.5	2.9
Medic-wheat	29.1	41.3	2.2
L.S.D. (p= 0.01)	2.8	0.6	0.3

Zuhair Masri and John Ryan, [6]

Table 4. Hydraulic conductivity in the laboratory and infiltration in the field at the end of 12 years of various crop sequences

Crop rotation	Hydraulic conductivity (cm hr^{-1})	Infiltration (cm hr^{-1})
Watermelon-wheat	8.4	15.1
Fallow-wheat	7.4	14.4
Wheat-wheat	6.2	13.9
Chickpea-wheat	8.7	16.2
Lentil-wheat	9.3	18.5
Vetch-wheat	9.3	19.3
Medic-wheat	12.4	21.8
L.S.D. (p= 0.01)	0.1	2.7

Zuhair Masri and John Ryan, [6]

Zuhair Masri and John Ryan [6] reported that medic as a forage crop to improve soil quality in a Mediterranean wheat-based rotation. Medic has an extensive root system, which contributes organic matter in the root zone rather than merely leaf fall on the soil surface, which increased macro aggregation and aggregate stability leads to lower dispersion coefficient. This study gave a one-time look at how different rotations, mostly cereal/legumes, paired with less tillage, could affect associated aggregation and hydraulic qualities. Hydraulic conductivity and infiltration was found high in cereal/legume rotation due to the aggregation of soil particles. Continuous wheat cropping for 12 years led to reduced soil quality.

As a function of soil moisture content, ten percent air-filled porosity, soil penetration resistance, and non-limiting water range at 0.15–0.18 m soil depth are presented. Soybean–wheat had the highest moisture content and NLWR, equal to 10% air-filled porosity. After 18 years of rotation, the moisture content equivalent to 2 MPa SPR was lowest in soybean– wheat (23.9%). This system maintained superior soil physical conditions than the other farming systems under investigation, owing to regular leaf biomass inputs to the soil, which increase soil physical qualities. Due to the breakdown of soil aggregates induced by rice puddling, the rice–wheat system had low soil physical production.

3.4 Long Term Legume Based Crop Rotations on Soil Chemical Properties

Dehydrogenase is a very useful soil enzyme, can provide an index of endogenous soil microbial activity, indicating soil microbial metabolism had been greatly enhanced and it also related with cumulative carbon mineralization. They were found significantly high in legume wheat rotation due to increased soil organic matter resulting from legume green manuring, even without any complementary addition of animal manures. Phosphatase and arylsulfatase also was high in legume rotation indicating that legume green manuring stimulated rates of organic P and S mineralization have positive implication for nutrient cycling and soil fertility improvement.

Table 5. Long-term effects of cropping systems on soil physical property

Cropping system	Duration (years)	Water content (%)		NLWR (%)
		10 % fa	2 MPa SPR	
Maize–wheat	32	37.5	24.3	13.1
Maize–wheat	13	39.2	23.8	15.4
Soybean–wheat	18	40.7	23.9	16.8
Rice–wheat	18	34.6	27.1	7.5
Rice–wheat	14	36.9	26.8	10.2
Rice–wheat	6	37	26.1	11
L.S.D. (P = 0.05)	–	1.3	0.9	1.3

Note: fa: Air filled porosity, SPR: Soil Penetration Resistance, NLWR: Non-limiting water range
Verma and Sharma, [7]

Table 6. Influence of legume – wheat rotation on potential C mineralization and activities of selected soil enzymes in 0–10 cm depth (sampled after 11 years)

Cropping systems	Cumulative C mineralization		Dehydrogenase (mg TPF g^{-1} 24 hr^{-1})	Phosphatase (mg PNP g^{-1} hr^{-1})	Arylsulfatase (mg PNP g^{-1} hr^{-1})
	(mg kg^{-1} soil)	(% of total C)			
Fallow–wheat	152_d	0.99_b	47.3_e	537_e	30.2_e
Continuous wheat	206_c	1.20_b	63.7_d	665_d	42.3_d
Black lentil-wheat	339_a	2.01_a	109.1_a	978_a	97.8_a
Taniger flatpea- wheat	286_b	1.64_a	85.6_c	833_c	73.5_c
Chickling vetch– wheat	319_{ab}	1.81_a	98.4_{ab}	908_b	85.1_b
Feedpea-wheat	301_{ab}	1.69_a	89.1_{bc}	955_{ab}	90.3_{ab}
LSD (P=0.05)	51	0.38	11.3	67	9.7

Values in columns sharing the same letter do not differ significantly (P < 0.05)
TPF, triphenyl formazan formed. PNP, p-nitrophenol released. Biederbeck et al. *[5]*

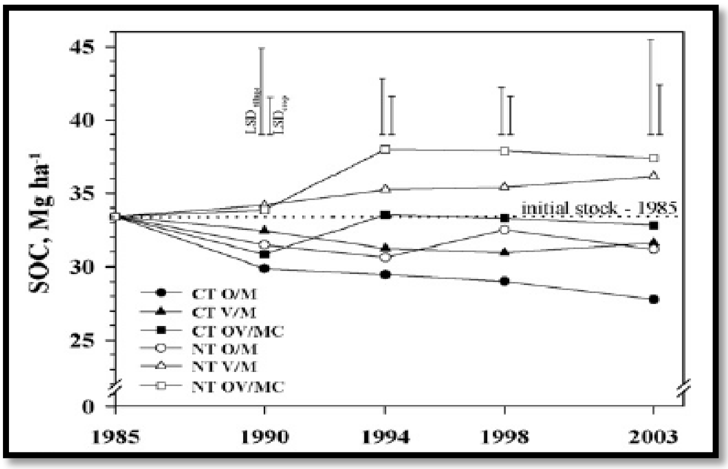

Fig. 1. Long term experiment (18 years) on soil organic carbon accumulation related to tillage and cropping systems

Note: oat/maize (O/M), vetch/maize (V/M) and oat + vetch/maize + cowpea (OV/MC)
Zanatta et al. [8]

Proper rotation systems with legume species maintain SOC under no-tillage. The results underlined the importance of high residue addition cropping systems and emphasized that no-tillage practice is not enough to increase or maintain SOC stocks.

Zuhair Masri and John Ryan [6] reported that medic has an extensive root system, which contributes organic matter in the root zone rather than merely leaf fall on the soil surface. So presence of organic matter was highest for medic and least for continuous wheat or fallow. All fractions (humic and fulvic acids, and water and acid extractable polysaccharides) followed the same general trend as total organic matter.

Organic C and available nutrients (N, P_2O_5 and K_2O) were higher in potato-greengram-rice rotation. This was mainly due to greengram crop residues were incorporated into the soil during puddling of rice, which after decomposition increased the organic matter content in soil. Greengran as a leguminous crop fixed the atmospheric N which in turn increased the nitrogen content in soil. With respect to phosphorus and potassium also found high in legume rotation due to higher mineralization of nutrients.

Ramachandrappa et al. [9] stated that inclusion of legume in finger millet cropping system increased organic C status in soil due to production of more above ground biomass, which after decomposition improved organic matter content in soil. It was also reported that soil available nutrients found high in legume cropping systems, mainly due to cowpea and horsegram fixed atmospheric N and also released various organic acids in soil which helped in releasing fixed P and K in available form.

3.5 Long Term Legume Based Crop Rotations on Soil Biological Properties

Biederbeck et al*.* [5] noticed that soil microbial populations were significantly higher in legume-wheat rotations compared to fallow-wheat and continuous wheat rotations. This was mainly due to leguminous crop improved soil organic matter content which is a source of food for micro-organisms.

Lupwayi et al. [10] found that microbial biomass C was significantly high in rhizosphere and bulk soil with respect of wheat-pea rotation compared to pea-pea rotation, presumably due to higher amounts and diversity of C inputs. The low crop biomass (and organic C) returned to the soil with field pea residues under pea-pea is probably connected to the low microbial biomass carbon in field pea monoculture compared to a rotation with wheat.

Effects of long term legume based crop rotations on productivity: Ramachandrappa et al*.* [8] observed that when fingermillet crop rotated with groundnut, the yield of fingermillet has increased by 145 per cent in control to 26 per cent in FYM @ 10 t ha^{-1} + 100 per cent NPK.

This clearly indicates that by adopting crop rotation along with INM, yield stability is possible in fingermillet under dryland situation. It was mainly due to groundnut helped in maintaining soil quality and sustaining crop productivity.

John Ryan et al., 2011: This 11-year barley-based rotation project focused on animal grazing and forage management, adding to the growing body of evidence supporting the use of forage legumes, particularly vetch, as a fallow or continuous barley cropping alternative. The findings demonstrate that barley that had been green-grazed with common vetch consistently out-yielded both barley and straw yield. In terms of residual soil moisture and perhaps the amount of nitrogen fixed by the legume, it has an impact on the future barley crop.

Mitchell and Entry [11] reported that including winter legume in the cotton cropping system increased the cotton production significantly in long run without application of synthetic nitrogenous fertilizers over monocropping of cotton. It was mainly due to increased organic matter status in soil and increased availability of nutrients, essential for better cotton growth and yield.

Table 7. Soil organic matter and component fractions at the end of 12 years of various cropping sequences

Crop rotation	Organic matter ($g\ kg^{-1}$)	Humic acid ($g\ kg^{-1}$)	Fulvic acid ($g\ kg^{-1}$)	Polysaccharides ($g\ kg^{-1}$)	
				H_2O	3N H_2SO_4
Watermelon-wheat	11.0	3.80	1.03	0.26	2.78
Fallow-wheat	11.4	3.70	1.06	0.28	2.73
Wheat-wheat	10.9	3.70	1.10	0.26	2.38
Chickpea-wheat	11.7	3.80	1.15	0.33	2.36
Lentil-wheat	12.0	3.70	1.21	0.37	3.62
Vetch-wheat	11.5	3.70	1.13	0.39	3.90
Medic -wheat	13.8	4.60	1.26	0.41	3.91
L.S.D. (P = 0.01)	0.12	0.12	0.13	0.10	0.11

Zuhair Masri and John Ryan [6]

Table 8. Changes in soil chemical properties in long term cropping sequences

Treatment	Organic C (%)	Available nutrients (kg/ha)			SYI
		N	P	K	
Initial value	0.42	238.2	23.4	262.4	
Cropping systems					
Potato-greengram-rice	0.52	258.7	27.7	287.4	0.88
Potato-maize-rice	0.48	245.8	25.2	278.6	0.86
Potato-onion-rice	0.47	251.9	26.3	281.5	0.84
SEm ±	0.01	1.45	0.22	2.01	
CD (0.05)	0.02	5.7	0.88	7.9	

Singh and Lal, [4]

Table 9. Effect of legumes -finger mille double cropping system on soil fertility status (average of 7 years: 1980-86)

Treatments	Available nutrients ($kg\ ha^{-1}$)			Organic C (%)
	N	P_2O_5	K_2O	
Finger millet in July	208	49	174	0.46
Finger millet transplanted in Sept	213	49	173	0.46
Cowpea-Finger millet	222	58	190	0.49
Horsegram-Finger millet	220	60	190	0.51
CD at 5%	13.6	4.7	8.9	0.02

Ramachandrappa et al. *[8]*

Table 10. Influence of legume cropping systems on soil microbial populations in 0–10 cm depth (sampled after 11 years)

Cropping systems	Organisms g^{-1} dry soil					
	Bacteria (10^6)	Actinomycetes (10^6)	Bacteria-to actinomycetes ratio	Fungi (10^3)	Yeasts (10^3)	Nitrifiers (10^3)
Fallow–wheat	16.8_e	14.6_b	1.2_d	58_d	0.7_c	17.1_b
Continuous wheat	27.5_d	14.2_b	1.9_c	68_d	1.0_{bc}	7.1_b
Black lentil-wheat	73.0_a	17.3_a	4.2_a	130_{ab}	1.9_{ab}	34.4_{ab}
Taniger flatpea-wheat	54.1_c	16.6_{ab}	3.3_b	103_c	1.4_{abc}	54.9_a
Chickling vetch– wheat	67.7_{ab}	16.4_{ab}	4.1_a	112_{bc}	2.3_a	52.0_a
Feedpea-wheat	63.4_{bc}	17.7_a	3.6_b	142_a	2.1_a	23.5_{ab}
LSD (P=0.05)	9.5	2.5	0.3	23	0.9	31.7

Values in columns sharing the same letter do not differ significantly (P =0.05)

Biederbeck et al. *[5]*

Table 11. Microbial biomass C in field pea and wheat rhizosphere and bulk soil in long term cropping sequence

		Microbial biomass C			
		Wheat-pea		Pea-pea	
Crop	N	Rhizosphere	Bulk soil	Rhizosphere	Bulk soil
	kg ha^{-1}	µg g^{-1} soil			
Field pea	5	757	961	661	782
	20	791	932	699	892
	40	768	964	727	734
LSD @ 5 %		152			
Wheat	80	789	942		
	80	883	1008		
	80	816	907		
LSD @ 5 %		121			

Lupwayi et al. *[9]*

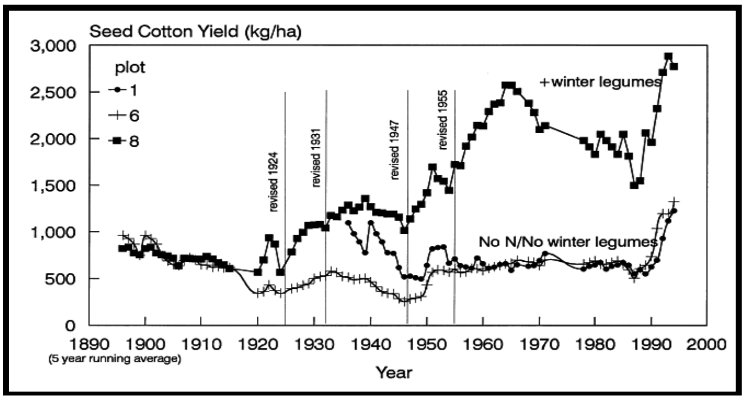

Fig. 2. Long-term effects (100 years) of including winter legumes in the cotton production system

Mitchell and Entry, [11]

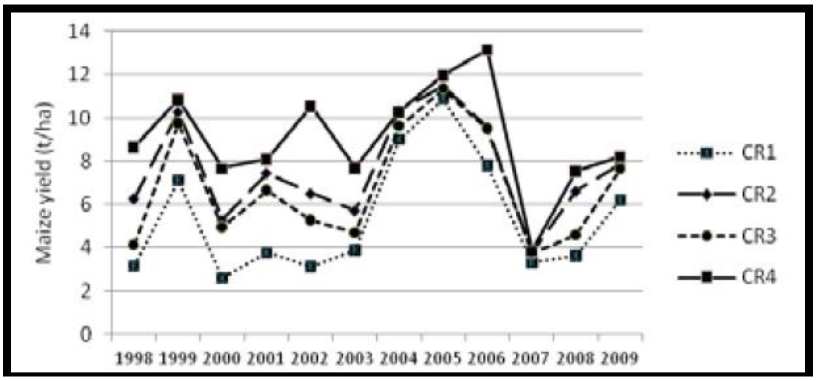

Fig. 3. Maize productivity and the impact of long-term rotation and fertiliser application

Note: CS1 - continuous maize cropping; CS2 - two crop rotation: maize - soybean; CS3 - two crop rotation: maize-winter wheat; CS4 - three crop rotation: maize – winter wheat-soybean

Videnovic et al*. [12]*

Ramachandrappa et al. [9] stated that inclusion of legume in fingermillet cropping system increased the fingermillet grain yield significantly. It was also reported that straw yield was high in legume-fingermillet rotation compared to fingermillet transplanted in September. Legume increased N-availability to fingermillet, and thereby supported increased yield without mineral-N inputs.

Table 12. Effect of legumes on performance of finger millet in double cropping system (average of 7 years: 1980-86)

Treatments	Finger millet yield (kg ha^{-1})	
	Grain	Straw
Fingermillet in July	2020	3470
Fingermillet transplanted in Sept	1820	2900
Cowpea-Fingermillet	2170	3240
Horse gram-Fingermillet	2290	3200
CD at 5%	180	440

Ramachandrappa et al. *[9]*

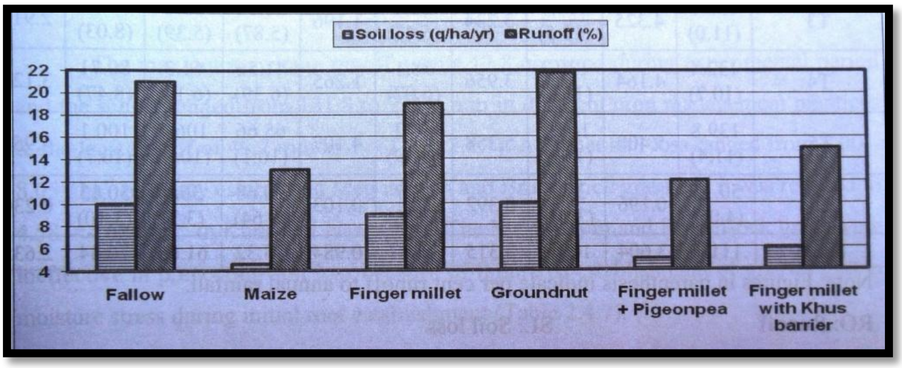

Fig. 4. Runoff and soil loss under different crop canopies (17 years Average: 1978-1995)
Ramachandrappa et al. *[9]*

Maize grain yield was high in legume rotation even though the 50 per cent lower amount of nitrogen fertilizer was applied compared to continuous maize cropping and maize-winter wheat rotation. Increased nitrogen availability through atmospheric N fixation is considered one of the important factors responsible for the beneficial effect of the legume on the following non-legume crop. Improvement of soil structure and water-holding capacity by legume crops and their residues influence the organic C content in soil, and thereby improved maize grain yield.

Long term legume inter cropping systems on soil health and productivity: Because of the flexibility of sowing and planting dates, profit maximisation, risk minimization, soil conservation, soil fertility management, weed control, and nutritional reasons, intercropping is popular among smallholder farmers. ntercropped legumes, in addition to enhancing the overall productivity of the system, can help to save resources, particularly nitrogen. The amount of nitrogen added by include legumes in an intercropping system is predicted to be 0.746 million tonnes. Quantifying the "direct transfer" of nitrogen from the legume component to the non-legume component is a crucial factor in N management in intercropping systems.

Long term legume inter cropping systems on soil physical properties: The fallow plot recorded a higher percentage of soil loss and runoff compared to the cropped plots. The loss of water as well as soil in maize plot was less as they were raised up and ridges were formed later. Further fingermillet + pigeonpea and fingermillet with khus barrier noticed lesser soil and water loss due to better vegetative cover.

Long term legume inter cropping systems on soil chemical properties: Diekow et al. [13] reported that after 17 years of continuous cropping system soil N as well as C stacks increased than initial values with respect to legume and maize inter cropping systems. Legume-based cropping systems (lablab + maize and pigeon pea + maize) increased C stock due to the higher residue input. Increased N stack through atmospheric N fixation is considered one of the beneficial effects of the legume.

At the cover cropped (CC) site, organic C and total N levels were markedly higher in the organic layers compared to the mineral layers. Between sites, organic C and total N levels were markedly lower in both the organic and mineral layers of the control site compared to the corresponding levels in the CC site. Likewise, total N was high in CC site compare to control site. Also, the average levels of various microbial substrates viz., carbohydrates, DOC, DON, LON etc were markedly higher CC sites. This is due mainly to greater accumulation of organic matter in soil.

Effects of long term legume based inter cropping systems on soil biological properties: Blanchart, 2006: The density and biomass of macrofauna were two to four times greater in plots with Mucuna than in plots without Mucuna (T and NPK). This demonstrates how vulnerable macrofauna communities are to the presence of a legume cover crop. Earthworms, millipedes, centipedes, Coleoptera adults, Diptera larvae, and Isopoda thrived after Mucuna was introduced, whereas ants and Dermaptera populations declined. The Mucuna treatment's organic matter accumulation could provide a resource foundation for the soil macrofauna community. Nematodes were also affected, resulting in significant changes in community structure. Mucuna favoured facultative plant feeders (Tylenchidae), bacterial feeders (mostly Rhabditidae and Cephalobidae), and predatory nematodes, while obligatory plant feeders (primarily Criconemella, Scutellonema, and Meloidogyne) were reduced slightly. Mucuna may boost bacterial activity by increasing the presence of bacterial-feeding nematodes and decreasing the F/B ratio (as compared to treatment T).

Effects of long term legume based inter cropping systems on Productivity: Maize cropping system intercropped with velvet bean recorded higher maize productivity compared with pure maize and pure maize with mineral fertilizers. It was mainly due to different factors like higher C content, higher litter amount, higher nutrient availability, higher aggregate stability and less erosion. Soil fauna was also deeply effected by the introduction of Mucuna in maize crops which improved the total soil health and productivity.

Long term effects of legume alley cropping systems on soil health and productivity: Alley cropping is a farming practise in which arable crops are cultivated in alleyways formed by trees or bushes, with the goal of improving soil fertility and production. Alley cropping is a system technique that ensures the utilisation of green leaf manures while pruning the trees. Another method of partially recycling plant nutrients is to incorporate the lopping of leguminous trees such as Glyricidia into the field. These trees' green leaves have a high nitrogen content and a low C:N ratio. Before final land preparation, the green leaves of these trees, which are growing or can be grown on bunds, hedges, and/or neighbouring non-cultivable land, are spread out on the fields and integrated into the soil. This is thought to be a more cost-effective option with the ability to boost and maintain productivity.

Effects of long term alley cropping systems on soil physical properties: The bulk density of soil profiles in glyricidia maize cropping system was found to be lower compared to sole maize and maize grass fallow. In glyricidia maize cropping system, the pruning was incorporated into the soil thereby increasing the pore space and reducing the bulk density. However, the rate of decrease in bulk density is lower in maize grass fallow due to the addition of lower organic matter.

The run off loss of water was found to decrease with the use of glyricidia pruning used as green leaf manure. The introduction of green leaf manure in the cropping system increased the organic matter content of the soil thereby increased the porosity of the soil. This increased porosity increases the water holding capacity, thereby reduced the runoff losses.

Effects of long term alley cropping systems on soil chemical properties: The pH in the maize glyricidia cropping system was found to be near neutral compared to sole maize and maize and grass fallow. This might be due to the decomposition of the glyricidia leaves which formed humic complexes which formed chelates with the acidic cations thereby bringing the ph towards neutrality. The organic carbon was also found more in the maize glyricidia cropping system due to the higher biomass addition compared to the other systems. Carbon sequestration was 149 Mg ha^{-1} in 0-200 cm soil depth which was significantly higher than other treatments.

The figure shows that intercropping with glyricidia, where glyricidia leaf biomass incorporated into the soil, did not increase the CEC with the clay content which may be due to the formation of organic complexes which optimized the CEC. But in sole maize system, increase in clay per cent increased the adsorption sites of the clay particles which in turn increased the CEC.

Table 13. Long-term effects of leguminous inter cropping on bio-chemical characteristics of soil in a coconut plantation

Crops	Layer	Organic C (%)	Total N (%)	C:N	DOC	DON	LON	LFOM-C	LFOM-N	WSC
							mg kg^{-1}			
Control	0-10	1.18d	0.18c	6.5	206.4c	21.2c	3.62c	202c	6.8c	3.4c
	10-20	0.86c	0.11c	7.8	183.6c	21.6c	2.87c	193c	6.9b	3.0c
Calopo	0-10	2.9c	0.23b	12.6	452.7a	44.9b	5.96b	798a	30.6a	4.9b
	10-20	2.1b	0.23b	9.1	402.8b	31.8b	6.04b	604a	32.4a	5.3b
Pueraria	0-10	5.3a	0.49a	10.8	512.8a	48.3ab	6.83a	746b	25.6b	8.3a
	10-20	4.2a	0.28ab	15	483.2a	40.4a	7.12a	635b	31.4a	7.9a
Centrosema	0-10	2.7c	0.29b	9.3	432.7b	42.4b	5.65b	796a	40.8a	5.6b
	10-20	2.7b	0.23b	11.7	420.1b	38.6a	5.21b	612a	31.3a	5.9b
Atylosia	0-10	4.1b	0.32b	12.8	486.2a	49.3a	7.14a	783b	38.4a	7.2a
	10-20	3.1ab	0.29a	10.7	412.3b	38.4a	6.13b	602b	31.3a	6.5b

Dinesh et al. *[14]*

Note: DOC- Dissolve organic carbon, DON- Dissolve organic nitrogen, LON- Labile organic nitrogen, LFOM-C- Light fraction organic matter- carbon, LFOM-N- Light fraction organic matter- nitrogen, WSC- water soluble carbohydrate

Table 14. Long-term effect of a legume cover crop (velvet bean) on maize grain yield

Treatments	Maize grain yield (Kg ha^{-1})	
	1986	**1999**
Pure maize cropping system	500	200
Pure maize cropping system with mineral fertilizer	500	2500
Maize cropping system intercropped with velvet bean	500	3500

Blanchart, [15]

Table 15. Effect on bulk density (g cm^{-3}) along the soil profile between 0 and 200 cm soil depth in three production systems

Soil depth (cm)	Sole-maize	Glyricidia + Maize	Maize - Grass fallow
0–20	1.47	1.23	1.35
20-40	1.40	1.29	1.27
40-60	1.38	1.28	1.42
60-80	1.31	1.31	1.45
80-100	1.37	1.34	1.41
100-120	1.49	1.39	1.34
120-140	1.49	1.45	1.47
140-160	1.41	1.42	1.41
160-180	1.37	1.34	1.48
180-200	1.36	1.33	1.45

Wilkson Makumba et al*. [16]*

Table 16. Mean runoff as influenced by tree production system (Glyricidia) with fingermillet/soybean/maize cropping system

Treatments	Mean runoff (mm)
Green leaf manure to supply rec. N (50 kg ha^{-1})	96.99
Green leaf manure to supply 50 % N + 50 % rec. NPK	92.97
FYM to supply 50 % N + 50 % rec. NPK	97.92
Rec. NPK	102.23
Control	139.54

Note: Rec NPK (Fingermillet- 50: 50: 25; soybean-25: 60: 25; fodder maize- 100: 50: 25 kg ha^{-1})
Ramachandrappa et al. *[8]*

Table 17. Effect on pH and C concentration (mg g^{-1}) along the soil profile between 0 and 200 cm soil depth in three production systems

Soil depth (cm)	Sole-maize		Glyricidia + Maize		Maize - Grass fallow	
	pH	**OC**	**pH**	**OC**	**pH**	**OC**
0–20	5.3	7.7 (0.45)	6.1	12.0 (0.70)	5.7	11.9 (0.30)
20-40	5.3	6.7 (0.10)	5.9	10.2 (0.35)	5.7	11.0 (0.09)
40-60	5.1	5.0 (0.39)	5.6	7.4 (0.45)	5.5	5.6 (0.38)
60-80	5.1	2.8 (0.40)	5.7	5.9 (0.25)	5.4	4.5 (0.26)
80-100	5.1	2.0 (0.05)	5.4	5.1 (0.12)	5.6	3.9 (0.30)
100-120	5.3	1.7 (0.25)	5.2	4.3 (0.15)	5.5	3.4 (0.22)
120-140	5.2	1.4 (0.15)	5.3	3.4 (0.09)	5.5	2.0 (0.25)
140-160	5.1	Trace	5.1	3.3 (0.18)	5.4	1.8 (0.06)
160-180	5.3	Trace	5.1	2.7 (0.16)	5.6	0.7 (0.24)
180-200	5.2	Trace	5.1	2.7 (0.11)	5.6	0.3 (0.09)

Wilkson Makumba et al*. [16]*

The available N, content was found to increase with the application of Green leaf manure (glyricidia pruning). The green leaf manure is the source of nutrients and also they bring the fixed nutrients to their available forms by optimizing the soil pH.

Table 18. Carbon sequestration (Mg ha^{-1}) in soil layers 0–20, 20–200 and 0–200 cm

Soil layer (cm)	Sole-maize	Gs-maize	Grass-F	SED $_{0.05}$
0–20	22	30	32	4.29
20–200	51	119	91	5.76
0–200	73	149	123	8.57
Relative soil organic carbon increase (%) over sole-maize				
0–20		36	45	
20–200		133	78	
0–200		104	68	

Wilkson Makumba et al. *[15]*

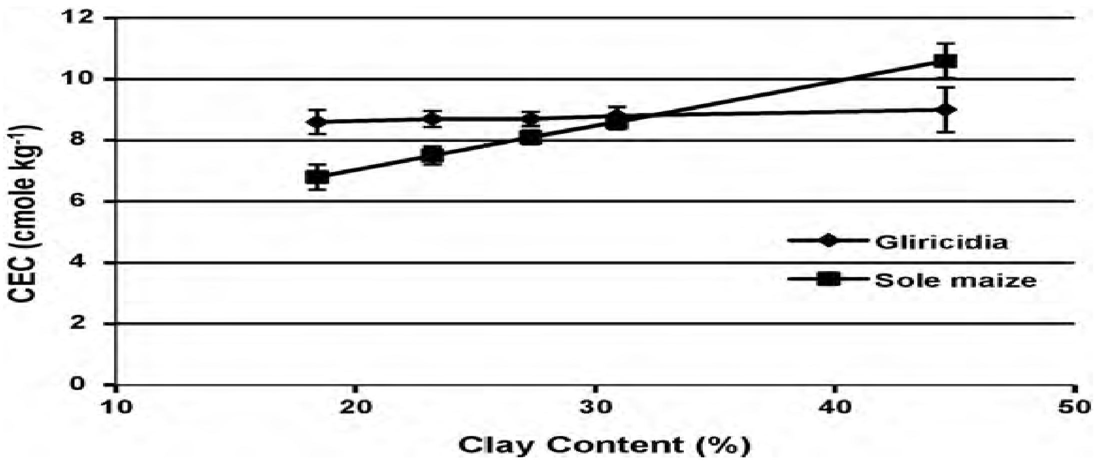

Fig. 5. Impact of 14 years of *Glyricidia sepium* intercropping on Cation- exchange capacity in soil

Beedy et al. *[17]*

Table 19. Soil chemical properties as influenced by tree production system with fingermillet/ soybean/ maize cropping system

Treatments	Available N (kg ha^{-1})		Available P_2O_5(kg ha^{-1})		Available K_2O (kg ha^{-1})	
Years	1995	2005	1995	2005	1995	2005
Green leaf manure(GLM) to supply N (50 kg ha^{-1})	160	198	120	159	108	134
GLM to supply 50 % N + 50 % rec. NPK	175	218	155	160	113	127
FYM to supply 50 % N + 50 % rec. NPK	174	215	169	183	109	112
Rec. NPK	142	184	147	108	116	102
Control	135	156	96	81	84	59

Note: Rec NPK (Fingermillet- 50: 50: 25; soybean-25: 60: 25; fodder maize- 100: 50: 25 kg ha^{-1})

Ramachandrappa et al. *[9]*

Table 20. Fingermillet yield (mean of 12 years) as influenced by tree production system with fingermillet/ soybean/ maize cropping system in micro-watershed (1993-2004)

Treatments	Fingermillet yield (kg ha^{-1})	SYI
Green leaf manure to supply rec. N (50 kg ha^{-1})	2557	0.62
Green leaf manure to supply 50 % N + 50 % rec. NPK	3132	0.77
FYM to supply 50 % N + 50 % rec. NPK	2704	0.66
Rec. NPK	2664	0.65
Control	1045	0.25

Note: Rec NPK (Fingermillet- 50: 50: 25; soybean-25: 60: 25; fodder maize- 100: 50: 25 kg ha^{-1})

Ramachandrappa et al. *[9]*

Effects of long term alley cropping systems on productivity: The highest yield and sustainable yield index was observed in green leaf manure to supply 50 % N + 50 % rec. NPK. This might be due to the improvement of soil physical, chemical and biological properties apart from the supply of nutrients which sustain the yield for long period. Incorporation of FYM also increased the yield but lesser than the previous due to lesser biomass incorporation in soil.

4. CONCLUSION

Wheat rotated with soybean improved moisture content and non-limiting water range in soil, while inclusion of green gram in potato cultivation improves soil organic C and available nutrients. Barley grain yield and straw yield were significantly high when barley rotated with vetch (grazing). Maize legume *viz*., lablab, pigeon pea intercropping system increased the soil C and N stacks compared to cereals-based cropping system, while maize productivity was found significantly high when intercropped with velvet bean. Glyricidia maize intercropping system reduced bulk density and optimized cation exchange capacity in long run. The highest grain yield of fingermillet and sustainable yield index were recorded in alley cropping system.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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