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Contribution of previous legumes to soil fertility and millet yields in West African Sahel

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Studies on combined effects of 4 legume crops residues and rock phosphate application on pearl millet yield were undertaken on sandy acid soil field from 2012 to 2015 at ICRISAT Sahelian center (ISC)-Sadore, Niger. The objective of the experiment was to assess the best combination of legume species x rate of crop residue x rock phosphate doses that can sustainably improve pearl millet yield in cereal monoculture system with a low input cost and minimum soil tillage. Over 3 years, the residual effect of previous legume crop residue significantly improved not only the grain yield ($P<0.001$) and dry residue yields ($P<0.001$) but also the growth parameters of pearl millet than millet mono-cropping. Treatments with or without natural rock phosphate did not show any statistical differences on millet yield while adding a micro dose of urea improved significantly the yield ($P<0.001$). The interaction effects of preceding legume crops in rotation with millet and restitution of dry residue on the earlier mentioned parameters across 3 years mono-cropping were studied in this experiment.

Key words: Millet, legume, cropping system, soil fertility.

INTRODUCTION

The practice of mono-cropping drastically reduces soil nutrients (Beninga, 2014). In Sub Saharan Africa, pearl millet yield is constantly very low because of monoculture and mining of nutrients by the cropping pattern followed in the previous rainy season crop. Many other causes of low productivity can be cited but the difficult availability and high cost of fertilizers have contributed greatly to the reduction of agricultural soils productivity in the Sahelian Western Africa (Bado and Kumar, 2002, Bado, 2012; Adamou et al., 2007).

The use and good management of locally available legume crop residues, and rock phosphate fertilizer can be an alternative for improving the soil fertility at lower cost. Many studies have been carried over the last two decades and have proved the efficiency of crop rotation combined with chemical and organic fertilizers on increasing crop yield (Bationo et al., 2004 Saidou et al., 2009). Soil content in Nitrogen and soluble phosphorus are two limiting factors that are determinant in cereal grain and dry residue yields (Bationo and Ntare 2006).

As such, all soil fertility management system intended to increase cereal production seeks to induce, develop

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and maintain the availability of these two limiting factors (Wopereis et al., 2008). The use of legumes crops in rotation with cereals have a lot of advantages not only on soil physical and chemical properties but also on soil biological efficiency in terms of nutrients balance regulation through the symbiotic links that are established between crops and soil bio fertilizers (Bationo et al., 2011; Bado et al., 2012). So, the crop rotation is a very important aspect and part of West African farming system (Traore et al., 2004).

Many studies have been carried over the last two decades and have proved the efficiency of crop rotation, the restitution of crop residues on soil surface, and being combined with chemical and organic fertilizers (Bationo et al., 2004, 2007; Saidou et al., 2009) on millet yield. But yet Sahelian farmers in Niger are still practicing millet mono-cropping and removal of crop residues while they do not systematically do soil amendment. Therefore, there is crucial need to help farmers with cheaper cropping techniques that will help them rise their millet yield performance, and also to identify the appropriate legumes crop species and dry residue as well the rate of rock phosphate that will be more effective in soil fertility improvement.

This research was undertaken to study the effects of crop rotation and the restitution of previous dry crop residues on pearl millet yield in mono-cropping system. Therefore, our hypothesis for this study is that in the legume based rotation, the restitution to the above-ground dry residue of previous crop has durable impacts on the yield of the millet crop. The main objective is to investigate the effects of legumes crops (Cowpea, Voandzou, Dolichos, Sesbania), and pearl millet, as well as the restitution of their dry residue on the performance of millet. The specific objectives include:

1. To assess the impact of the return of the dry residue of the previous crop on the yield of millet.
2. Identify the legume species, the most effective as a previous crop for durably improving the performance of pearl millet in monoculture system.

MATERIALS AND METHODS

Description of the area

The experiment was carried out in the experimental field at ICRISAT Sahelian Centre of Sadoré (13°14'N, 2°16'E) which is located about 45 km south of Niamey, Niger. Plant development conditions are affected by yearly weather conditions, mostly rainfall pattern and other soil properties.

Weather conditions

The climate of this region is typically Sahelian, with the raining season being between June and September. The pick rainfall is in August and has fluctuated between Mean annual rainfalls at Sadore for the period 2012 to 2015 which was 593.±64.55 mm (Figure 1). The mean rainfall of the 33 years period from 1983 through 2015 is 556.92mm (ICRISAT unpublished). Air temperatures during the dry season tend to be high, with monthly mean daily maximum temperatures (Figure 2 and 3) ranging from 33 to 40°C between October and May (Sivakumar et al., 1993). Prevailing winds blow from the southwest during the rainy season, disturbed by mostly easterly storms. During the dry season, easterly winds dominate.

Vegetation

The vegetation is essentially made of shrubs of Combretaceae, such as *Combretum glutinosum, Combretum micranthum,* and *Guiera senegalensis*, Mimosaceae such as *Acacia Senegal* and *Ziziphus mauritiana*. The tree species include *Prosopis africa, Ferdherbia albida, Sclerocarya birrea, Balanites aegyptiaca, Cassia sieberiana, Pilostigma reticulatum and Hyphaena tebaica,* etc (ICRISAT, 1991). The grass stratus, deeply affected by the overgrazing of cattle and small ruminants, is very poor and is dominated by species such as *Sida cordifolia* and *Sesbania pachycarpa* that are less appetited by cattle. On the other hand, the inventory made on the experiment plots showed a very rich weeds species that include gramineous grass species such as *Eragrostis tremula, Digitaria gayana, Cenchrus biflorus, Cleome vicosa, Pennisetum sp and Andropogon gayanus,* legumes such as *Tepphrosia, gracilice, Zornia glochidiata and legumes species including Alysicarpus ovalifolius, Fimbristylis hispidula, Ipomea pes-tigridis, Ipomea vagans Merremea pinnata, Mitracarpus scaber, Pandiaka involucrata, Sesamum alatum, Commelina forskalaei, Indigofera pilosa* and *Phyllanthus pentandrus*.

Soils

The trial was conducted from 2012 to 2015 on a sandy soil of the ICRISAT Sahelian Center at Sadore station in the main rainy cropping season from July to October. The soil of the experiment belongs to the family of the paleustalf (ICRISAT, 1990). It is a tropical, reddish, friable, sandy ferruginous soil strongly acid (pH = 4-5.2), low in fertility and poor in organic matter. Between 0 to 17 cm, water holding at field capacity is 16.5 mm and permanent wilting point is 1.7 mm while between 17 and 32 cm, the field capacity reaches 7.4 mm and the permanent wilting point is of 2.5mm (ICRISAT, 1990). Particle size analysis, according to Saminou (2003), showed an enrichment of 90 to 95% of wind moved sand to a depth of 20 cm, 3% of silt, 2.9% of clays and 0.22% of organic matter.

Plant material

Seed material for this study is a high yielding, genetically improved millet variety ICMV IS 89305 developed by ICRISAT in 1989. The average plant height is 250 cm and its ability to produce tillers averages between 5 to 6 productive tillers per plant. The length of the panicle is intermediate and the yield potential is 2 t/ha. Natural phosphate of Tahoua (PNT), Urea, and dry residue of previous cropping have been used as fertilizing materials.

The dry residue applied in 2013 trial comes from 4 legumes ((*Sesbania pachycarpa, Vigna unguiculata* (L.)Walpers*; Voandzea subterranean (*L.) Verdc)*; Dolichos lablab* (L.)), and 1 pearl millet ((*Pennisetum glaucum* (L.) R.Br) crops cultivated in 2012 in 2 densities each and restituted in the form of mulch in May 2013, two months before planting of the trial on 15 July 2013. Then, the 2014 trial received the dry residue (dry matter) of previous trial. No dry residue was applied in rainy season (RS) 2015 trial.

It is worth to mention that the dry residue returned to the soil are those obtained on their respective plots. Crops that have produced

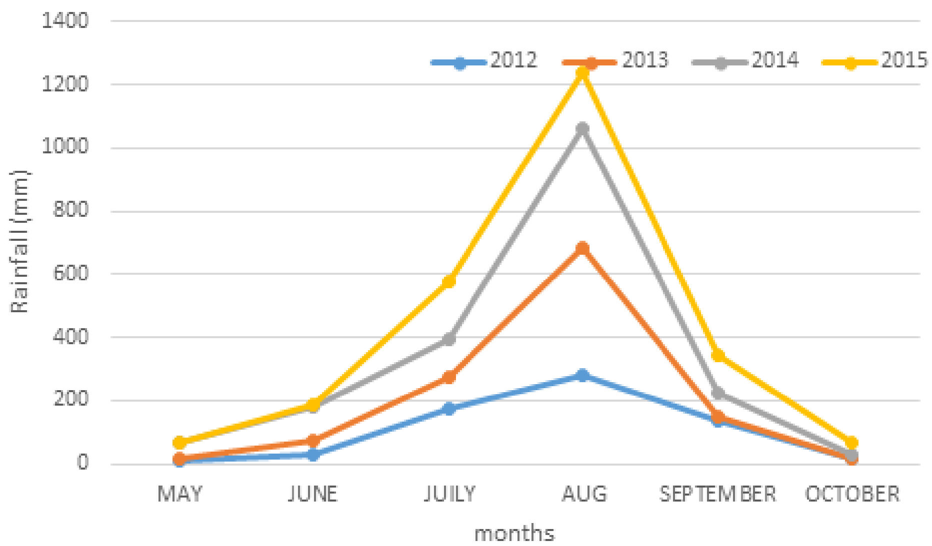

Figure 1. Monthly rainfall during the periods of cropping from 2012 to 2015 as recorded on the Sadore weather station.

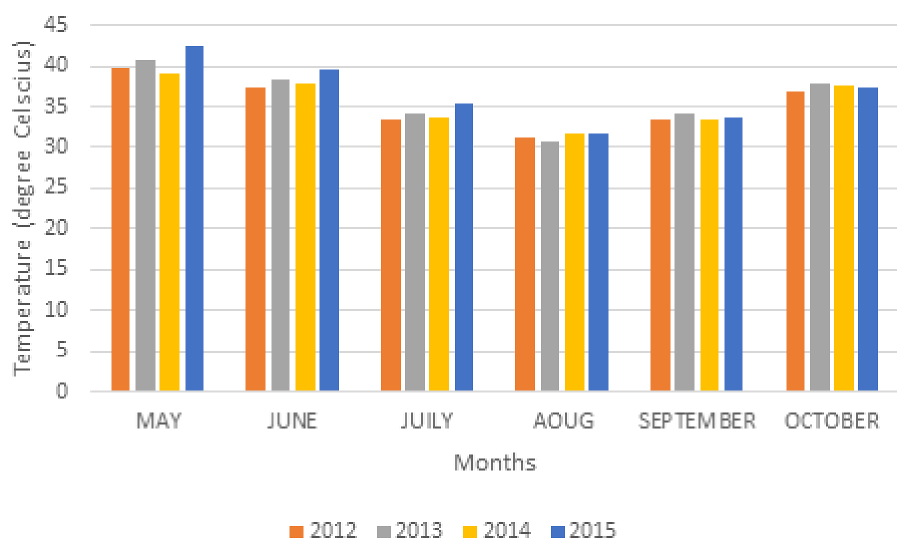

Figure 2. Monthly maxi temperature during crop growing periods for 2012 thru 2015 (degree Celcius) at ICISAT Sadore.

dry residue the most have proved well suited to the soil conditions (Sesbania, millet, cowpeas) while others having produced low productions have had difficulties to withstand the environmental conditions. This is the case of Voandzou (Bambara groundnut) which has suffered attacks by rodents (squirrels, rats, hedgehogs). Dolichos although having had very good germination, did not withstand well because of the texture of the sandy of soil.

Agronomic experiment

The objective of the experiment was to study the effects of crop dry residue on soil fertility, the experiment was initiated in rainy season (RS) 2012 in order to produce the required dry residue. To achieve the objectives, a preliminary test has first been implemented in 2012 to produce the crop dry residue necessary for the test itself (2013 through 2015), from 4 legumes species and a cereal crops sown at two densities each. This preliminary test permitted to characterize the soil in terms of initial physical, chemical and biological properties as a starting situation. The second test has been implemented in 2013 with a sole millet crop and a unique plant spacing of 0.8m x0.8 m. Just before planting the millet, 3 levels of Tahoua Rock Phosphate (PNT) were applied accordingly to the trial protocol. The aim was to study the rear effects of 2012 legumes and cereal crops and their returned dry residue to their respective plot, on the soil fertility, the mycorrhizae colonization and the performance of millet yield. The subsequent 2014 and 2015 trials were laid out using the same variety of millet crop and

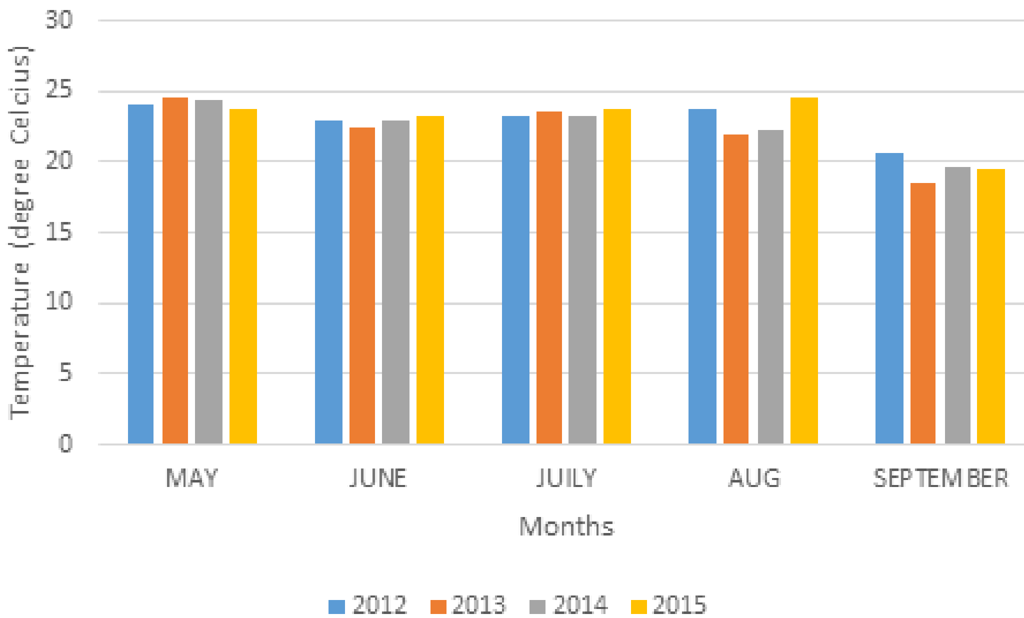

Figure 3. Monthly mini temperature during the growing periods for 2012 thru 2015 (degree Celcius) at Sadore at ICRISAT Sadore.

spacing. No other basal fertilizer was applied except Urea applied in micro-dosing as a top dressing fertilizer. The aim was to investigate on the effects of the previous crops and restituted dry stalks on a monoculture of millet on the one hand, and the contribution of 2013 applied rock phosphate levels on soil fertility level mostly available Phosphate-Bray1 on the other hand. So, the 2013 trial seeks the effects of previous legume crop and incorporation of their stalks on millet yield while the 2014 and 2015 seek for the durability of a system of mono-cropping of millet on an underlying legume crop.

Experimental design

The experiment was layout in split plot design with three replications and five main treatments that represent the five previous cropping including four legumes and one cereal. Two secondary treatments are the two doses of buried dry residue of previous cropping, characterized by the clearances of seedlings, and the three tertiary treatments that are 3 doses of applied phosphate. The additional check plots are the natural fallow (J) and bare soil fallow parcel (Pnue) (So either: 5x2x3x3 + (2 x 3 x 3) = 108 experimental units).

Prior to the initiation of the experiment, the site was fallow until 2011. During cropping season of 2011, all plots were cropped with mucuna. The composition of the site soil has been evaluated before and after 2012 before and during each growing season after up to 2015 season harvesting. Soil samples were taken from the plot before any soil perturbation.

After the delimitation of repetitions, soil sampling has been done before seedlings at depths: 0 to 10 cm, 10 to 20 cm and 20 to 30 cm at the level of each repetition on the diagonals and the etc. Samples were mixed by depth to have three composite samples by repetition, to end up with a total of 9 composites samples which were analyzed pour initial physical and chemical properties such as a texture in 5 fractions and the content elements undermined mostly for P total, P Olsen, P Bray1, N total, C org, pH eau et pH Kcl, Al, Fe, Mg, Ca, CEC etc.

Soil analysis

For the assessment of the effect of the different treatments applied, the evaluation focused on some physical and chemical properties of the soil, prior to the layout of the trial: pH Kcl, Al, C org., Total P, P Olsen, Na, K, Ca, Mg, CEC, N; the results are shown in Table 1. The analysis of particle size in 5 fractions concerned the percentages of coarse sand, fine sand, coarse silt, fine silt, and clay that are expressed in Table 2.

Plants culture

Each crop specie was planted at two densities including farmer usual density (D1) and research recommended density (D2) at spacing as indicated in Table 3. The number of row per plot depended on the crop species and row spacing. The number of seed per hill also was depending on crop species. For millet, a pinch of two fingers was put in each hill with an average of 8 to 10 seed per hill. For cowpea and Dolichos, 3 seeds per hill. For Sesbania, a pinch of 2 fingers was seeded. The seeds were presoaked 12 h before planting. The seed of cowpea and millet were treated with Apron Star at a rate of 50 g of chemical for 5 kg seed.

Measurement of yield attributing traits

Plant germination was monitored 7 days and 14 days after sowing in order to get the percentage of germination of all the crops. Plant stand was recorded at harvesting. SPAD meter was used to measure the chlorophyll content in leaves. For millet, the measurement was taken on the leaves located at the third position below the flag leaf. Harvesting was done accordingly to the duration of each crop (Table 4). For cowpea, this was done twice starting when 50% of the pods were maturing. Millet was harvested when the grain attained physiological maturity. Voandzou (Bambara

Table 1. Initial soil chemical properties of the trial field in 2012.

Variable	pH-H_2O	pH-KCl	H^+	Al^{3+}	C. O	Total-P	P-Bray1	P-Olsen	Na^+	K^+	Ca^{2+}	Mg^{2+}	CEC
	1:2.5	1:2.5	cmol+/kg	cmol+/kg	%	mg-P/kg	mg-P/kg	mg-P/kg	cmol+/kg	cmol+/kg	cmol+/kg	cmol+/kg	cmol+/kg
Depth : 0-10 cm													
SD	0.06	0.23	0.01	0.00	0.02	9.88	1.47	1.78	0.04	0.03	0.22	0.01	0.37
Mean	5.39	4.59	0.06	0.04	0.23	75.08	7.30	9.05	0.13	0.19	1.30	0.19	1.85
Depth : 10-20 cm													
SD	1.89	1.50	0.03	0.10	0.07	26.79	2.23	2.81	0.04	0.06	0.39	0.06	0.58
Mean	5.39	4.16	0.08	0.23	0.15	84.02	5.21	6.18	0.12	0.13	1.15	0.14	1.88
Depth : 20-30 cm													
SD	1.69	1.33	0.03	0.19	0.06	26.73	2.18	2.51	0.04	0.05	0.38	0.06	0.65
Mean	5.27	4.00	0.11	0.49	0.13	53.64	3.34	5.26	0.09	0.14	1.13	0.10	2.20

Table 2. Initial soil physical properties at 5 fractions (%) in 2012.

Depth	Coarse sand %	Fine sand %	Coarse silt %	Fine silt %	Clay %
0-10	43.73	52.42	1.89	1.23	0.74
10-20	41.18	53.82	1.59	1.13	2.28
20-30	43.42	48.60	1.48	1.13	5.36
Standard deviation	1.39	2.70	0.21	0.06	2.35

Table 3. Effect of previous crop species on millet grain yield (kg/ha).

Crop specie	Mean grain yield (kg/ha)	Duncan's multiple range test	Mean stalk yield (kg/ha)	Duncan's multiple range test	Mean plant height (cm)	Duncan's multiple range test
M	69.90	a	357.00	a	62.28	a
J	74.60	ab	459.90	abc	65.22	a
Pnue	99.70	abc	427.60	ab	76.18	ab
V	127.90	bcd	398.60	ab	74.37	a
N	145.80	cde	499.90	bc	86.46	ab
D	163.70	de	437.00	ab	88.90	ab
S	185.00	e	603.80	c	103.73	B

Lsd grain yield: 53.7 cv%: 89.1 Lsd plant height: 67.888 cv%: 83.70; Lsd stalk yield: 145.48 cv%: 68.70; Lsd (least significant differences) ; cv% (coefficient of variation percent) M (pearl millet); J (natural fallows); Pnue (Bare soil); V (Voandzou); N (Cowpea); D (Dolichos); S (Sesbania); Letter a, b, c, d, and e indicate difference between means; same letter in the same column means that mean are equivalent that is have the same level of impact.

Table 4. Impact of previous crop specie and year x crop specie on millet stalk weight (kg/ha).

Crop specie	D	J	Pnue	M	N	S
-	437.02[a]	459.86[a]	427.55[a]	357.04[a]	499.89[a]	603.82[b]
Year* crop specie						
2013	545.84[a]	77.50[b]	286.46[cb]	183.02[d]	520.01[a]	658.69[a]
2014	213.40[a]	252.15[a]	376.16[a]	328.00[a]	407.16[a]	478.98[a]
2015	551.84[a]	1049.93[b]	620.04[a]	560.10[a]	572.50[a]	673.78[a]

lsd *Crop Specie* =142.621 lsd Year x Crop Specie =247.026; cv%: 58.3.

groundnut) harvesting was undertaken after checking that the underground pods contained matured seeds.

Only 40 to 50% of Sesbania pods were harvested because the senescence of leaves occurred earlier due to drought spell which took in September. The harvesting of fallows plot consisted in cutting the above ground bulk vegetation cover. On the bare soil, no harvesting was done as no vegetation was allowed to grow during the season. The harvesting of plant stalks was done also accordingly to the specific maturation state of each crop. After harvesting the stalks, these were weighed then put to dry under the sun for a month. The final dry weight was recorded when, after, two consecutive measurements, the weight remained the same. This later weight was taken to calculate the yield in terms of total dry matter production of each treatment.

The interest in this 2012 trial was in priority axed on dry residue production of the crops and secondarily on pearl millet grain yield. The reason is that this is an initiating experiment with the objective of producing initial soil conditions for the following 2013 through 2015 trials. Before harvesting, soil samples were taken in each treatment plot in order to assess the status of chemical properties. In addition, the initial soil chemical and physical properties, and the fungal biodiversity of the soil as well were assessed.

From year 2013 to 2015, the experiments were axed on studying the rear effects of previous 2012 legumes crop and their residue on mono-cropped pear millet yield. A factorial split-splot design was used to lay out the trials. The 2013 experiment consisted of the following factors: 3 replications, 5 preceding crops including Dolichos (D), Cowpea (N), Sesbania (S), Voandzou (V), and Pearl millet (M), as main factors, additional 2 check factors such as Natural Fallows (J) and Bare soil (Pnue); two levels of returned dry residue of previous crops as minimum dose of dry residue restituted to the soil (D1) and maximum dose previous crop dry residue restituted to the soil (D2), as secondary factors, 3 levels of phosphorus into the form of rock phosphate (P0, P1, and P2) and they were applied on the 4th of July, 2013 for five days before the planting on July 9, 2013. Only the Pearl millet variety used in 2012 experiment was planted with a spacing of 0.8m x 0.8 m on each treatment plot. It is important to notice that in the subsequent following experiments, D1 and D2 refer to the minimum and maximum doses of dry residue of preceding crop applied to the respective plots. Natural fallows and bare soil did have only D1.

The 2014 experiment was a follow up of 2013's and comprised the following factors: 3 replications, 5 preceding crops (Dolichos, cowpea, Sesbania, Voandzou, and pearl millet), as main factors, two levels of returned dry residue of previous crops (D1 and D2), as secondary factors, 3 levels of phosphorus into the form of Tahoua rock phosphate (PNT) with P0 (no PNT), P1 (60kg/ha of PNT), and P2 (120kg /ha of PNT. Only the same Pearl millet variety used in 2012 experiment was planted with 0.8 m x 0.8 m spacing on each treatment plot.

No fertilizer was applied but the above ground dry residue of 2013 pearl millet was restituted on their originating previous plot. The stalks were not incorporated but dispatched over the plots as a mulch. The rainy season (RS) 2015 experiment was the same as that of the previous year experiment except that each plot was split in two subplots corresponding to 2 levels of nitrogen (U0 and U1) under the form of Urea in micro-dosing. No previous millet dry residue from 2014 RS was returned on to the plot of 2015 RS.

Plot preparation

The dry stalks of the legumes and millet of 2012 trial were manually cut into pieces using machetes, then thoroughly dispatched all over their respective originating plot during the month of February, 2013. To avoid deep disturbing of the soil (protection of mycorrhiza arbuscular fungi) a superficial mixing with soil was done using hoes. Then each plot was subdivided into 3 subplots corresponding to the 3 levels of phosphate. The rock phosphate was in the form of powder. The method of application of rock phosphate was as follows: for each plot, on the basis of treatment the required quantity of rock phosphate was weighed then thoroughly mixed in a 10 L plastic bag manually with soil taken inside the respective treatment plot. The mixture was dispatched all over the plot then incorporated into the soil. To apply the Urea fertilizer, a 3 fingers pinch of urea (ICRISAT, 2009) that is about 3.31 g, was put in each planting whole at panicle initiation stage and at panicle emergence stage. In 2012, along with experiments plots, two blocks of check plots were laid out above each block of replications. One block of natural fallows (J) on which weeds were allowed to grow naturally, and one block with bare soil (Pnue) which was kept cleaned from weeds and crop. Each of the check blocks consisted of plot (5mx10m) replicated 6 times. There was no planting density for them, however they were treated as having density D1. In 2013 thru 2015, these were planted with millet as the other plots.

Data analysis

For the statistical analysis of collected data, an unbalanced ANOVA analysis was used with GENSAT14.1 program. Whenever a significant difference was found between treatments, couples of means were tested using the least significant difference (LSD) and DUNCAN test for multivariate test of multi-annual data.

Calculation of legume dry biomass efficacy value vs millet dry biomass (Bado et al., 2012)

The efficacy of millet dry biomass on millet yield was estimated based on the following formula:

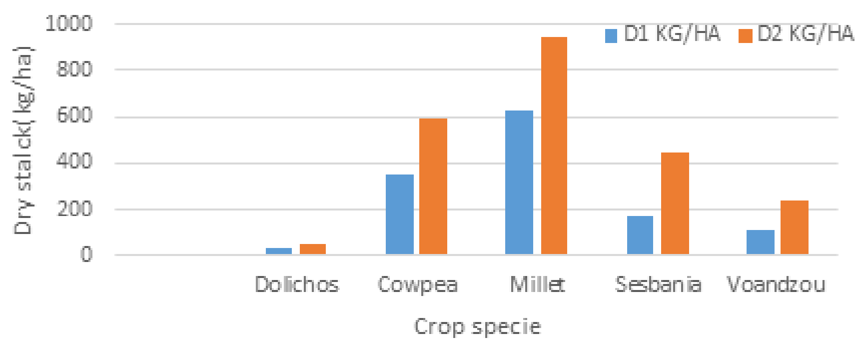

Figure 4. Crop residue yield as affected by planting density in 2012.

Eff Leg = (B- A)/X

Where A is yield of millet after mono-cropping, B is yield of millet after legume, X is quantity of legume biomass returned to the soil.

RESULTS

Millet yield

The influence of planting density on millet yield is indicated in Figure 4. Millet grain yield in 2012 experiment was significantly influenced by the farmer planting density D1 (6666.66 plant pocket/ha with 1.5m x 1m) recommended planting density D2 (10000 plant pocket/ha with 1m x1m); the effect of planting density D2 (459.54kg/ha) was greater than that of D1 (358.44 kg/ha). The dry residue production was influenced by the planting density (P = 0.011) and planting density D2 gave more dry residue than D1. The analysis of variation indicated that the dry residue production of crop species was highly depending on the interaction Culture x Density (P<0.001).

The impact of crop planting density on dry residue yield was significantly depending on the specie. All the species produced lower quantity of dry residue with farmer usual planting density D1 compared with D2. For instance, Sesbania produced the rate of dry residue with 671.84kg/ha with farmer usual planting density D1, while1795.95 kg/ha were produced with recommended planting density D2; at the recommended planting density D2, Dolichos produced the maximum of 199.37 kg/ha while only a minimum of 140.19 kg was obtained at density D1 (Figure1). In the same way, Voandzou produced 243.67 kg/ha of dry residue with recommended planting density but produced 106.65 kg/ha with farmer usual planting density.

Effects of preceding crop on millet yields

Millet grain yield varied from year 2012 to 2015 as indicated in Table 3. The pearl millet yields in 2012 trial are considered as the initial yields. As such, it was observed that the millet yield decreased significantly in all 3 years from 2013 through 2015 (Table 3). The effect of year on grain yield was highly significant (P <0.001) with the following ranking: 2012>2013>2015>2014. Millet yield was highly influenced by preceding crop species (P <0.001); as indicated in Table 3, the preceding Sesbania, Dolichos and Cowpea had higher impact on 2013, 2014, and 2015 millet grain yield compared with preceding Voandzou, natural Fallow, Bare plot and millet. The output of ANOVA table indicated that millet grain yield is also highly affected (P <0.001) by the dose of dry residue of previous crops; the Duncan's multiple range test showed the following ranking in Table 3. On the other hand, the interaction of the Year x Dose dry residue had some positive impact on millet grain yield at P = 0.07 as shown by the result of the analysis of variance; and the impact on plot having received the maximum dose D2 of dry residue of preceding crop which was greater than those having received the minimum dose D1 of dry residue of preceding crop. The dry residue of previous RS 2012 cultures was restituted to the soil in 2013 (kg /ha).

Effect of phosphorus doses on millet grain yield

The impact of phosphorus application on millet mean grain yield was not significant for no statistical difference was found (Prob. 5%) while comparing means of millet grain yield with the DUNCAN test over the 3 years under the rate P0 (no application), the study obtained 123 kg/ha of millet grain, P1 (60 kg/ha of PNT), 130 kg/ha of grain, and with P2 (120 kg/ PNT) 136.5 kg/ha of grain.

Effect of nitrogen

The application of Urea in micro dosing at the rate of 3.31 g/hill, had highly influenced the yield of millet in 2015, (P<0.001) as indicated by the analysis of variance. The

Table 5. Impact of previous crop on millet yield over rainy seasons 2013-2015.

Preceding crops	RS 2013				RS 2014				RS 2015			
	D1		D2		D1		D2		D1		D2	
S	192	a	192	ab	113	b	123	ns	125	ns	653.1	b
D	188	a	169	ab	77	a	96	ns	140	ns	657.2	b
N	161	b	175	ab	96	ab	84	ns	124	ns	655.2	b
V	136	c	150	bc	80	a	78	ns	119	ns	549.8	b
Pnue	128	c	128	cd	99	ab	99	ns	139	ns	620	b
J	88	d	80	e	114	b	114	ns	140	ns	1049.9	a
M	80	d	101	de	84	a	98	ns	144	ns	618	b
Mean	139	-	142	-	95	-	99	-	133	-	686	-
P0	138	ns	138	ns	95	ns	42	ns	134	ns	141	ns
P1	138	ns	146	ns	99	ns	46	ns	135	ns	142	ns
P2	141	ns	143	ns	90	ns	48	ns	130	ns	134.7	ns
Mean	139	-	142	-	95	-	45	-	133	-	-	-
	-	-	-	-	-	-	-	-	-	-	-	-

very limited contribution of returned crop stalk to the plot had been observed at Prob. 0.082. The Phosphorus x Nitrogen interaction did not have any impact on the millet grain yield over the 3 years of mono-cropping. This might mean that the treatments had impacted on millet grain yield with the same efficiency.

Effects of previous legumes

The mean dry residue production significantly ($P<0.001$) varied over the three years of trial with the maximum obtained in 2015 (621.1kg/ha), 2013 (422.2kg/ha), and the minimum in 2014 (326.7 kg/ha). Among the preceding crop, Sesbania had the highest impact on millet dry residue production (Table 5). .

The interaction Year x Preceding crop specie had a significant influence on the production of millet dry residue ($P<0.001$) as shown in Table 6 and Sesbania was ranked first with 603.82 kg/ha of millet dry residue; this represents 16.9, 14.1, and 13.1% respectively of the impact obtained with the mono-cropping of millet preceding Pnue and J. On the other hand, no statistical difference was observed among the remaining four crops meaning that each of these later did not bring to the millet better suitable growth condition than the others.

The impact of the dose of previous crop straw on millet dry residue production was highly significant ($P <0.001$). The most important effect was observed for the maximum dry residue dose D2 (527.34 kg/ha of dry residue) against D1 (406kg/ha). In the condition of 2013 experiment, the legume dry residue use efficiency is the best for Cowpea (0.49) followed by Sesbania (1.01) and Voandzou (1.02) while for Dolichos it is very low (6.16). This means that for producing 1 kg of millet grain it is necessary to apply only 0.49 kg of Cowpea dry residue while 6.16 kg of Dolichos dry residue will be requested.

Use efficiency of crops residues

The residual effect of the dry residue of preceding crop has a much reduced use efficiency on 2014 millet grain yield as shown in Figure 5. In the 2014 experimental conditions previous legumes, their residual residues plus the previous millet residues have lower contribution to millet grain yield buildup as compared with 2013 millet grain production; however, the millet grain yields have globally decreased, we can notice that preceding legumes have requested more of dry residue for each kg of grain produced. For instance, while for millet on preceding Sesbania and Dolichos, 0.09 kg of dry residue was necessary to produce 1 kg of millet grain, 0.05 kg of dry residue from preceding natural fallows were requested to produce 1 kg of millet grain.

Effect of preceding crop and subsequent cumulative preceding crop residues on millet plant height

In 2013, significant differences on millet height increases were found among preceding crops; the predominance of the effects of preceding Sesbania, Dolichos and cowpea over the others precedents for both minimum and maximum doses of dry residues D1 and D2 could be noted. Millet and natural fallow had reducing impact on plants height. The year 2014 brought a general shortening of plant height for both crop residues doses D1 and D2 while in 2015, the overall increase of millet height was observed no matter the preceding crops.

The effects of preceding crop on soil contain in minerals

The results, as shown in Table 7, indicated the available nutrients in the soil for each preceding crop as per year

Table 5. Impact of preceding crop and residue on millet plant height (cm).

Preceding crop	RS 2013				RS 2014				RS2015			
	D1		D2		D1		D2		D1		D2	
S	192	a	192	a	113	b	123	ns	125	ns	125.7	b
D	188	a	169	ab	77	a	96	ns	140	ns	144.9	b
N	161	b	175	ab	96	ab	84	ns	124	ns	148.6	b
V	136	c	150	bc	80	a	78	ns	119	ns	144.9	b
Pnue	128	c	128	cd	99	ab	99	ns	139	ns	139.1	b
J	88	d	80	e	114	b	114	ns	140	ns	140.2	a
M	80	d	101	de	84	a	98	ns	144	ns	131.1	b
Mean	139	-	142	-	95		99		133		139	-

Treatment values with alphabetical letters a, b, c, d, have significant differences; Treatment value with same letters in the same columns have equivalent impact while those with different letters are different; ns: no significance; PNT: natural phosphate of Tahoua; D1: minimum dose of dry residue; D2: maximum dose of dry residue; S (Sesbania); D (Dolichos); N (Cowpea); V (Voandzou); M (pearl millet), J (natural fallows) Pnue (Bare soil).

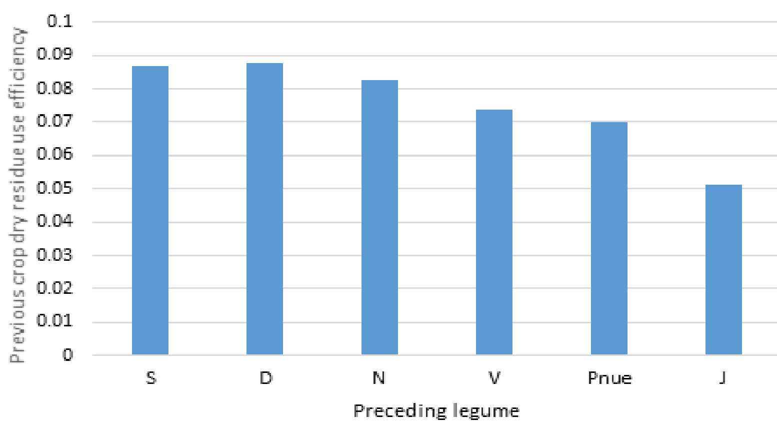

Figure 5. Legume biomasse use efficiency on millet grain yield in RS 2014 (Notes: S (Sesbania); D (Dolichos); N (Cowpea); V (Voandzou); M (pearl millet), J (natural fallows) Pnue (Bare soil).

Table 6. Available nutrient in the soil for preceding crop in 2013.

Preceding crops	C. orga (%)	P_Bray1 (mg /kg) soil	N_Total (mg /kg)
S	0.1845[a]	5.752[a]	150.8[a]
D	0.1681[a]	6.902[b]	139.7[a]
N	0.1671[a]	6.113[ab]	142.2[a]
V	0.1626[a]	6.999**c**[b]	140.6[a]
Pnue	0.1927**c**	6.602[ab]	152.5[a]
J	0.2219[b]	7.605**d**[b]	196[b]
M	0.1713[a]	6.53[ab]	145.7[a]
Dose of dry residue			
D1	0.1673ns	6.791ns	140.4[a]
D2	0.1748ns	6.191ns	149.9[b]

Treatment values with alphabetical letters a, b, c, d, have significant differences; Treatment value with same letters in the same columns have equivalent impact while those with different letters are different; ns: no significance; PNT: natural phosphate of Tahoua; D1: minimum dose of dry residue; D2: maximum dose of dry residue; S (Sesbania); D (Dolichos); N (Cowpea); V (Voandzou); M (pearl millet), J (natural fallows) Pnue (Bare soil).

2014. The ANOVA analysis showed that the rate of the different elements organic carbon, P-Bray1, and total nitrogen are the highest in the soil having had J and Pnue with respectively 0.2219% , 7.605 and 196 mg/kg for organic carbon, phosphorus Bray1, and total nitrogen for J and 0.1927%, 6.602 and 152.5 mg/kg for pour Pnue.

DISCUSSIONS

In this study, we wanted to firstly find out if millet grain yield and dry matter yield were influenced by its planting density, secondly, to investigate on the effects of previous crop and the restitution of its dry above ground residue would increase or not the yield of the following millet grain and dry biomass (dry residue). The residual effect of rock phosphate applied on mono cropped millet yield is also investigated.

Effect of planting density on millet grain yield and dry residue yield

The effect of recommended planting density D2 on millet grain (459.54kg/ha) was greater than that of farmer usual planting density D1 (358.44 kg/ha). This is supported by the results of Bationo and Mokwunye (1991) who obtained a millet grain yield increase by 400% when the number of planting hills increased from 2000 to 7000 per ha millet, planting with no fertilizer application. An increase in dry biomass resulting from the effect of lower planting density was obtained while comparing the effect of planting density D1 and D2. These results are showing that high density of planting reduces the quantity of dry residue produced while lower planting density will increase the dry residue production. The main reason is that with a high number of plants per unit area, individual plants compete for light, nutrients and water more than with a reduced number of plants per unit area.

This goes in the same direction with the results of Maobe et al. (2014). The study indicated that for each crop there exists an optimum planting density below or above the yield (Maobe et al., 2014). Depending on the production objectives, crop planting density must be decided. The competition for nutrients, water, and sun light takes place among reduced spacing planted crop which is observable through erected plant stand, less leave biomass, and reduced number of fruit or grain compared with increased spacing planted crops which would be laterally extended branching, more leave biomass and adequate fruit and grain number (personal observations).

Effects of preceding crop on millet yield performance

The interaction of the Year x Dose dry residue had some positive impact on millet grain yield at P = 0.07 as shown in Figure 2, and the impact on plot having received the maximum dose D2 of dry residue of preceding crop was greater than those having received the minimum dose D1 of dry residue of preceding crop. Similar results were obtained by Power et al. (1998) who found, in a 10 years study, significant impact of preceding crop residue returned to soil on corn grain yield (of about 16% gain from the return of 150% of previous crop residue) and soil properties with an increase of N being available in the soil; grain yield increases were function of the quantity of previous crop residues returned to soil.

The depreciating effect of millet mono-cropping on soil fertility and the yield of millet or sorghum has been similarly demonstrated in many studies in Niger, Burkina, and Mali, in similar condition, by many scientists (Bationo et al., 2011; Bado et al., 2012)**.** Other studies are also in the same direction as that of this study which showed that the cowpea cropping can generate about 40 to 80 kg of N/ha (Quin, 1977), and the millet grain yield increase can reach between 149 to 252 kg/ha, and still provide an increase of 40 to 65 kg/ha of the dried stalk (Bationo and Kumar, 2002).

The legume/cereal rotation is the commonly used practices in sub Saharan Africa and with usually the legume crop as first crop although cereal/legume and cereal/cereal rotations might be performed somewhere else (Bationo et al., 1989; Traore et al., 2003**;** Bado et al., 2012). The advantages of crop rotation include improving soil fertility mostly with nitrogen fixing legumes as previous crops as these improve soil contain in nitrogen fixed in the nodes that can be available for succeeding cereals (Bationo and Ntare, 2006). The preceding legume crop roots can help to solubilize adsorbed phosphorus by their root exudates and also made it available to the subsequent cereal crop the Nitrogen content in dead nodules and leaves (Odendo et al., 2011).

The use of legumes crops in rotation with cereals have a lot of advantages not only on soil physical and chemical properties but also on soil biological efficiency in terms of nutrients balance regulation through the symbiotic links that are established between crops and soil bio fertilizers. For instance, while the rhizobium bacteria improves soil nitrogen status via nodulation of host legumes roots, the arbuscular mycorrhiza fungi (AMF) develop symbiotic relationships with the roots of both legume and cereals plants (Jean-Pascal, 2005).

The impact of natural rock phosphate on millet yield

The effect of Tahoua natural rock phosphate (PNT) application at 3 different doses did not show any statistical difference on millet yields. It implies that the effects of 60 kg/ha of PNT and that of 120 kg/ha of PNT on the millet yield were not better than no application of PNT. This is in contradiction with some studies done in the sub-region that demonstrated that the agronomic effectiveness of natural phosphates increased the crop yields of 30 to 80% in the first year of application depending on pH and soil moisture conditions (Bationo et al., 1986; Sef Van et al., 2001; Gbadamassi, 2008).

This might be due to the missing of soluble Nitrogen in the soil as we did not apply any Nitrogen until the last year of the trial. Our expectation in this experiment was that the nitrogen resulting from the synthesis of biological nitrogen via the symbiotic fixation in the legume roots, would be enough to enhance the efficiency of the partially soluble PNT applied in the following season. This argument is supported by the results of Wopereis et al. (2008) that advised that Nitrogen has to be applied along with rock phosphorus to support its efficiency. The lack of Nitrogen in the soil after the legumes crop is imputable to the fact that no nitrogen was applied to these crops in 2012. Similar responses were obtain by Bado et al. (2012) in a trial where cowpea yield and performance were lower if no fertilizer applied at the young stage of growth. In fact, legume crops request a minimum basal fertilizer in order to boost nodulation and dry matter production of Bado et al. (2012).

Effect of nitrogen application on millet grain yield

The application of nitrogen significantly increased the millet grain yield performance. The application of nitrogen (N) was determinant in uprising the level of millet growth and yield as the dry residue and grain yield were increased after applying 45 kg of urea/ha. In fact, there was a sink of millet global production from 2012 to 2014 meaning that the residual effects of previous 2012 legumes crop residues and that of 2013 millet, in addition to the rate of PNT added, were not enough to rise up or at least to keep the magnitude reached in 2012.

The lack of interaction Nitrogen x Phosphorus might indicates that phosphorus was not certainly a missing nutrient but rather nitrogen was the limiting factor. This could be explained by the fact that there was not enough stock of available nitrogen in soil solution deriving from the previous legumes crop microorganism's symbiotic activities. The millet straw contain in nitrogen is usually very low (Ganry et al., 1978). The nitrogen might be used by the bacteria involved in the decomposition process of applied previous crop residue.

This is contradicting the findings of Prasad and Power (1991) and Power et al. (1998) in Nebraska, who found that the soil physical properties (water retention) and biochemical (activities of microorganisms, organic matter contains, nutrient availability), and crop (corn /sorghum) yield were improved when increased previous crop residues were added to the soil. But the difference with our trial is that in theirs, nitrogen (46N) was regularly added every year while we did not apply nitrogen until the last year (46N); in addition, the experimental conditions are different in terms of soil texture and climatic conditions. This shows the importance of nitrogen as limiting factor to enhance and sustain the residual impact on soil productivity in mono-cropping.

This result corroborates with the findings of Traore et al. (2003) in Mali who found that after a preceding legume crop with phosphate fertilizer applied, the millet yield increased when nitrogen with 23N was added and increases of 20% grain and 30% dry residue could be yielded. Adamou et al. (2007) found 210 kg increase of millet yield with a treatment of nitrogen fertilizer added to crop residue and up to 1012 kg/ha of yield with a combination of nitrogen fertilizer added to crop residue and phosphorus fertilizer. The rate of residue decomposition depends not only the crop but also on the climate. Consequently, the amount of resulting nutrients, organic matter, and impact on erosion protection vary (Soil Quality, National Technology Development Team, 2006)

Millet dry residue production as a function of preceding crop specie and restitution of dry residue

Except for Sesbania as preceding crop, no statistical difference was observed among the effects of four crops on millet dry residue production; this means that effects each of these preceding crops did not bring to the millet better suitable growth condition than the others. The good performance of Sesbania as preceding crop in terms of high impact on soil fertility and following crop production was also demonstrated by Becker and Johnson (1998) in Cote d'Ivoire. The restitution of crop residues to the soil, allows to return parts of nutrients exported by previous crop (Bationo et al., 2011; Wopereis et al., 2008). It improves soil organic matter and maintains the durability of soil biological activities, termites channeling in the soil profile (Badjissaga, 2007; Bationo, 2008). Crop residues as mulch, protect soil surface against wind, and water erosion while improving soil water conservation (Bado et al., 2012). It reduces the impact of sun rays on the soil surface and maintains a soil temperature that is favorable to the development of microorganisms.

Effect of preceding crops millet plant height

In 2013, significant differences on millet height increases were found among preceding crops; the predominance of the effects of preceding Sesbania, Dolichos and Cowpea over the others precedents for both of dry residues doses D1 and D2 could be noted. Millet and natural fallow had reducing impact on plants height. This is in line with the results of Kouyate et al. (2000). The main reason of 2014 bad performance of millet can be attributed to the combined effect of nitrogen deficiency and of climatic conditions linked with the rainfall which exceeded 740 mm. But, in 2015 rainy season, while the plants were in the stage of panicle exertion, the whole crop suffered serious damaging attacks of spiders (unspecified) from

August thru September. Consequently, the plants dried and the yield was compromised.

The effects of preceding crop on soil contain in minerals

The overpassing of the effects of preceding legume crops by the effects of natural fallows in terms of available carbon, phosphorus, and nitrogen, can be explained by the fact that on fallow soil, weeds are dense in population, rich in species diversification and consequently, develop very abundant network of root systems that explore the maximum soil volume and produce all kind of exudates that solubilize fixed form of phosphorus and others nutrients (Kolawole and Tian, 2010). On the other hand, these roots accumulate important amount of carbon in the soil (Bado et al., 2012). In addition, the weed population comprise legumes species that can fix nitrogen via symbiotic link with rhizobium bacteria. The decomposition of the dense root system increases the stock of organic matter and organic carbon of the soil (Fonte et al., 2009). This explains the accumulation of these elements in soil having had previously natural fallow compare with soil having had legume crops.

Conclusion

The effects of the restitution to the soil of aerial dry residue of the previous crop on the yield performance of the millet vary depending not only on the quantity of dry residue returned to soil but also species of previous cropping. The effects of the doses of dry residue on the yield of millet for the previous crops Sesbania, natural fallows, and cowpea surpassed those of Voandzou (Bambara groundnut) and the millet. With these preceding crops, the yields of millet were higher with the maximum dose of dry residue than the minimum dose of dry residue. The residual effects of Sesbania culture on the yield of millet have been the highest during the year 2013 and 2015 (with about 4 to 5 times) but could not still reach the level of the 2012 millet yield.

The expected effects of Tahoua rock phosphate to gradually supply the necessary phosphate to the mono-cropped millet could not be seen over the year 2013, 2014 to 2015 of mono-cropping because the first year grown legumes failed to produce enough nitrogen stock to sustain the efficiency of the system. These two nutrients are limiting factors and must be in appropriate proportion in order to fill crop needs.

Applying natural rock phosphate, previous crop residues after only a first year legume crop, and successive millet stalk in a system of mono-cropping cannot be profitable if a source of nitrogen is not applied. It is necessary to strengthen the sustainability of the residual effects of the preceding legumes and subsequent additional previous millet stalk by providing a source of nitrogen in micro-dosing on a yearly basis.

The natural fallow and bare soil as preceding have increased the overall available soil nutrients level more than other legume crops and millet.

RECOMMENDATION

Further researches need to be done using more indigenous wild species legumes to assess their ability to improved soil organic matter level and phosphorus, nitrogen and other nutrients as well. More investigation should be done on improved fallows using weeds that can trap more carbon while their aptitude to develop symbiotic mycorhization should be studied in order to have targeted species to be included in improved fallows.

Conflict of Interests

The authors have not declared any conflict of interests.

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