

Long term benefits of legume based cropping systems on soil health and productivity. An overview

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 effects on soil nutrient stocks influence the sustainability of crop production are major benefits of regular additions 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 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 perform well in conservation systems, intercropping systems, which are very important in developing countries. Legumes fix atmospheric nitrogen and facilitate soil nutrients' cycle and water retention. Based on the multiple functions legume have high potential for conservation agriculture, being functional either as growing crop or as crop residue.

Keywords: cropping system, Legumes, Soil health, Sustainability.

INTRODUCTION

Crop production systems around the world are characterized by large regional differences. They continue to evolve in response to increasing pressures on land, crop introductions, as well as new technologies. Land becoming increasingly limiting due to increasing population and land pressures. Soil is an important component of the earth's biosphere and its proper maintenance is essential to sustaining the production of food and fiber and environmental quality. Inappropriate land use and poor soil management exacerbate soil degradation, adversely affect the environment and jeopardize productivity. Inorganic fertilizer use requires an economic shift involving huge investments in the local manufacture. Otherwise, they will remain expensive and beyond the reach of farmers. Premised on their nitrogen fixing characteristics, intensive and adequate incorporation of legumes in cropping systems should reduce the amounts of inorganic nitrogen applied. Legumes have long been advocated as the missing ingredient for conserving soil resources, yet farmer production of legumes is minimal. This should reduce the cost of N fertilizer input and the risks of water pollution in addition to improving the soil physical status. Systems that add Carbon (C) to soil have been identified as having the potential for storing N and making it available for future crop use, while minimizing the risk of environmental pollution. A challenge to the long-term sustainability of cropping systems in developing countries is that food insecure

farmers rely on cereal-dominated cropping systems. Legumes recycle nutrients from deep in the subsoil. In addition, legumes have capacity to excrete root compounds that access phosphorus (P) pools that otherwise remain unavailable. Legumes not only have the capacity to grow in low fertility environments, they also produce nutrient-enriched foods, e.g. high protein grain and leaves. These are important benefits, but there are many challenges to expanding legume presence in smallholder farming systems.

Legume in cropping systems

The use of different food, herbaceous (green manure) and forage legumes in systems, either as intercrops or in rotations with other crops, for improving soil fertility is a well-known practice in the tropics. Herbaceous legumes that serve the single purpose of improving soil fertility, however, have not been widely adopted by small farmers because they cannot afford to grow them at the expense of food crops on their limited land holdings. 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. Besides generating cash income to farmers through sale of grain and/or livestock products (milk, meat, manure), these legumes increase the yields of subsequent cereal crops grown in rotation by improving the soil chemical, physical and biological properties. The choice of legume will significantly influence the benefits derived from diversification. Long-season legumes are biologically superior at fixing significant amounts of N, enhancing P availability and yields of subsequent cereal crops, compared to short-duration legumes. The trade-off is that short-duration varieties tend to have the highest yield potential, while contributing fewer nutrients for soil enhancement. Farmers may be interested in access to both types of legumes. 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. Cultivars of legumes such as cowpea, pigeonpea, mucuna and soybean have minimally competitive growth habit traits, such as late-season branching patterns and deep taproots that minimize intra-row competition. Relay planting minimizes competition by establishing the secondary crop well after the primary crop is planted. Rotational systems reduce the presence of parasitic weeds and soil-borne pests.

Perennial tree legumes may have greater scope to replenish soil fertility than annual grain legumes by their ability to exploit the residual water and subsoil nutrients that crops cannot utilize, withstand drought, and hence produce higher biomass. Their year-round growth may lead to higher biological N fixation. Other advantages of perennial legumes include an absence of recurring establishment costs, opportunity to grow crops simultaneously without sacrificing land and improved soil physical conditions and higher water infiltration because of their root activity. If the species are palatable, some or all of the multiple harvests in a year can be fed to livestock to improve their productivity and manure recycled to the fields to maintain soil fertility. However, most tree legumes could be highly competitive with crops for growth resources if they are not managed properly. The competition from perennial legumes can be minimized by pruning them low and/or frequently, or by selecting species that produce coppice growth slowly.

Soil fertility benefits of legume diversification depend on the legume–cereal ratio, the duration of legume biomass production and residue management. Edible legumes are usually harvested, and their leaves used as a vegetable or for forage thereby reducing nutrient input to the soil. Residue management techniques are expected to increase N inputs. Improved understanding of the soil building properties, farmer-acceptability and residue practices is particularly important to minimize requirements for external addition of nutrients.

Legume and soil health

Soil health is combination of physical, chemical and biological properties. Central to the effects of various cropping systems on soil quality is accumulation of soil organic matter or soil organic carbon, because it affects many of the other soil properties and processes important for soil quality. Organic matter accumulation can improve soil quality by decreasing bulk density, surface sealing and crust formation, and by increasing aggregate stability, cation exchange capacity, nutrient cycling and biological activity. Soil organic matter can be affected by the quantity and type of carbon input from crop biomass and manure and by practices such as tillage that affect the decomposition rate and stratification of soil organic matter (Weil and Magdoff, 2004).

Nitrogen Fixation: The ability of legumes to fix atmospheric nitrogen is perhaps the most notable aspect that sets them apart from other plants. Inoculated with the proper strain of *Rhizobia* bacteria, legumes can supply up to 90% of their own nitrogen (N) (Hamdi Hussein Zahran, 1999). Nitrogen gas present in the soil air is bound by the bacteria which feed on carbohydrates manufactured by the above-ground plant during photosynthesis. The bacteria produce ammonia (NH_3) from the hydrogen acquired from the plant's carbohydrates and nitrogen from the air. The ammonia then provides a source of nitrogen for the plant to grow. Soil microorganisms decompose the relatively nitrogen-rich organic material and release the nitrogen to the soil when they die. Usually about two-thirds of the nitrogen fixed by a legume crop becomes available the next growing season after a legume in a rotation.

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. Nitrogen supplied by legumes facilitates the decomposition of crop residues in the soil and their conversion to soil building organic matter.

Soil Porosity: Several legumes have aggressive taproots reaching 6 to 8 feet deep and a half inch in diameter that open pathways deep into the soil. Nitrogen-rich legume residues encourage earthworms. The root channels and earthworm burrows increase soil porosity, promoting air movement and water percolation deep into the soil.

Recycle Nutrients: Because perennial and biennial legumes root deeply in the soil, they have the ability to recycle crop nutrients that are deep in the soil profile. This results in a more efficient use of applied fertilizer and prevents nutrients (particularly nitrate nitrogen) from being lost due to leaching below the root zone of shallower-rooted crops in the rotation.

Improve Soil Structure: Research in both the United States and Canada indicate improved soil physical properties following legumes. The improvements are attributed to increases in more stable soil aggregates. The protein, glomalin, symbiotically along the roots of legumes and other plants, serves as “glue” that binds soil together into stable aggregates. This aggregate stability increases pore space and tilth, reducing both soil erodibility and crusting.

Lower Soil pH: Because inoculated, nodulated legumes acquire their N from the air as diatomic N rather than from the soil as nitrate, their net effect is to lower the pH of the soil. In greenhouse studies, alfalfa and soybeans lowered the pH in clay loam soil by one whole pH unit. Legumes could lower the pH and promote increased plant-soil-microbial activity on soils with a pH above the range for optimum crop growth and development.

Biological Diversity: Legumes contribute to an increased diversity of soil flora and fauna lending a greater stability to the total life of the soil. Legumes also foster production of a greater total biomass in the soil by providing additional N. Soil microbes use the increased N to break down carbon-rich residues of crops like wheat or corn.

Break Pest Cycles: Legumes provide an excellent break in a crop rotation that reduces the build-up of grassy weed problems, insects, and diseases. A three year interval between the same type (grassy, broadleaf, cool season, warm season) crop is usually sufficient to greatly reduce weed, insect and disease pressure.

Legume in Indian context

In India, about 60% area comes under rainfed lands (Anon., 202). The so-called grey patches untouched by Green Revolution, occupies a very important position in the Indian agriculture. They are sometimes more hungry than thirsty which adds to its low productivity. Loss of organic matter, whether by erosion or due to high temperature, adds to impoverishment of soil resources for several elements essential for plants growth. A decline in organic matter multiplies nutrient deficiencies; its fall by the two-thirds symbolizes a serious suppression in nutrient availability. In addition, fertilizer consumption is very low. Thirty-five per cent of the total 464 districts, where fertilizer consumption is less than 50 kg ha⁻¹, which is one of the reasons for low productivity due to excessive nutrient mining in this rainfed area.

In India, arable land per capita is steadily decreasing, inherently sustainable practices and indigenous technical knowledge (ITK) adopted before Green Revolution have been systematically replaced. For instance, the subsistence agriculture of the pre-chemical era efficiently sustained the N status of soils by maintaining a balance between N lost in grain harvest and N gained in biological N fixation. This was possible with less intensive cropping, adoption of rational crop rotations and intercropping with legumes. The modern agriculture concentrates on maximum output but overlooks input efficiency. There is increasing evidence that fertilizers alone cannot sustain yields for long periods because crops utilize hardly 30% to 40% of the applied fertilizer nutrient and the rest is lost through various pathways like leaching, surface runoff, volatilization, denitrification, soil erosion and fixation in soil.

Nutrient-related stress are becoming increasingly widespread in many soils due to nonuse of organic manures and indiscriminate use of fertilizers, leading to low productivity. It is in this context that legumes assume great importance to sustain soil fertility in cropping systems operating at high productivity levels. As a matter of fact, legume is a natural mini-nitrogen manufacturing factory in the field and the farmers by growing these crops can play a vital role in increasing indigenous nitrogen production. Some legumes namely chickpea and pigeon pea have the ability to solublize occluded P and highly insoluble calcium-bound P by their root exudates in addition to improving the soil fertility. Legumes help in improving the soil physical environment, increase soil microbial activity and organic matter restoration, and help in disease and pest control. Besides, legume has a smothering effect on weed and some legumes seem to reduce the nitrate concentration in the soil profile.

Long term effects of legume crop rotations on soil health and productivity:

Crop rotation is the practice of growing different crops in succession on the same land chiefly to preserve the productive capacity of the soil. Growing a short-duration grain legume like green gram, black gram, or cowpea and incorporating the residues into the soil after harvesting the grains/pods is suggested not only for increasing the system productivity but also for making a considerable saving on chemical fertilizer.

Long term legume based crop rotations on soil physical properties:

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, 2011

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.

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
Fieldpea-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., 2006

Biederbeck et al. (2006) 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. Wet aggregate stability suggests how well a soil can resist raindrop impact and water erosion, while, size distribution of dry aggregate can be used to predict resistance to abrasion and wind 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 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, 2006

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, 2006

Zuhair Masri and John Ryan (2006) 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 provided a one-time snapshot of how various rotations, mainly cereal/legumes, combined with reduced tillage, could influence associated aggregation and related hydraulic properties. 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.

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, 2008

Ten percent air-filled porosity, soil penetration resistance and non limiting water range at 0.15–0.18 m soil depth as a function of soil moisture content under different cropping system is shown. The moisture content corresponding to 10 % air-filled porosity and NLWR were highest in Soybean–wheat. The moisture content corresponding to 2 MPa SPR was lowest in soybean– wheat (23.9 %) till after 18 years of rotation. This system supported better soil physical conditions than other cropping systems under study, probably through regular additions of leaf biomass to soil, as organic residue additions improve soil physical properties. Rice–wheat system exhibited poor soil physical productivity due to destruction of soil aggregates caused by puddling for rice.

Long term legume based crop rotations on soil chemical properties:

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

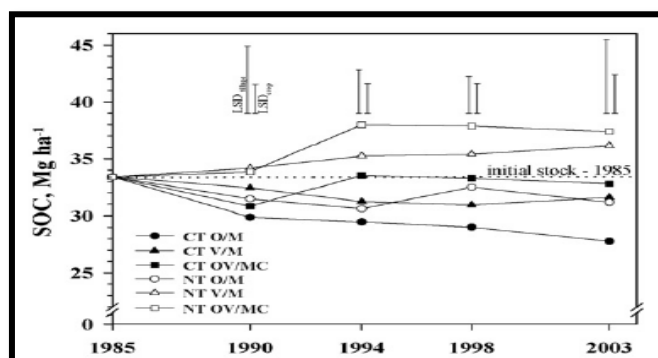
Values in columns sharing the same letter do not differ significantly ($P < 0.05$)

TPF, triphenyl formazan formed.

PNP, p-nitrophenol released.

Biederbeck et al., 2005

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.



Note: oat/maize (O/M), vetch/maize (V/M) and oat + vetch/maize + cowpea (OV/MC)

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

Zanatta et al., 2007

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.

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 ₂ O	3N H ₂ SO 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, 2006

Zuhair Masri and John Ryan (2006) 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.

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, 2011

Organic C and available nutrients (N, P₂O₅ and K₂O) 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. Greengram 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.

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

Treatments	Available nutrients (kg ha ⁻¹)			Organic C (%)
	N	P ₂ O ₅	K ₂ O	
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

Ramachandrapa et al., 2013

Ramachandrapa et al. (2013) 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.

Long term legume based crop rotations on soil biological properties:

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 _{ab} c	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., 2005

Biederbeck et al. (2005) 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.

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	$\mu\text{g g}^{-1}$ 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			

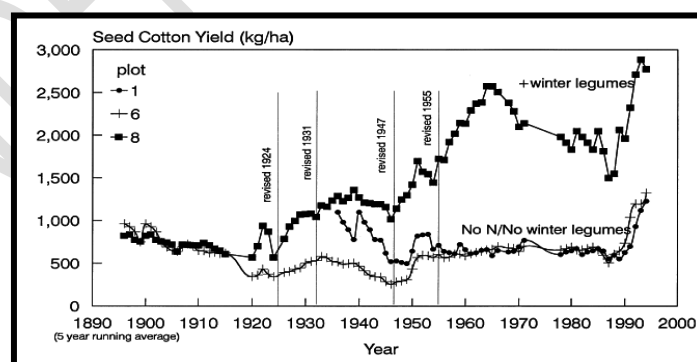
Lupwayi et al., 2012

Lupwayi et al. (2012) 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. Low microbial biomass carbon in field pea monoculture relative to a rotation with wheat is probably related to the low crop biomass (and organic C) returned to the soil with field pea residues under pea-pea.

Effects of long term legume based crop rotations on productivity:

Ramachandrapa et al. (2013) observed that when finger millet crop rotated with groundnut, the yield of finger millet 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 finger millet 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 trial, which focused on animal grazing and forage management, added to the existing, and often fragmentary, body of evidence that supported the use for forage legumes, especially vetch, as a substitute for fallow or continuous barley cropping. The results showed that barley following green-grazed common vetch consistently out-yielded barley as well as straw yield. It influences the subsequent barley crop in terms of residual soil moisture and possibly the amount of N fixed by the legume.



Mitchell and Entry, 2004

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

Mitchell and Entry (2004) 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

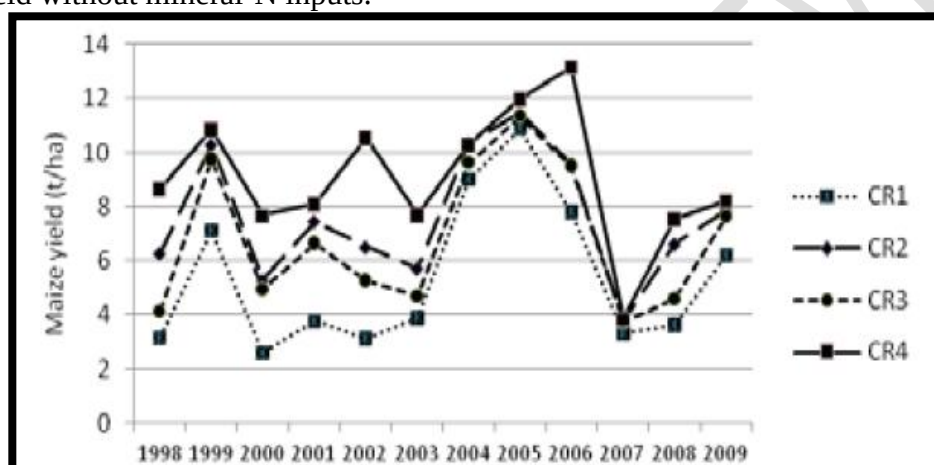
increased organic matter status in soil and increased availability of nutrients, essential for better cotton growth and yield.

Table 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

Ramachandrapa et al., 2013

Ramachandrapa et al. (2013) 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.



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., 2013

Fig. 3: Effect of long term rotation and fertilizer application on maize productivity

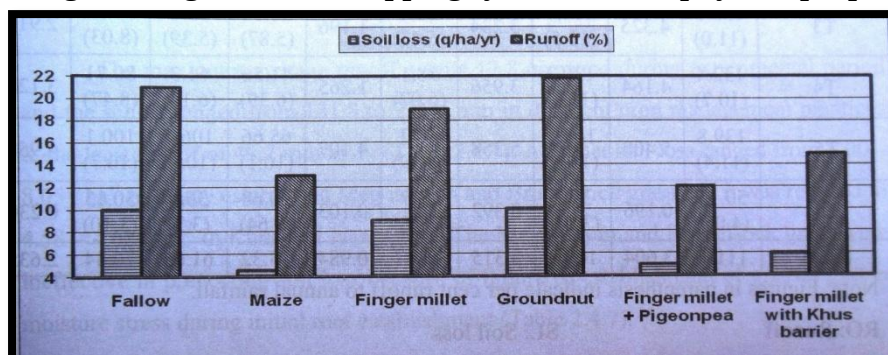
Maize grain yield was high in legume rotation even though the 50 per cent lower amount of nitrogen fertilizer was applied compared to continuous maize cropping and maize-winter wheat rotation. Increased nitrogen availability through atmospheric N fixation is considered one of the important factors responsible 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

Intercropping is popular among farmers of smallholdings because of flexibility of sowing and planting dates, profit maximization, risk minimization, soil conservation, soil fertility maintenance, weed control, and nutritional reason. Intercropped legume, besides

increasing the total productivity of the system, also plays an important role in economizing the resource use, especially N. It has been estimated that by inclusion of legumes in intercropping system, the extent of N addition would be 0.746 million tonnes. The major consideration in N management in intercropping systems is to quantify the “direct transfer” of N from legume component to the non-legume component.

Long term legume inter cropping systems on soil physical properties:



Ramachandrappa et al., 2013

Fig. 4 Runoff and soil loss under different crop canopies (17 years Average: 1978-1995)

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 finger millet + pigeonpea and finger millet 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. (2005) reported that after 17 years of continuous cropping system soil N as well as C stocks 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 stock through atmospheric N fixation is considered one of the beneficial effects of the legume.

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	LFO M -C	LFO M -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., 2006

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

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 : Macrofauna density and biomass were two to fourfold higher in the plot with Mucuna than in plots without Mucuna (T and NPK). This underlines how sensitive the macrofauna community response is to the presence of a legume cover crop. The introduction of Mucuna favoured the development of earthworms, millipedes, centipedes, Coleoptera adults, Diptera larvae and Isopoda and decreased the density of ants and Dermaptera. The accumulation of organic matter in the Mucuna treatment may provide a resource base for soil macrofauna community. Nematodes were also affected, with considerable modifications in the structure of communities. Under Mucuna, facultative plant feeders (Tylenchidae), bacterial feeders (mainly Rhabditidae and Cephalobidae) and predatory nematodes were favoured while obligatory plant feeders (mainly Criconemella, Scutellonema and Meloidogyne) were slightly reduced. The increased presence of bacterial-feeding nematodes and the decrease in F/B ratio under Mucuna (if compared to treatment T) may indicate that Mucuna promotes bacterial activity.

Effects of long term legume based inter cropping systems on Productivity:

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, 2006

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 system in which arable crops are grown in alleys formed by trees or shrubs, established mainly to hasten soil fertility restoration and enhance soil productivity. Alley cropping is a system approach, which ensures use of green leaf manures as the trees are pruned during cropping. This is another way of partial recycling of plant nutrients, where lopping of leguminous trees such as *Glyricidia* are incorporated into the field. The green leaves of these trees have high N content and narrow C: N ratio. The green leaves of these trees that are growing or can be grown on bunds, hedges, and/or nearby non-cultivable land, are spread out in the fields before final land preparation and incorporated into the soil. This is considered to be an economically attractive alternative and has the potential to increase and sustain productivity.

Effects of long term alley cropping systems on soil physical properties:

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., 2007

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.

Table 16: Mean runoff as influenced by tree production system (Glyricidia) with finger millet/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 (Finger millet- 50: 50: 25; soybean-25: 60: 25; fodder maize- 100: 50: 25 kg ha^{-1})

Ramachandrappa et al., 2013

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:

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)

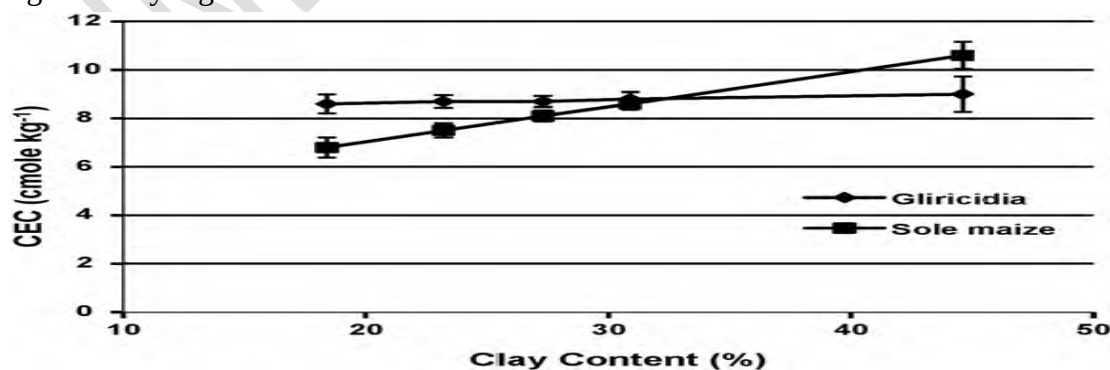
Wilkson Makumba et al., 2007

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., 2007

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.



Beedy et al., 2010

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

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

Treatments	Available N (kg ha ⁻¹)		Available P ₂ O ₅ (kg ha ⁻¹)		Available K ₂ O (kg ha ⁻¹)	
	1995	2005	1995	2005	1995	2005
Years						
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 (Finger millet- 50: 50: 25; soybean-25: 60: 25; fodder maize- 100: 50: 25 kg ha⁻¹)
Ramachandrappa et al., 2013

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.

Effects of long term alley cropping systems on productivity:

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

Treatments	Finger millet 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 (Finger millet- 50: 50: 25; soybean-25: 60: 25; fodder maize- 100: 50: 25 kg ha⁻¹)
Ramachandrappa et al., 2013

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.

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 finger millet and sustainable yield index were recorded in alley cropping system.

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