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Review Article *Natural Resource Management*

Impact of Cereal+legume Intercropping Systems on Productivity and Soil Health -A Review

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Abstract

Intercropping involves growing of two or more cropsin definite row proportion in the same field in a given season.Presently, the practice of intercropping is mostly followed over sole cropping by small holderfarmers especially in rainfed farming, due to uncertain yield in sole cropping following abiotic stresses like drought, temperature, disease/pest incidence etc.Intercropping offers many benefits likeinsurance against total crop failure, assured or increased yield and biomass,less weed, pest and diseasemenace.The choice of compatible crops for an intercropping system depends on several factors like growth habit, ideotype, land, light, water and fertilizer utilization. In this article, we have focused only on cereal+legume intercropping systems as their associationhelp in improves soil fertility and enhance productivity. However, this cropping system have also great importance in rainfed situation, particularly Maize based intercropping system with wheat cropping sequence.We hope that this review report willprovide a valuable guideline for the researchers, extension functionaries and other stakeholders those working on intercropping systems.

Keywords: Cereal, intercropping, legume, sole crop, yield, soil health

1. Introduction

Recent report of United Nations Organization (UNO) says that additional people added to the world population in each year is approximately 83 million and the world population is expected to reach the 8.6 billion markby the year 2030. India shares only 2%of global land area but houses 16% of world's population, thus India is second highly populated country after China. In the recent times, global food requirements including that of India have increased sharply while the availability of cultivated land has been decreasing day-by-day due to rapid urbanization, hence, there is a direct need to enhance cropping intensity and productivity many folds. India is having net sown area of 67% under rainfed agriculture, contributing 44% of food grains and supporting 40% of the population. Butvariouschallenges affect the rainfed situation like low and uneven distribution of rainfall and land degradation cause the low efficiency of different inputs and technology. However, livestock production is also hampered by quality fodder availability. Therefore, these factors create problems to the resource poor farmerin their year-round food production or in their subsistence livelihood. Around 1.9 billion adults are overweight or obese, while 462 million are underweight and near

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about 45% of deaths among children under 5 years of age due to undernutrition. These mostly occur in low- and middle-income countries. India contributes one third of population are undernourished. In India, Rajasthan, Uttar Pradesh, Assamand Bihar are having highest percentage of malnutrition cases. Poverty of world's population is the main reason of causing malnutrition by restricting dietary diversity. However, malnutrition can adversely affect educational and economic of the country.Augmenting the food production sustainably on same land area may be the only option to combat poverty and malnutrition, respectively. In this context, intercropping i.e. growing of two or more crop species simultaneously in the same field in a definite row arrangement during a growing season (Ofori and Stern, 1987) could play a vital role for achieving food security and maintaining environmental quality. Intercropping system increases the yield and resource use efficiency due to enhanced temporal and spatial resource use efficiency, for which all the above-ground as well as belowground parts of crops play a vital role (Midega et al., 2014). Cereals intercropped with legumes which can efficiently utilize solar and soil resources with minimum nutrient inputs are a better option in an intercropping system.Cereal+legume intercropping system is popularized as an insurance against crop failure for monocropping under rainfed conditions though its chief goal is to ensure improved and sustainable production (Seran and Brintha, 2010; Ali et al., 2012) and higher grain yields than sole cropping (Olufemi et al., 2001; Dapaah et al., 2003). It also controlsthe quality of irrigation water through minimizing the use of inorganic N fertilizers (Dhiman et al., 2007).In the intercropping system, the loss of nitrogen by leaching from leavesand the decomposition of legume vines may also result in nitrogen transfer to the associated crop (Burton et al.,1983).

2. Importance of Cereal+Legume Intercropping System

a) Cereal+legume intercropping system is more stable than sole cropping or monoculture regarding soil fertility improvement, yields enhancement and financial returns (Machado, 2009; Himmelstein et al., 2017).

b) It helps to risk reduction associated with associated with growing only one crop (Snapp et al., 2010; Himmelstein et al., 2017).

c) In extreme weather condition, cereal intercropped with pigeonpea gave greater insurance against crop failure (Odeny, 2007; Snapp et al., 2010; Rusinamhodzi et al., 2012).

d) Cereal intercropped with pigeon pea can not only be advantageous for resourcefull farmers but also for resource-poor farmers.This system had same positive returns in central Malawi (Kamanga et al., 2010).

e) This intercropping system play a vital role for not only enhancing productivity and profitability, nutrient-water-radiation use efficiency, weeds-pests-diseases control but also helps to biological nitrogen fixation to complement non-leguminous crop.

f) Intercropping system particularly cereal+legume intercropping improves the soil fertility, soil physical and chemical condition (Sanginga and Woomer, 2009).

g) Most of the smallholder farmers prefer legumes because of its ability to reduce soil erosion and combat with declining soil fertility. In maize+cowpea and wheat+faba bean intercropping systems,cereal biomass and grain yield was increased, as reported by Barker and De Mollo (2000).

h) Complementary relationship exists between cereals and legumes in the use of N and P, where both crops compete for available soils pool ofNand P, but the legumes have the potential to access atmospheric N (Bollen and Renders, 2008).

i) Cereal+legume intercropping plays great role insubsistence agriculture as it provides diversified food crops in both developed and developing countries particularly in areas with irrigation water as limiting factor (Tsubo et al., 2005).

j) Land which follows legume rotations increase the fertility of the land and helps in carbon sequestrations and biodiversity (Peoples et al., 2009). Inclusion of legume crops in cropping systems not only helps in atmospheric nitrogen fixation but also it helps in reducing CO_2emission. As there is less nitrogen need to be given from outside into the field, hence, it reduces the carbon content in food products (Nieder and Benbi, 2008; Fustec et al., 2010; and Gan et al., 2011).

k) Legumes are highly recommended for organic farming as it can fulfill the nitrogen requirement through organic source, especially where there is no livestock production going on in the farm (David et al., 2005).Absence of legumes in cropping system can lead to poor yield and decreased protein content of non-legume products.

This article attempts to make tabulated different intercropping systems (Cereal+legume) under rainfed regions for sustaining the livelihood (Table 1).

Table 1: Different intercropping systems (Cereal+legume) under rainfed regions

Region	Intercropping system
Vertisols	Sorghum+Pigeonpea/ Black gram/ Cowpea (2:1) Maize+Soybean/ Black gram (2:2 & 2:1) Pearlmillet+Pigeon pea (1:1)
Alfisols and red soils	Sorghum+Pigeonpea (3:1) Fingermillet+Pigeonpea (8:2) Maize+Pigeonpea (2:1)
Aridisols	Pearlmillet+Black gram/ Green gram/ Cowpea (2:1 & 1:2) Pearlmillet+Cluster bean (3:1)
Entisols	Maize+Black gram (1:1) Pearl millet+Green gram/ Black gram/ Pigeon pea (2:1)

3. Assessment of Yield Improvement Under Cereal+Legume Intercropping System

3.1. Growth and yield of crops

Growth and yield responses of component crops in any intercropping system are influenced by various factors like nature of crops, variety grown, row arrangement, and other management practices. In maize+cowpea system, the yield in sole maize (6.53 t ha^{-1}) was significantly (p=0.003) higher than in maize (6.47 t ha^{-1}) intercropped with cowpea. However, the above-ground total biological yield in sole maize (31.8 t ha^{-1}) was insignificantly (p=0.055) larger than in maize (26.7 t ha^{-1}) intercropped with cowpea. On the contrary, it has been observed that grain yield of cowpea was reduced by 43% as compared to sole crop (Polthanee et al., 2000).

The average number of pods/ plants in sole cowpea (7.7) was significantly (*p*=0.039) higher than in cowpea (6.8) intercropped with maize. In addition, the average number of seeds/pods in cowpea intercropped with maize (15.0) was significantly (p=0.009) lower than in sole cowpea (15.43) (Table 2a and 2b) (Nyasasi and Kisetu, 2014).

Table 2a: Performance of maize under sole and cowpea+maize intercropping systems

Cropping system	Plant height (cm)	Total biomass (kg plot^{-1})	Dehusked cob weight (kg plot^{-1})	Seed weight (kg plot^{-1})	Yield (t ha^{-1})	Biological yield (t ha^{-1})
Intercrop maize	211.6	10.7	4.8	2.56	6.47	26.7
Sole maize	222.9	12.7	4.7	2.63	6.53	31.8

Source: Nyasasi and Kisetu (2014)

Table 2b: Performance of cowpea under sole and cowpea+maize intercropping systems

Cropping system	Pod length (cm)	Pod diameter (cm)	Pods plant^{-1}	Pods plot^{-1}	Seeds pod^{-1}	Seed weight (kg plot^{-1})	Yield (t ha^{-1})
Intercrop maize	15.3	0.6	37.3	15.0	6.8	2.3	6.25
Sole maize	16	0.73	212.1	15.43	7.7	2.7	6.7

Source: Nyasasi and Kisetu (2014)

Among the maize based cropping system under rainfed area, intercropped maize with mash and wheat cropping sequence was given higher maize equivalent yield (52.98 q ha^{-1}), Wheat equivalent yield (21.67 q ha^{-1}) and maximum net return (Rs. 15933 ha^{-1}) followed by others (Table 3) (Sharma et al., 2000).

Plots under sole maize had minimum soil moisture, while the highest value recorded in plots under sole cowpea (Ghanbari et al., 2010). Maize+cowpea intercropping under conservation agriculture resultedin significant increase in soil organic carbon (OC), total nitrogen and exchangeable calcium after six years of practice which might be due to the amount and type of residue retained and the contribution of biologically fixed nitrogen from the cowpea (Banda et al., 2018). Intercropping of fodder maize with legumes increases dry matter yield and crude protein yield of forage over sole cropping (Javanmard et al., 2009). Maize intercropped with lablab bean along with 50 and 75 kg P_2O_5 ha^{-1} significantly improved the crude fiber, ash and ether extract content and dry matter digestibility with slight decreases in detergent fiber digestibility (Amasaib et al., 2011). Baby corn intercropped with legumes increased the productivity per unit area and land use efficiency and it also increased the atmospheric N fixing ability of the intercrops (Banik and Sharma, 2009). Fixed N remains as 'free N' for the use of host plant or associated or subsequent crops (Adigbo et al., 2013). Jat et al. (2014) suggested that intercropping maize and mung bean awfully influenced cobs plant^{-1}, length of cobs, grains cob^{-1}, 1000-grains weight, grain yield and stover yieldof maize. Grain and stover yield was found better with maize+mungbean (1:2) over maize+mungbean (1:1) and sole maize. Maize intercropped with soybean recorded significantly higher values of leaf area index (LAI), crop growth rate (CGR) and net assimilation rate (NAR). Soybean crop also gave significantly higher value of LAI, CGR and NAR. Addo-Quaye et al. (2011) also demonstrated that soybean planted in double row arrangement with maize gave significantly higher growth than soybean planted in alternate row arrangement with maize. LER can be discussed under other heading on

Table 3: Maize based intercropping – Wheat Cropping system under rainfed regions

Cropping Systems	Maize equivalent yield (q ha^{-1})	Wheat equivalent yield (q ha^{-1})	Net returns (₹ ha^{-1})
Maize+Mash - Wheat	52.98	21.67	15933
Maize+Soybean - Wheat	50.99	21.0	14715
Maize+Arhar - Wheat	49.31	21.74	17365
Maize+Cowpea - Wheat	45.59	21.59	14244

Source: Sharma et al., 2005

intercropping indices

In Sole maize consumed higher amount of water than maize+cowpea intercropping system (Morgado and Rao, 1985). Due to higher soil matric potential (ψm) for maize (-0.07 MPa) than that of inter-cropping (-0.04 MPa) (Pinheiro, 2000). Intercrop utilized less energy at surface soil for evaporation of water because of the radiation intercepted by the intercrop canopy. In intercropping system maize helps to improve the plant water status and it showed greater water availability to intercropped maize. Intercropping system was positively affected leaf water potential (leaf ψw), as a result sole crop for maize had significantly lower values (Pinheiro, 2000).

3.2 *PAR (Photosynthetically Active Radiation) and LAI (Leaf Area Index)*

Radiation use efficiency (RUE) and crop intercepted photosynthetically active radiation (PAR) are influenced greatly in different intercropping systems. Eskandari (2012) demonstrated that cereals+legume intercropping system effect on PAR interception on crop canopies over the sole crop (Table 4). In strip cropping systemsoybean recorded a 1.35 times greater value of intercepted PAR than that of row intercropping (RI), although a significant reduction intercepted PAR of soybean dry matter was found in RI due to lack of intercepted PAR (Liu et al., 2017). Cereals with greater height, growth rate, and deep and wide root system is better at competing for inputs rather than the associated minor legume crop which results in poor yield due to less availability of PAR (Liu et al., 2010). However, in cereal+legume intercropping system, the cereal component with relatively higher growth rate, height advantage and a more extensive rooting system is favored in the competition with the associated legume crop. Therefore, the greater yield loss of the minor crop occurs mainly due to reduced PAR reaching the lower parts of the intercrop canopy occupied by the minor legume (Liu et al., 2010). As soybean is sensitive to shade, the intensity and the quality of solar radiation hampered by the crop canopy highly affects the yield components and finally yield (Purcell, 2000: Liu et al., 2010). Sole crop of maize and cowpea showed a significant difference in light interception over the intercrop when cowpea was sown alone, light interception was increased linearly reaching about 80% interception of PAR at the time of 95 day after planting (DAP). Sole crop of maize and maize+cowpea intercropping system recorded a lower light interception compared to sole cowpea. Absorption of PAR was greater in additive design over the replacement series (Ghanbari et al., 2010).

Table 4: Effect of different cropping system on PAR (%) interception by crop canopies

Cropping system	55 DAS	65 DAS	75 DAS	85 DAS	95 DAS	105 DAS
Sole maize	70.79c	80.23c	89.2c	89.20c	83.02c	78.21c
Sole cowpea	71.22c	80.23c	89.5c	89.54c	86.45c	77.77c
Sole Mungbean	71.55c	81.71c	88.0c	89.21c	85.03c	77.78c
Maize+cowpea (re-placement series)	75.08b	84.75b	94.75b	93.56b	91.04b	81.21b
Maize+Mungbean (replacement series)	74.21b	86.02b	93.71b	93.78b	91.52b	80.06b
Maize+Cowpea (ad-ditive series)	79.06a	88.72a	98.75a	98.52a	96.09a	87.21a
Maize+Mungbean (additiveseries)	79.11a	89.62a	98.61a	99.21a	97.21a	88.76a

DAS-Days after sowing; PAR-Photosynthetically active radiation; Different letters (a,b,c) in each row indicates significant levelat 0.05%; Source: Eskandari (2012)

In maize+soybean intercropping system, significant differences were observed in light interception (PAR) and leaf area index (LAI) at Embu (Table 5). Sole soybean crop had more intercepted light (58.2%) and LAI (1.03) at 35 DAP. During this period, only soybean under MBILI (Managing Beneficial Interactions for Legume Intercrops)treatment recorded strong correlation between grain yield and PAR intercepted (r=0.98) and LAI (r=0.97). The soybean crop at 63 DAP in MBILI treatment had the highest light interception (84.2%) than sole soybean, maize+soybean under (2:4), and maize+soybean (2:6) systems (Matusso et al., 2014).

Similarly, Pinheiro (2000) found that growth of plant in intercropping system was not significantly influenced. Incase of sole maize and sole cowpea, LAI were 3.36 and 2.8 respectively. But in case of intercropping LAI values fell between 1.6 and 1.39 which accounts for 47.6 and 49.6% of the sole cropping values.

3.3. *Weed biomass*

The intercropping practice allows more competition between crops and weeds. It also increases light interception of a weakly competitive crop and can be useful to suppress weed growth (Baumann et al., 2001). Significant negative correlation was observed between the fraction of photosynthetically active radiation intercepted(F_{int}PAR) by the canopy and both weed density and weed dry matter (WDM). In the study of Bilalis et al. (2010), maize+legume intercropping exhibited higher soil canopy cover (leaf area) than sole crops, as lowest values for F_{int}PAR were received in sole crops. Hence, maize+legume intercropping leads to lower light availability for weeds and thus it lowers weed density and weed dry matter. Fenández-Aparicio et al. (2007) reported

Table 5: Effect of Maize shade on PAR (%) intercepted of soybean

Treatment	Crop	35 DAP		49 DAP		63 DAP	
		PAR	LAI	PAR	LAI	PAR	LAI
Sole maize	Maize	57.23	1.03	66.50	1.28	83.40	3.61
Sole soybean	Soybean	58.23	1.09	54.97	1.00	73.12	2.87
Maize+soybean (1:1)	Maize	32.41	0.47	56.55	0.99	74.19	2.74
	Soybean	41.65	0.66	56.67	0.99	78.05	3.06
Maize+soybean (2:2)	Maize	45.88	0.74	61.00	1.24	74.10	3.21
	Soybean	53.70	0.95	66.92	1.45	84.15	4.26
Maize+soybean (2:4)	Maize	42.67	0.70	55.58	0.95	69.05	2.34
	Soybean	55.89	1.00	48.74	0.87	68.24	2.40
Maize+soybean (2:6)	Maize	46.34	0.75	51.38	0.87	66.95	2.23
	Soybean	53.82	0.95	59.13	1.10	77.73	3.35
p value		0.0002**	0.0003**	0.285	0.356	0.0310*	0.0962
LSD (0.05)		10.10	0.25	14.97	0.52	10.95	1.33

DAP-days after planting; PAR-Photosynthetically active radiation; LAI-Leaf area index; *significant at $p \leq 0.05$; **significant at $p < 0.001$; Source: Matusso et al. (2014)

that intercropping of fababeans and pea with oat decreases the infection of *Orobanche crenata,* but sowing them as sole crops leads to more prone to infection of *O. crenata.* They also opined that seed germination of this weed species was reduced due to the allelo-chemicals released by cereal roots. In a study of maize+legume intercropping system, Bilalis et al. (2010) observed that density of weed value was highest for sole crops maize and the lowest in bean crop. No significant difference was found between the maize+bean and maize+ cowpea intercrop, while the differences between intercrop and sole crops were statistically significant. A significant negative correlation was observed between F_{int}PAR) and WDM. Lawson et al. (2007) reported that legume cover crops when planted 0 to 4 weeks after planting maize, weed suppression was highest. Intercropping treatments also helped to control weed densities as compared to the sole treatments. The lowest value of weed density (24.45 m^{-2}) was observed in cowpea+maize (10:6) intercropping system whilethe highest value (36.88 m^{-2}) was recorded in sole maize. Further, legume+maize with 5:6 row arrangement had comparatively higher weed density than 10:6 arrangement (Table 6). Conclusively, intercropping system can play a great role in reducing the weed density in crop production system.

Table 6: Weed density and fresh weed biomass as affected by herbicide use and intercropping treatments

Treatments	Weed density m^{-2}	Fresh weed biomass (kg ha^{-1})
Herbicides (A)		
Stomp 330EC (pendimethalin)	16.47 b	529.8 b
Control	42.90 a	2751.5 a
LSD0.05	*	*
Intercropping (B)		
Sole maize (6 rows)	36.88 a	2389.5 a
Sole mungbean (15 rows)	31.57 c	1836.7 c
5 Rows Mungbean+6 rows maize	28.033 d	1456.0de
10 Rows Mungbean+6 rows maize	24.450 f	1100.6 g
LSD (0.05)	1.9873	113.89
LSD (0.05) Interaction of AxB	2.8105	161.06

Different lettersin each row indicates significant levelat 0.05%; *Significant at $p \leq 0.05$; Source: Lawson et al. (2007)

4. Advantage of Cereal+Legume Intercropping Over Sole Cropping as Assessed by Different Competition Indices

Intercropping indices like land equivalent ratio (LER), relative crowding coefficient (K), aggressivity (A), competitive ratio (CR), actual yield loss (AYL) and intercropping index (IA) are the important indicesfor evaluating intercropping patterns or describing competition between component crops of intercropping systems (Ghosh, 2004; Yilmaz et al., 2007). Dariush et al. (2006) reported that average LER (1.16) gave efficient productivity in maize+soybean intercropping than sole crop.

Maize and cowpea planted as a mixed proportion of 50:50 and 60:40 showed that the LER for maize was above 1.00, while it decreased when the maize population was more than 60% (Takim, 2012). LER is used for assessing the farming system productivity and portion of land saved (Undie et al., 2012). Takim (2012) recorded positive values of aggressivity (A) for maize and ultimately suggested that maize were dominant species in all mix-proportion. Several studies reported that maize crop always showed the positive values for aggressivity (A) index that means maize was the dominant species while cowpea crop showed negative value in view of all mixture proportion and planting patterns (Dhima et al., 2007; Yilmaz et al., 2007). Takim (2012) found higher competition ratios (CRs) for intercropped maize in all mixtures excluding 40M:60C. The mix-proportion of 50M:50C gave the higher CR value for maize and when the mixture of maize proportion increased the CR value decreased gradually. But incase of cowpea with an increase in proportion of cowpea mixtures the CR values also increased.With the increased of aggressivity (A) index, the value of competition ratio (CR) is also increased. Relative crowding coefficient helps to know the yield advantage. Values of the crowding coefficient (K) for both crops (maize and cowpea) were less than one, excluding at 100M:100C plots where cowpea crop showed the K value of 1.89 indicating an absolute yield advantage over maize while other remaining plots showed that there was no yield advantage of one crop over another. In cereals+legume intercropping system, the cereal component is known as aggressive/suppressing crop while the legume component is known as suppressed crop (Haynes, 1980). For example, in intercropping systems of barley+fababean (Strydhorst et al., 2008), maize+groundnut (Inal et al., 2007), and wheat+soybean, pigeonpea+pearlmillet, the barley, maize, wheat and pearl millet are the aggressive crops, and the faba bean, groundnut, soybean and pigeonpea are the suppressed crops. When cowpea was intercropped with extra early sown maize, it showed the higher crop values (2907.8 US\$ ha^{-1}) and lowest when intercropped with late sown maize. Maize+ cowpea intercropping with extra early, early and late maize variety showed higher crop valuesof 139, 109 and 97% respectively over sole crop (Sylvester et al., 2014). IT89KD-391 (maize+cowpea cultivar) recorded a higher mean crop value i.e. 132% compare to the sole cowpea and another maize+cowpea cultivar (IT99K-241-2) obtained a crop value that was higher than the sole cowpea by 100% (Table 7).

Table 7: Mean crop values of maize-cowpea intercrops and sole cowpea over 2 years

Intercrop combination	IT89KD-391 (US\$ ha^{-1})	IT99K-241-2 (US\$ ha^{-1})	Mean (US\$ ha^{-1})
Extra early Maize+cowpea	2861.8	2953.7	2907.8
Early Maize+cowpea	2627.4	2464.5	2546.0
Late Maize+cowpea	2364.5	2429.0	2396.7
Mean	2617.9	2615.7	
Sole cowpea	1126.4	1311.0	1218.7

Source: Ewansiha et al. (2014)

5. Assessment of Soil Health Improvementunder Cereal+Legume Intercropping System

5.1. Physico-chemical properties of soil

Intercropping of cereal+legume has been recognized as one of the sustainable intensification pathways because it gives greater stability than sole cropping in terms of soil fertility improvement and environmental stability. So, the pulses have become a viable alternative to improve the soil health and conserve the natural resources and agricultural ssustainability. Pulse are known as soil fertility restoration crop, as they improved soil fertility status through deep rooting, nitrogen fixation, leaf sheddingability, and mobilization of insoluble soil nutrientsto soluble form. It improved not only the soil chemical properties but also the soil physical and biological properties. The inclusion of legume crops in the cereal-based cropping system is a component of integrated plant nutrient supply (IPNS) system. Expanded nutrient uptake in intercropping systems can happen over time and space. Spatial nutrient uptake can be increased through expanding root mass, while the temporal benefit of enhanced nutrient take-up occurs when there is no synchronization in nutrient demand by component crops in an intercropping system (Layek et al., 2018). Besides, if the species have diverse establishing and uptakebehaviors, as observed in cereal+legume intercropping system, the utilization of accessible supplements through different soil layer withhigher nutrient uptake is more over monocropping system. Pulse based intercropping systems improves several aspects of soil fertility, namelysoil organic matter, and humus content along with N and P availability (Jensen et al., 2012). Grain legume crops can increase soil organic matter (SOC) by several means viz, by supplying biomass, organic C and N (Garrigues et al., 2012) as well as releasing hydrogen gas as by-product of biological nitrogen fixation (BNF), which promotes bacterial population in the rhizosphere(La and Focht,1983).Some investigatorsobserved the relative advantage of intercrops over monocrops in build up of soil fertility. For example, maize+cowpea intercropping is profitable for N-deficit soil and it improved the available N, P and K content in the soil as compared with monocropping of maize (Vesterager et al., 2008). It was also reported that pulses acquire a larger part of N requirement from the air as diatomic nitrogen rather thanfrom the soil as NO_3^-. Legume increase the soil organic matter that enhances soil physico-chemical and biological properties, ultimately reduces soil disintegration and iincreasing water and nutrient availability (Sharma et al., 2005; Dhakal et al., 2016).Intercrops can reduce the risks of nitrate leaching compared to sole cropped legume due to complementary use of soil mineral N and N_2 from the air between cereals and legumesin the intercropping system(Hauggaard-Nielsen et al., 2003). Recently, cereal+legume intercropping systems is getting more attention by the researchers all over the world with the reported phenomena of enhanced soil P acquisition by cereals+legume intercropping (Li et al., 2007) and enhanced Fe and Zn uptake (Zuo and Zhang, 2009). In calcareous soils, cereals intercropped with legumesincreased P uptake of intercropped wheat as the roots of white lupin exude citrate which competes withphosphate ions for calcium phosphates and as a result, P availability and other soil chemical properties increased significantly (Gardner and Boundy,1983). Other investigators reported that chickpeaeffectively accessed organic P fromphytate by enzymatic hydrolysis and thereby facilitate P acquisition of wheat and maize in wheat+chickpea (Li et al., 2003a) and maize+chickpea system (Li et al., 2004), respectively. Oelbermann et al. (2015) conducted a study on maize+soybean intercropping system and found that soil physical and chemical characteristics were significantly different in 2007 compared to 2012, except for soil pH (Table 8). Soil bulk density was significantly higher at both sampling depths during 2012and was in increasing trend ranging from 9to 20% at 0–20 cm and 15 to 31% at 20–40 cm respectively. Soil organic C concentration (%) and C and N stocks (g m^{-2}), and C:N ratio were significantly greater in 2012 for all treatments and at both depths, except for the C:N ratio in soybean sole crop at 20–40 cm depth. Soil organic C concentration showed a relative increase by 2012, ranging from 27 to 37% at 0–20 cm and from 38 to 53% at 20–40 cm. Total N concentration (%) of soil increased in 2012, but was significantly greater only in soybean sole crop at both depths and in the 1:2 intercrop at 20–40 cm. Soil total N concentration had a relative increase that ranged from5 to 20% at 0–20cmand from13 to 33% at 20–40 cm. Soil bulk density, SOC, soil total N, and C:N ratio were significantly lower at 20–40 cm depth, whereas soil pH was significantly greater at 20–40 cm.

Table 8: Changes in soil characteristics at different depths in maize and soybean based sole and intercropping systems during 2007 to 2012

Characteristics	Soil depth (cm)	Sole maize		Sole soybean		Maize+soybean (1:2)		Maize+soybean (2:3)	
		2007	2012	2007	2012	2007	2012	2007	2012
Bulk density (g cm^{-3})^{b}	0–20	1.23^{A,b}	1.34^{A,a}	1.18^{A,b}	1.42^{A,a}	1.18^{A,b}	1.38^{A,a}	1.14^{A,b}	1.30^{A,a}
	20–40	1.25^{A,b}	1.44^{A,a}	1.23^{A,b}	1.48^{A,a}	1.16^{A,b}	1.52^{A,a}	1.24^{A,b}	1.53^{A,a}
pH^{a}	0–20	5.9^{A,a}	5.7^{A,a}	5.6^{A,a}	5.4^{A,a}	5.9^{A,a}	5.6^{A,a}	5.7^{A,a}	5.7^{A,a}
	20–40	6.1^{A,a}	5.9^{A,a}	5.9^{A,a}	5.8^{A,a}	6.1^{A,a}	5.8^{A,a}	6.0^{A,a}	5.8^{A,a}
Soil Organic Carbon (%)^{b}	0–20	3.57^{A,b}	4.52^{A,a}	3.36^{A,b}	4.61^{A,a}	3.35^{A,b}	4.48^{A,a}	3.41^{A,b}	4.58^{A,a}
	20–40	1.74^{A,b}	2.44^{A,a}	2.07^{A,b}	2.86^{A,a}	1.79^{A,b}	2.69^{A,a}	1.94^{A,b}	2.87^{A,a}
Nitrogen (%)^{b}	0–20	0.21^{A,a}	0.22^{A,a}	0.20^{A,b}	0.24^{A,a}	0.20^{A,a}	0.23^{A,a}	0.20^{A,a}	0.21^{A,a}
	20–40	0.15^{A,a}	0.18^{A,a}	0.16^{A,b}	0.21^{A,a}	0.15^{A,b}	0.20^{A,a}	0.15^{A,a}	0.17^{A,a}
Calcium/sodium (Ca Na^{-1})	0–20	16.7^{A,b}	20.3^{A,a}	16.7^{A,b}	19.2^{A,a}	17.4^{A,b}	19.7^{A,a}	17.3^{A,b}	24.0^{A,a}
	20–40	12.0^{A,b}	13.6^{A,a}	13.1^{A,a}	13.9^{A,a}	12.0^{A,b}	13.5^{A,a}	12.9^{A,b}	21.0^{A,a}
SOC stock (g m^{-2})b	0–20	6191^{A,b}	806^{A,a}	5863^{A,b}	8759^{A,a}	5413^{A,b}	8432^{A,a}	5309^{A,b}	7576^{A,a}
	20–40	4453^{A,a}	3531^{A,b}	3990^{A,b}	4903^{A,a}	4172^{A,a}	3824^{A,b}	4475^{A,a}	4087^{A,b}
N Stock (g m^{-2})^{b}	0–20	525^{A,b}	607^{A,a}	470^{A,b}	681^{A,a}	457^{A,b}	634^{A,a}	450^{A,b}	616^{A,a}
	20–40	371^{A,a}	260^{A,b}	410^{A,a}	304^{A,b}	347^{A,a}	285^{A,b}	373^{A,a}	306^{A,b}
SOCT (years)^{c}	0–20	5.9^{B,a}	6.3^{C,a}	11.9^{A,b}	56.6^{A,a}	6.2^{B,b}	10.2^{B,a}	6.2^{B,b}	7.5^{C,a}
	0–40	10.0^{B,a}	9.0^{C,a}	17.9^{A,b}	88.3^{A,a}	10.9^{B,b}	14.8^{B,a}	11.5^{B,a}	11.6^{B,a}

Values followed by the same upper case letters, comparing differences among treatments within years and depth, are not significantly different at Probability 0.05 according to Tukey's multiple comparison test. Values followed by the same lower case letters, comparing differences between years within treatments and depth, are not significantly different at Probability 0.5 according to the F-statistic; a: Values are significantly greater at the 20–40 cm depth for all treatments and years; b: Values are significantly lower at the 20–40 cm depth for all treatments and years; c: Values are significantly different between depths for all treatments and years; Values followed by the same upper-case letters, comparing differences among treatments within year and depth for SOCT, are not significantly different at Probability 0.05 according to LSD; Values followed by the same lower-case letters, comparing differences between years within treatments and depth for SOCT, are not significantly different at Probability 0.05 according LSD; Source: Adapted from Oelbermann et al. (2015)

Intercropping controls soil disintegration by reducingimpact of falling rain drops from directly hitting the soil surface and possible sealing of surface pores, resulting an increase in water infiltration and reduces the runoff volume (Seran and Brintha, 2010). In maize+cowpea intercropping system, cowpea was reported as the best cover crop which decreased soil disintegration than a maize-bean sequence (Kariaga, 2004). Intercropping of sorghum+cowpea reduced soil loss by 50% against growing them separately (Zougmore et al., 2000).

5.2. Biological properties of soil

Legume crops are well known for enriching the soil by supplying N through the process of biological nitrogen fixation (BNF), especially when N fertilizer is restricted (Fujita and Ofosu-Budu 1996). However, the nitrogen fixation in legume intercropping system depends ontype of legumes grown, the crop morphology, plant density, cultivation practices followed, nitrogen fixating capacity and aggressiveness of component crops. The legume crop modifies the carbon: nitrogen (C:N) ratio and enhances the activity of soil enzyme, as a result conversion of unavailable to available form of nutrients is also increased. Pulses also play an important role for improving the microbial environment in the soils (Kumar and Goh, 2000; Meena et al., 2014). Some legume crops like soybean, common bean, cowpea, lablab, groundnuts etc. act as an important host for these microorganisms to perform biological nitrogen fixation. They are also reported to release a part of unused nitrate fixed through symbiotic nitrogen fixation to the soil (Herridge et al., 1995).Interestingly, it was reported that about 50–60% of soybean N demand was met by biological N_2 fixation (Salvagiotti et al., 2008). Song et al. (2007) found a greater soil microbial biomass and C:N ratio in intercrops (wheat+fababean, wheat+maize and maize +bean) compared to sole crops. Song et al. (2007) opined that differences in microbiological properties of the rhizosphere in the intercrops led to a greater soil microbial biomassand resulted a more diverse and active microbial communities which are capable of effectively decompose a larger variety of carbon compounds. This is probably due to microbes present in the intercropsrich in organic matter compared to the sole crops which ultimately enhances the interaction and simultaneous assimilation of C and N by heterotrophic soil organisms (Sall et al., 2007; Chen et al., 2008). The enzymatic activity occurred in the soil is generally the product of the magnitude of the microbial population in soil. The grain-legume crops boost the dehydrogenase, urease, protease, phosphatase, and β-glucosidase reactions in the soil (Roldan et al., 2003).

5.3*Soil moisture and water use efficiency*

Various improved technologies and methodologies are used to save water in agriculture like adoption of regulated deficit irrigation in crop production and productivity (Chai et al., 2014), the use of innovative water-saving practices (Fan et al., 2013) and the enforcement of bylaws and policies in water resource management (Chai et al., 2014). Water availabilityand its use efficiency are the most important factorsto determine the productivity in cereal-legume intercropping systems. Intercropping systems had significantly affect on environmental resources consumption *i.e* better utilization of all resources including water and uptake of nutrient as compared to sole crop due complimentarily effect of the components in an intercropping system (Eskandari, 2012). It was found that improved water use efficiency (WUE) increase the uses of other resources in an intercropping system (Hook and Gascho, 1988). Both higher leaf area and leaf area index in early crop growth stage help to conserve water (Ogindo and Walker, 2005). Hulugalle and Lal (1986) also found greater WUE in cereal+legume intercropping system than the sole crops, when soil moisture was not limiting.For the efficient crop production and WUE, continuous pearl millet and forage legume intercropping system is very important (Garba and Renard, 1991).It has been reported that soil moisture content (at 20, 60 and 80 cm except 40 cm) was significantly affected by cropping system. Sole cowpea showed higher moisture content at 20 cm depth at what stage while maize at its booting, silking and maturity stages reflected greater soil moisture content in maize+ cowpea intercropping system at what depth. Further, sole maize crop had lower moisture content compared to maize+cowpea intercropping system.Stripcropping not only enhanced the spatialdistribution of soil water across 0-110 cm rooting zones. In maize+pea intercropping system, pea plants absorbed soil moisture mostly in the top 20 cm layers,whereas maize plants consumed water from deeper-layers of the acquaintance pea strips.Intercropped maize absorbed compensatory soil moisture from the pea strips after harvesting pea andwithout any root barrier inthe intercropping system, it increased grain yield and WUE by 25 and 24%, respectively compared to intercropping with the root barrier (Chen et al., 2018).Strip-intercropping was one of such most effective approaches to improve WUE in field crops production.To reduce runoff and conserve soil moisture in field, intercropping can be used as a key strategy and improve water productivity (Fan et al., 2013; Chai et al., 2014; Tanwar et al., 2014; Sharma et al., 2017). In case of sole crop, soil moisture content was significantly ($p<0.05$) higher than for intercrop treatments. Intercropping system of additive design had lower soil moisture content as comparedto replacement designof intercropping (Eskandari, 2012).

6. Residual Effect of Cereal+Legume Intercropping System

In cereal+legume intercropping system, legume crops fix the atmospheric Nin the soil and this helps to improve the soil fertility and supplies nutrients for the sequential crops (Ofori and Stern, 1987). Grain yield of maize was significantly increased by 46% when sown after leguminous soybean crop than that of natural fallow (Yusuf et al., 2009). Kureh and Kamara (2005) also reported thatwhen maize is sown after one year of soybean and cowpea cultivation, it increased the grain yield of maize by 28 and 21%, respectively than the continuous sowing of maize crop. But maize sowing after two years of soybean+maize and cowpea+maize intercropping, brought about 85 and 66% yieldincrease in maize, respectively than that of mono-cropping of maize.Maize yield could be increased to the tune of 340% due to four successive cropping seasonsin *glyricidia*+maize intercropping system as compared to unfertilized sole maize (Akinnifesi et al., 2007).

7. Economic Benefits of Cereal+Legume Intercropping System

Smallholder farmers are supposed to get more monetary benefit from the intercropping system than the monocrops (Seran and Brintha, 2010). Osman et al. (2011) opined that intercropping systems increased the productivity and income especially for smallholder farmers and reduced risk of crop failure. According to Mucheru-Muna et al. (2010), MBILI (Managing Beneficial Interactions for Legume Intercrops) system with bean as an intercrop reflected 40% higher net benefits compared to conventional system with beans, and similarly 50–70% higher benefits with cowpea or groundnut in MBILI system.While working on maize+cowpea intercropping system, Segun-Olasanmi and Bamire (2010) found that farmers get more profits than their sole crops. Osman et al. (2011) reported that in cowpea+millet intercropping system, 2:1 ratio gave significantly higher economic benefit than 1:1 ratio with better monetary advantage index (MAI). Sorghum+cowpea system (2:1) gave higher economic return compared to the other arrangements and the sole crops (Oseni, 2010).

8. Conclusion

The cereal+legume intercropping systemsarepopular among farmers across rainfed regions as they ensure minimum to higher productivity and net farm income,risk minimization, soil conservation, weed control and restoration of soil health. They also improve soil physical, chemical and biological properties which in turn support better crop growth and yield. Though, intercropping has been in vogue since several decades, many farmers don't adopt definite row proportions and select proper combination of crops. Hence, efforts must be made to map location specific, highly productive and profitable intercropping systems across different agro-climatic zones and the same have to be upscaled and out scaled.

9. References

Addo-Quaye, A.A., Darkwa, A.A., Ocloo, G.K., 2011. Growth analysis of component crops in a maize-soybean intercropping system as affected by time of planting and spatial arrangement. Journal of Agriculture and Biological Science 6(6), 34–44.

Adigbo, S.O., Iyasere, E., Fabunmi, T.O., Olowe, V.I.O., Adejuyigbe, C.O., 2013.Effect of spatial arrangement on the performance of cowpea/maizeintercrop in derived Savannah of Nigeria. American Journal of Experimental Agriculture 3(4), 12.

Akinnifesi, F.K., Makumba, W., Sileshi, G., Ajayi, O.C., Mweta, D., 2007. Synergistic effect of inorganic N and P fertilizers and organic inputs from *gliricidia sepium* on productivity of intercropped maize in southern Malawi. Plant and Soil 294, 203–217.

Ali, R.I., Awan, T.H., Ahmad, M., Saleem, M.U., Akhtar, M., 2012. Diversification of rice-based cropping systems to improve soil fertility, sustainable productivity and economics. Journal of Animal and Plant Sciences 22(1), 108–112

Amasaib, E.O., Balgees, A., Elmnan, A., Mahala, A.G., Elseed, A.M.A.F., 2011.Nutritive value of maize (Zea mays) and dolecous (Lablabpurpureus) as affected by phosphorous fertilization andintercropping. Journal of Animal and Feed Research 2(6), 488–492.

Banda, J.S.K., Mweetwa, A.M., Ngulube, M., Phiri, E., 2018. Chemical and biological properties of soils under maize-cowpea cropping systems in conservation agriculture. Journal of Agricultural Science 10(5), 100–108.

Banik, P., Sharma, R.C., 2009. Yield and resource utilization efficiency inbaby corn-legume intercropping system in the eastern plateau of India. Journal of Sustainable Agriculture 33, 379–385.

Barker, P.P., De Mollo, R.W., 2000. Determining the impact of distributed generation on power system: I. Radial distribution systems, Power Engineering Society Meeting 3, s. 1645–1656.

Baumann, D.T., Bastiaans, L., Kropff, M., 2001. Effects of intercropping on growth and reproductive capacity of late-emerging *Senecio vulgaris* L., with special reference to competition of light. Annals of Botany 87, 209–217.

Bilalis, D., Papastylianou, P., Konstantas, A., Patsiali, S.,Karkanis, A.,Efthimiadou, A., 2010. Weed-suppressive effects of maize-legume intercropping in organic farming. International Journal of Pest Management 56, 2, 173–181.

Blumenberg, M., Berndmeyer, C., Moros, M., Muschalla, M., Schmale, O., Thiel, V., 2013. Bacteriohopanepolyols record stratification, nitrogen fixation and other biogeochemical perturbations in Holocenesediments of the central Baltic Sea. Biogeosciences 10, 2725-2735.

Bollen, M.H.J., Renders, B., 2008. Distributed Generation for Mitigating Voltage Dips in Low-Voltage Distribution Grids, IEEE Transaction on Power Delivery 23(3), 1581–1588.

Burton, J.W., Brim, C.A., Rawlings, J.O., 1983. Performance of non-nodulating and nodulating soybean isolines in mixed culture with nodulating cultivars. Crop Science 23, 469–473.

Caviglia, O.P., Sadras, V.O., Andrade, F.H., 2011. Yield and Quality of Wheat and Soybean in Sole- and Double-Cropping. Agronomy Journal 103, 1081–1089.

Chai, Q., Gan, Y., Turner, N.C., Zhang, R.Z., Yang, C., Niu, Y., Siddiquem K.H.M., 2014. Water-saving innovations in Chinese agriculture. Advances in Agronomy 126, 149–201). Academic Press.

Chen, G., Kong, X., Gan, Y., 2018. Enhancing the systems productivity and water use efficiency through coordinated soil water sharing and compensation in strip-intercropping. Scientific Reports 8, 10494.

Chen, M., Chen, B., Marschner, P., 2008. Plant growth and soil microbial community structure of legumes and grasses grown in monoculture or mixture. Journal of Environmental 20, 1231–1237.

Connolly, J., Goma, H.C., Rahim, K., 2001. The information content of indicators in intercropping research. Agriculture, Ecosystems & Environment 87, 191–207.

Dapaah, H.K., Asafu-Agyei, J.N., Ennin, S.A., Yamoah, C., 2003. Yield stability of cassava, maize, soybean and cowpea intercrops. Journal of Agricultural Science 140, 73–82.

Dariush, M., Ahad, M., Meysam, O., 2006. Assessing the land equivalent ratio of two corn varieties intercropping at various levels in karaj, Iran. College of Agriculture of Tehran University Islamic Azad University of Ramhormoz, Khosestan. Journal of Central European Agriculture 7(2), 359–364.

David, C., Jeuffroy, M.H., Henning, J., Meynard, J.M., 2005. Yield variation in organic winter wheat: a diagnostic study in the Southeast of France. Agronomy for Sustainable Development 25, 213–223.

Dhakal, Y., Meena, R.S., Kumar, S., 2016. Effect of INM on nodulation, yield, quality and available nutrient status in soil after harvest of green gram. Legume Research 39 (4), 590–594

Dhima, K.U., Lithougidis, A.A., Vasilakoqlou, I.B., Dordas, C.A., 2007. Competition indices of common vetch and cereals intercropping in two seeding ratio. Field Crops Research 100, 249–258.

Dhiman, K.U., Lithourigids,AA., Vasilakoqlou, I.N., Dordas, C.A. 2007. Competition indices of common vetch and cereals intercropping in two seeding ratio. Field Crops Research 100, 249–258

Eskandari, H., 2012. Intercropping of Maize (*Zea mays*) with Cowpea (*Vigna sinensis*) and Mungbean (*Vigna radiata*): Effect of Complementarity of Intercrop Components on Resource Consumption, Dry matter Production and Legumes Forage Quality. Journal of Basic and Applied Scientific Research 2(1), 355–360.

Ewansiha, S.U., Kamara, A.Y., Onyibe, J.E., 2014. Performance of cowpea cultivars when grown as an intercrop with maize of contrasting maturities. Archives of Agronomy and Soil Science 4, 60(5), 597–608.

Fan, Z., Chai, Q., Huang, G., Yu, A., Huang, P., Yang, C., Liu, H., 2013. Yield and water consumption characteristics of wheat/maize intercropping with reduced tillage in an Oasis region. European Journal of Agronomy 45, 52–58.

Fenandez-Aparicio, M., Sillero, J.C., Rubiales, D., 2007. Intercropping with cereals reduces infection by Orobanche crenata in legumes. Crop protection 26(8), 1166–1172.

Fujita K., Ofosu-Budu, K. G., Ogata, S., 1992. Biological Nitrogen Fixation in Mixed Legume-Cereal Cropping Systems. Plant and Soil 141, 155–176.

Fustec, J., Lesuffleur, F., Mahieu, S., Cliquet, J.B., 2010. Nitrogen rhizodeposition of legumes.A Review, Agronomy for sustainable development 30, 57–66.

Gan, Y.T., Liang, C., Hamel, C., Cutforth, H., Wang, H., 2011 Strategies for reducing the carbon footprint of field crops for semiarid areas- a review. Agronomy for Sustainable Development 31, 643–656.

Garba, M., Renard, C., 1991. Biomass production, yields and water use efficiency in some pearl millet/legume cropping systems at Sadore, Niger. In: Proceedings of the Niamey Workshop, February 1991. IAHS Publ. No. 199, 431–441.

Gardner, W.K., Boundy, K.A., 1983. The acquisition of phosphorus by *Lupinus albus* L. IV. The effect of interplanting wheat and white lupin on the growth and mineral composition of the two species. Plant and Soil 70, 391–402

Garrigues, E., Corson, M.S., Walter, C., Angers, D.A., van der Werf, H., 2012. Soil-quality indicators in LCA: method presentation with a case study. In: Corson MS, van der Werf HMG, editors. Proceedings of the 8th international conference on life cycle assessment in the agri-food sector, 1–4 October 2012, INRA, Saint Malo, 163–68.

Ghanbari, A., Dahmardeh, M., Siahsar, B.A., Ramroudi, M., 2010. Effect of maize (*Zea mays* L.) - cowpea (*Vigna unguiculata* L.) intercropping on light distribution, soil temperature and soil moisture in arid environment. Journal of Food, Agriculture and Environment 8, 102–108.

Ghosh, P.K., 2004. Growth, yield, competition and economic of groundnut /cereal fodder intercropping systems in the semi-arid tropics of India. Field Crops Research 88, 217–237.

Hauggaard-Nielsen, H., Ambus, P., Jensen, E.S., 2003. The comparison of nitrogen use and leaching in sole cropped versus intercropped pea and barley. Nutrient Cycling in Agroecosystems 65(3), 289–300.

Haynes, R.J., 1980. Competitive aspects of the grass-legume association. Advances in Agronomy 33, 227–261.

Herridge DF, Maecellos H, Felton WL, Turner GL, Peoples MB. 1995. Chickpea increases soil N fertility in cereal systems through nitrate sparing and N_2 fixation. Soil Biology and Biochemistry 27, 545–551

Himmelstein, J., Ares, A., Gallagher, D., Myers, J.A., 2017. Meta-Analysis of intercropping in Africa: Impacts on crop yield, farmer income, and integrated pest management effects. Journal of Soil and Water Conservation 5, 1–10.

Hook, J.E., Gascho, G.J., 1988. Multiple Cropping for Efficient Use of Water and Nitrogen, 7-20. In: Hrgrofe, W.L. (Ed.) Cropping Strategies for Efficient Use of Water and Nitrogen. ASA Special Publication Number 51. American Society of Agronomy, Inc., Madison, Wisconsin, USA.

Hulugalle, N.R., Lal, R., 1986. Soil Water Balance in Intercropped Maize and Cowpea Grown in a Typical Hydromorphic soil in Western Nigeria. Agronomy Journal 77, 86–90.

Inal, A., Gunes, A., Zhang, F., Cakmak, I., 2007. Peanut/maize intercropping induced changes in rhizosphere and nutrient concentrations in shoots. Plant Physiology and Biochemistry 45, 350–356

Jat, P.C., Rathore, S.S., Sharma, R.K., 2014. Effect of Integrated Nitrogen Management and Intercropping Systems on Yield Attributes and Yield of Maize. Indian Journal of Hill Farming 27(1), 52–56.

Javanmard, A., Dabbagh Mohammadi-Nasab, A., Javanshir, A., Moghaddam, M., Janmohammadi, H., 2009. Forage yield and quality in intercropping of maize with differentlegumes as double cropped. Journal of Food, Agriculture and Environment 7(1), 163–166.

Jensen, E.S., Peoples, M.B., Boddey, R.M., Gresshoff, P.M., Hauggaard-Nielsen, H., Alves, B.J., Morrison, M.J., 2012. Legumes for mitigation of climate change and the provision of feedstock for biofuels and biorefineries. A review. Agronomy for Sustainable Development 32, 329–64.

Ju, X.T., Kou, C.L., Zhang, F.S., Christie, P., 2006. Nitrogen balance andgroundwater nitrate contamination: Comparison among threeintensive cropping systems on the North China Plain. Environmental Pollution143, 117–125.

Kamanga, B.C.G., Waddington, S.R., Robertson, M.J., Giller, K.E., 2010.Risk analysis of maize-legume cropcombinations with smallholder farmers varying in resource endowment in central Malawi. Experimental Agriculture 46, 1–21

Kumar, K., Goh, K.M., 2000 Crop residues and management practices: effects on soil quality, soilnitrogen dynamics, crop yield, and nitrogen recovery. Advances in Agronomy 68, 197–319.

Kureh, I., Kamara, A.Y., 2005. Effects of Sole Cropping, Intercropping and Rotation with Legume trap-crops on Striga Control and Maize Grain Yield in Farmers' Fields in the Northern Guinea Savanna. In: Badu-Apraku, B., Fakorede, M.A.B., Lum, A.F., Menkir, A., Ouedraogo, M., (Eds.), Demand-Driven Technologies for Sustainable Maize Production in West and Central Africa. Fifth Biennial West and Central Africa Regional Maize Workshop, 3–6 May 2005, IITA-Benin, 169–179.

La Favre, J.S., Focht, D.D., 1983. Conservation in soil of H2 liberated from N2 fixation by H up-nodules. Applied and Environmental Microbiology 46, 304–311.

Lawson, Y.D.I., Dzomeku, I.K., Drisah, Y., 2007. Time of planting mucuna and canavalia in an intercrop system with maize. Journal of Agronomy 6, 534–540.

Layek, J., Das, A., Mitran, T., Nath, C., Meena, R.S., Yadav, G.S., Lal, R., 2018. Cereal+Legume intercropping: an option for improving productivity and sustaining soil health. In: Meena, R.S., Das, A., Yadav, G.S., Lal, R. (Eds.), Legumes for Soil Health and Sustainable Management (347-386). Springer, Singapore.

Li, L., Li, S.M., Sun, J.H., Zhou, L.L., Bao, X.G., Zhang, H.G., Zhang, F.S., 2007. Diversity enhances agricultural productivity via rhizosphere phosphorus facilitation on phosphorus-deficient soils. Proceedings of the National Academy of Sciences, USA 104, 11192–11196.

Li, L., Tang, C., Rengel, Z., Zhang, F., 2003a. Chickpea facilitates phosphorus uptake by intercropped wheat from an organic phosphorus source. Plant and Soil 248, 297–303.

Li, S., Li, L., Zhang, F., Tang, C., 2004. Acid phosphatase role in chickpea/maize intercropping. Annals of Botany 94, 297–303.

Liu, B., Liu, X.B., Wang, C., Jin, J., Harbert, S.J., Hashemi, M., 2010. Response of soybean yield and yield components to light enrichment and planting density. International Journal of Plant Production, 4(1), 1–10

Liu, X., Rahman, T., Yang, F., Song, C., Yong, T., Liu, J., 2017. PAR Interception and Utilization in Different Maize and Soybean Intercropping Patterns. PLoS ONE 12(1):e0169218.https://doi.org/10.1371/journal.pone.0169218

Machado, S., 2009. Does intercropping have a role in modern agriculture? Journal of Soil and Water Conservation 64, 55A–57A.

Matusso, J., Mugwe, J.N., Muna, M.M., 2014. Effect of different maize (*Zea mays* L.) soybean (*Glycine max* (L.) Merrill) intercropping patterns onyields, light interception and leaf area index in EmbuWest and Tigania East sub counties Abstract. Academic Research Journal of Agricultural Science and Research 2(2), 6–21.

Meena, V.S., Maurya, B.R., Meena, R.S., Meena, S.K., Singh, N.P., Malik, V.K., 2014. Microbial dynamics as influenced by concentrate manure and inorganic fertilizer in alluvium soil of Varanasi, India. African Journal of Microbiology Research 8(1), 257–263

Midega, C.A.O., Salifu, D., Bruce, T.J., Pittchar, J., Pickett, J.A., Khan, Z.R., 2014. Cumulative effects and economic benefits of intercroppingmaize with food legumes on Striga hermonthicainfestation. FieldCrops Research 155, 144–152.

Morgado, L.B., Rao, M.R., 1985. Populacao de plantaseniveis de agua no consórciomilho x caupi. Pesquisa Agropecuária Brasileira, Brasilia 20(1), 45–55.

Mucheru-Muna, M., Pypers, P., Mugendi, D., Kung'u, J., Mugwe, J., Merckx, R., Vanlauwe, B., 2010. Staggered Maize–Legume Intercrop Arrangement Robustly Increases Crop Yields and Economic Returns in the Highlands of Central Kenya.Field Crops Research 115(2010) 132–139. 2009

Nieder, R., Benbi, D.K., 2008. Carbon and nitrogen in the terrestrial environment. Springer, Heidelberg Nyasasi, B.T., Kisetu, E., 2014. Determination of land productivity under maize-cowpea intercropping system in agro-ecological zone of mount Uluguru in Morogoro, Tanzania. Global Journal of Agricultural Science 2, 147–157.

Odeny, D.A., 2007. The potential of pigeonpea (*Cajanus cajan* (L.) Millsp.) in Africa. Natl. Res. Forum 31, 297–305.

Oelbermann, M., Regehr, A., Echarte, L., 2015. Changes in soil characteristics after six seasons of cereal–legume intercropping in the Southern Pampa. Geoderma Regional, 4, 100–107.

Ofori, F., Stern, W.R., 1987. Cereal-legumes intercropping. Advances in Agronomy 41, 41–90.

Ofori, F., Stern, W.R., 1987. Cereal-legume intercropping systems. Advances in Agronomy 40, 41–90

Ogindo, H.O., Walker, S., 2005. Comparison of Measured Changes in Seasonal Soil Water Content by Rained Maize-bean Intercrop and Component Cropping in Semi Arid Region in South Africa. Physics and Chemistry of the Earth 30(11-16), 799–808.

Olufemi, O., Pitan, R., Odebiyi, J.A., 2001. The effect of intercropping with maize on the level of infestation and damage by pod-sucking bugs in cowpea. Crop Protection 20, 367–372.

Oseni, T.O., 2010. Evaluation of Sorghum-Cowpea Intercrop Productivity in Savanna Agro-ecology using Competition Indices. Journal of Agricultural Science 2(3), 229–223.

Osman, A.N., Ræbild, A., Christiansen, J.L., Bayala, J., 2011. Performance of cowpea (*Vigna unguiculata*) and Pearl Millet (*Pennisetum glaucum*) intercropped under parkiabiglobosain an agroforestry system in Burkina Faso. Journal of Agricultural Science 6(4), 882–891.

Peoples, M.B., Hauggaard-Nielsen, H., Jensen, E.S., 2009. The potential environmental benefits and risks derived from legumes in rotations. In: Emerich, D.W., Krishnan, H.B. (Eds.), Nitrogen fixation in crop production. American Society of Agronomy, Madison, 349–385

Pinheiro, L., 2000. Physiological responses to maize. Pesquisa agropecuaria brasileria 35(5), 915–921.

Polthanee, A., Surachet, B., 2000. Comparison of single cropping, intercropping and relay cropping of corn with cowpea under rainfed conditions in an upland area of northeastern Thailand. Journal of International Society for Southeast Asian Agricultural Sciences 6, 1–12

Purcell, L.C., 2000. Soybean canopy coverage and light interception measurements using digital imagery. Crop Science 40, 834–837.

Roldan, A., Caravaca, F., Hernandez, M.T., Garci, C., Sanchez-Brito, C., Velasquez, M., Tiscareno, M., 2003. No-tillage, crop residue additions, and legume cover cropping effects on soil qualitycharacteristics under maize in Patzcuaro watershed (Mexico). Soil and Tillage Research 72, 65–73.

Rusinamhodzi, L., Corbeels, M., Nyamangara, J., Giller, K.E., 2012, Maize–grain legume intercropping is anattractive option for ecological intensification that reduces climatic risk for smallholder farmers in centralMozambique. Field Crops Research136, 12–22

Sall, S., Bertrand, I., Chotte, J.L., Becous, S., 2007. Separate effects of the biochemical qualityand N content of crop residues on C and N dynamics in soil. Biology and Fertility of Soils 48, 797–804.

Salvagiotti, F., Cassman, K.G., Specht, J.E., Walters, D.T., Weiss, A., Dobermann, A., 2008. Nitrogen uptake, fixation and response to fertilizer N in soybeans: A review. Field Crops Research 108(1), 1–13.

Sanginga, N., Woomer, P.L., 2009. Integrated Soil Fertility Management in Africa: Principles, Practices and Development Process. Tropical Soil Biology and Fertility Institute of the International Centre for Tropical Agriculture (TSBF-CIAT), Nairobi, 263.

Segun-Olasanmi, A.O., Bamire, A.S., 2010. Analysis of Costs and Returns to Maize-Cowpea Intercrop Production in Oyo state, Nigeria. Poster presented at the Joint 3rd African Association of Agricultural Economists (AAAE) and 48th Agricultural Economists Association of South Africa (AEASA) Conference, Cape Town, South Africa, September 19–23, 2010.

Seran, T.H., Brintha, I., 2010. Review on Maize Based Intercropping. Journal of Agronomy 9(3), 135–145.

Sharma, N.K., Singh, R.J., Mandal, D., Kumar, A., Alam, N.M., Keesstra, S., 2017. Increasing farmer's income and reducing soil erosion using intercropping in rainfed maize-wheat rotation of Himalaya, India. Agriculture, ecosystems & environment 247, 43–53.

Sharma, S.K., Thakur, R.C., Singh, R., 2000. Production potential of maize based cropping system under rainfed conditions. Agricultural Science Digest 20(3), 187–188.

Sharma, S., Aneja, M.K., Mayer, J., Munch, J.C., Schloter, M., 2005. Characterization of bacterial community structure in rhizosphere soil of grain legumes. Microbial Ecology 49, 407–415

Sing, H.P., Venkateswarlu, B., Vittal, K.P.R., Ramchandran, K., 2000. Management of rainfed agroecosystems. In: Yadav, J.S.P., Singh, G.B. (Eds.), Natural resource management for agricultural production in India ISSR, New Delhi.

Snapp, S.S., Blackie, M.J., Gilbert, R.A., Bezner-Kerr, R., Kanyama-Phiri, G.Y., 2010.Biodiversity can support agreener revolution in Africa. Proceedings of the National Academy of Sciences of the United States of America 107, 20840–20845.

Song, Y.N., Zhang, F.S., Marschner, P., Fan, F.L., Gao, H.M., Bao, X.G., Sun, J.H., Li, L., 2007. Effect of intercropping on crop yield and chemical and microbiological properties in rhizosphere of wheat (*Triticum aestivum* L.), maize (*Zea mays* L.), and faba bean (*Vicia faba* L.). Biology and Fertility of Soils 43(5), 565–574.

Strydhorst, S.M., King, J.R., Lopetinsky, K.J., Harker, K.N., 2008. Forage potential of strip intercropping: I. Yield advantage and interspecific interactions on nutrients. Field Crops Research 71, 123–137

Takim, F.O., 2012. Advantages of maize-cowpea intercropping over sole cropping through competition indices. Journal of Agriculture and Biodiversity Research 1(4), 53-59.

Tanwar, S.P., Rao, S.S., Regar, P.L., Datt, S., Jodha, B.S., Santra, P., Kumar, R., Ram, R., 2014. Improving water and land use efficiency of fallow-wheat system in shallow Lithic Calciorthid soils of arid region: Introduction of bed planting and rainy season sorghum–legume intercropping. Soil and Tillage Research 138, 44–55.

Tsubo, M., Walker, S., Ogindo, H.O., 2005 A simulation model of cereal–legume intercropping systems for semi-arid regions: I. Model development. Field Crop Research 93, 10–22.

Undie, U.L., Uwah, D.F., Attoe, E.E., 2012. Effect of intercropping and crop arrangement on yield and productivity of late season maize/soybean mixtures in the humid environment of South Southern Nigeria.

Vesterager, J.M., Nielsen, N.E., Høgh-Jensen, H., 2008. Effect of cropping history and phosphorous source on yield and nitrogen fixation in sole and intercropped cowpea-maize systems. Nutrient Cycling in Agroecosystems 80, 61–73

Yilmaz, S., Atak, M., Erayman, M., 2007. Identification of advantages of maize-legume intercropping over solitary cropping through competition indices in the East Mediterranean Region. Turkish Journal of Agriculture 16, 217–228.

Yusuf, A.A., Iwuafor, E.N.O., Olufajo, O.O., Abaidoo, R.C., Sanginga, N., 2009. Effect of crop rotation and nitrogen fertilization on yield and nitrogen efficiency in maize in the northern Guinea Savanna of Nigeria. African Journal of Agricultural Research 4(10), 913–921.

Zhang, A., Liu, Y., Pan, G., Hussain, Q., Li, L., Zheng, J., Zhang, X., 2012. Effect of biochar amendment on maize yield and greenhouse gas emissions from a soil organic carbon poor calcareous loamy soil from Central China Plain. Plant and soil 351(1-2), 263–275.

Zhang, F., Shen, J., Li, L., Liu, X., 2004. An overview of rhizosphere processes related with plant nutrition in major cropping systems in China. Plant and Soil 260, 89–99.

Zougmore, R., Kambou, F.N., Ouattara, K., Guillobez, S., 2000. Sorghum-cowpea intercropping: an effective technique against runoff and soil erosion in the Sahel (Saria, Burkina Faso). Arid Land Research Management 14, 329–334

Zuo, Y., Zhang, F., 2009. Iron and zinc biofortification strategies in dicot plants by intercropping with gramineous species. A review. Agronomy for Sustainable Development 29, 63–71.