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Improving agricultural productivity using agroforestry systems: Performance of millet, cowpea, and ziziphus-based cropping systems in West Africa Sahel

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ABSTRACT

Across the drylands of sub-Saharan Africa, resource-poor farmers typically apply little or no organic or inorganic fertilizers; they remove or graze crop residues, leaving the soils nutrient-depleted and vulnerable to degradation. High temperatures, soil erosion, and declining soil fertility call for farming systems that protect fragile soils as well as improve nutrient availability and water use efficiency (WUE) and soil fertility. In the present study, the agronomic performance of an agroforestry system with millet (*Pennisetum glaucum*), cowpea (*Vigna unguiculata*), and Ziziphus (*Ziziphus mauritiana*) was compared to that of a cropping system without Ziziphus at ICRISAT research station, Sadoré, Niger, for four years. The experiment was a factorial 3 × 4 design with three cropping systems: mono-cropping of millet (MM), mono-cropping of cowpea (CC), and millet/cowpea intercropping (M/C), and with four fertilizer treatments (FT) in a split-split arrangement. The same experimental design was installed on 2 blocks: with Ziziphus trees (ZT) at 80 plants ha^{-1} and without Ziziphus (WZ).

After the four years of cropping, ZT and WZ decreased SOC by 15 and 21 % and K by 105 and 110 %, respectively, compared with the original soil. Soil N was decreased only in the system WZ. Millet grain yields varied from 0.10 to 1.14 t/ha and the highest yields were obtained with NPK fertilizer alone or associated with farmyard manure (FYM) while the lowest yields were obtained with the control without fertilizer and FYM. The ZT system increased millet yields and its WUE with FYM and the control without fertilizer. However, millet yields decreased in ZT system with NPK fertilizer alone or associated with FYM. The ZT system increased the global annual incomes from 2–3 times compared with the system WZ. We concluded that including Ziziphus trees at the density of 80 plants ha^{-1} to the low input cropping systems of smallholder farmers improve agricultural productivity and farmers' incomes. The proposed agroforestry system is affordable and compatible with the low input farming systems, and it ensures sustainable management of soils, land resources, and ecosystem services. But future research could contribute by identifying the optimal combinations of the density of Ziziphus trees, cropping systems and the doses of fertilizer on crops to optimize the productivity of the propose agroforestry system.

1. Introduction

Rainfed agriculture and livestock are the main sources of livelihood for 80–90 % of the population of West Africa Sahel (WAS). The challenges of these farming systems include inherently poor soil fertility, low soil organic carbon (SOC) and clay content, limited resources for investing in fertilizers, exportation of crop residues for livestock and household needs, erratic rainfall, and frequent droughts. However, these fragile drylands remain the main source of socioeconomic goods and services, better livelihoods, and wellbeing of many millions of poor and vulnerable people. The traditional cropping systems, which involve mining soil nutrients, result in over-exploitation of the land, which can be seen in the declining crop biomass and soil fertility, cover, SOC, and soil fertility (Pieri, 1989; Bationo and Mokwunye, 1991; Bado et al., 1997a,b; Bationo et al., 2012; Bado and Bationo, 2018). The direct consequences of over-exploitation include land degradation, deforestation, desertification, food insecurity, and decreasing provision of ecosystem services for rural communities, thereby exacerbating their

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vulnerability to climate change (Várallyay, 2007). Long-term climate change projections (2050–2100) indicate that West Africa will exhibit a high degree of climate change (Diffenbaugh and Giorgi, 2012), leading to more frequent rainfall deficits and extreme events. The combination of climatic and non-climatic drivers and stressors will exacerbate the vulnerability of agricultural systems and increase food insecurity, thereby increasing the pressure on land and water resources (Pereira, 2017). Without smart technologies associated with improved capacities of rural communities for adaptation, WAS will become more vulnerable to climate change. Empirical evidence has shown that farmers can adapt to climate change by using sustainable land and water management practices, which provide local climate change mitigation benefits (Nknoya et al., 2013). There is a need for affordable and climate-smart technologies to cope with the harsh environments of poor drylands managed by smallholder farmers. Agroforestry practices have been reported to be among the ten best climate-smart options (Dinesh et al., 2017). Indeed, agroforestry systems could contribute to diversification of food products, improve soil fertility (Udawatta et al., 2008), protect the soil, and reduce wind erosion (Branca et al., 2013; Nair et al., 2009; Zhang et al., 2018).

The dominant crops of WAS are cereals, millet (*Pennisetum glaucum*) and sorghum (*Sorghum bicolor*), and legume crops, cowpea (*Vigna unguiculata*) and groundnut (*Arachis hypogea*). Cereals are mainly staple foods and cannot provide enough financial return for the farmer to be able to invest in the farming system. Cowpea and groundnut are usually cultivated in rotation or intercropped with cereals. Traditional intercropping systems cover from 50 to 90 % of the cultivated areas in semiarid tropics (Steiner, 1991). Mixed cropping used by farmers is a strategy for diversifying agricultural products and incomes as well as for minimizing the risks. (Giller et al., 2006). Nitrogen-fixing legume crops, such as cowpea and groundnut, are widely cultivated by farmers. Because of their role in recycling N in farming systems (Chalk, 1998; Bagayoko et al., 2000; Bationo and Ntare, 2000; Bado et al., 2006) along with providing incomes such as cash crops and quality feed for livestock, nitrogen-fixing legumes crops are very useful for improving soil fertility, land productivity, and incomes of smallholder farmers (Chapagain et al., 2018).

Introducing local fruit trees in farming systems through agroforestry could further contribute to the generation of income and improve the productivity and resilience of farming systems, thereby improving food and nutrition security. While annual crops are more affected by rainfall variability, some trees of high economic value, such as Ziziphus (*Ziziphus mauritiana*, commonly known as *Pomme du Sahel)*, are more tolerant to dry spells. Ziziphus shed their leaves before dormancy as a mechanism of adaptation to limited water availability during the long dry season (Ibrahim et al., 2015b). Ziziphus could be integrated in cropping systems, as it is able to cope with the harsh environment of drylands, thereby improving productivity as well as increasing incomes and food and nutrition security. For example, the Ziziphus tree/wheat agroforestry system is widely used in China and was reported to improve land-use and economic returns (Zhang et al., 2017). There is a high demand and growing market for the Ziziphus fruits in WAS. Improved agroforestry systems combining cereals, nitrogen fixing legume crops such as cowpea, and a high value tree species such as Ziziphus could offer an opportunity to improve the productivity of traditional farming systems in WAS.

In order to investigate the suitability of this or any crop combination, the competition for light, water, and nutrients between trees and crops should be considered (Singh et al., 1989; Schroth, 1998; Zhang et al., 2017). Therefore, this study aimed to investigate different management options for intercropping the most popular cropping systems of millet (mono-cropping) and millet-cowpea with Ziziphus. Our main objective was to test the technical options that could improve the productivity of traditional cropping systems. The goal of this study was to contribute to the development of promising agroforestry systems, which can sustainably improve productivity and income generation in the traditional cropping systems.

2. Materials and methods

2.1. Experimental site

The experiment was carried out at the research station of ICRISAT Sahelian Center (ISC), located at Sadore, 45 km away from the city of Niamey in Niger, West Africa (13° 15′N, 2° 18′E) at an altitude of 240 m a.s.l. The climate of the area is characterized by a short rainy season (90 days) from June to September. The average rainfall is 540 mm, and rainfall is irregular and normally comes in the form of thunderstorms (Fig. 1). Maximum temperatures vary in the range of 30–40 °C during the cropping season, and potential evapotranspiration (PET) exceeds the total rainfall in all months except July and August, which are the peak months of the rainy season (Sivakumar, 1986). The site is located on a sandy plain with Aeolian sands covering one of a series of stepped surfaces comprised cemented laterite gravels (West et al., 1984). The surface horizon (0–30 cm in depth) is yellowish red sand underlain by a thick (>1 m) red loam or red sand horizon. The soil has a coarse texture, with sand content exceeding 85 %.

2.2. Experimental design

In 2004, we started a preliminary study by planting Ziziphus (*Ziziphus mauritiana)* trees in two blocks as follows (Ibrahim et al., 2015b). One hectare of field that was previously under a 2-year-old natural fallow was divided into two blocks of 0.5 ha. The first block (control treatment) was kept under natural fallow without Ziziphus trees (WZ). The second block was planted with Ziziphus trees (ZT) and also kept under natural fallow. Taking into consideration the density of trees in West Africa Sahel (67–134 plants ha^{-1}, height from 0.4 to 3 m) (Gonzalez et al., 2012), and in order to minimize possible competition between crops and trees, the rootstocks were planted at the density of 80 plants ha^{-1} (16 × 8 m spacing). The two blocks were 10 m apart and oriented south-north in order to avoid the influence of shadowing (by crops and trees) between the two blocks. Then, the two blocks (WZ and ZT) were monitored under natural fallow for 11 years (2004–2015).

In 2015, we conducted an agronomic experiment with the same experimental design as that in the two blocks: with (ZT) and without Ziziphus trees (WZ). The experimental design was a factorial 3 × 4 in a split-plot arrangement with four replications, corresponding to three treatments of cropping systems as the first factor in the main plots and four fertilizer treatments as the second factor in the sub-plots. The three cropping systems were: mono-cropping of millet (MM), mono-cropping of cowpea (CC) and millet/cowpea intercropping (M/C). The cropping systems were randomly distributed as main plots in each replication. Each main plot of 224 m^2 (8 × 28 m) was divided into four sub-plots of 8 × 7 m (56 m^2), each of which received one of the four fertilizer treatments. Fertilizer treatments (Table 1) were randomly distributed as the second factor in the main plots. The same randomized block design with the two factors (cropping systems and fertilizer treatments) was installed on the two blocks (WZ and ZT). The same treatments (with the same cropping systems and fertilizer treatments) were conducted each season on the two blocks over four years (2015–2018). Ziziphus trees were pruned at the start of each growing season in May (before the rainy season) by removing about 50 % of the canopy at each pruning (Fig. 2). In the experiment, we used improved varieties of millet (ICMVIS99001, cycle 95 days, yield potential 1.5 t ha^{-1}) and cowpea (cycle 64 days, grain yield potential 1.2 t ha^{-1}) widely spread in Niger.

Similar to farmers' practices, the sowing density of millet in MM cropping was 1 × 1 m with three plants per hill (10,000 hills ha^{-1} or 30,000 plants ha^{-1}). The sowing density of cowpea in CC cropping was 1 × 0.5 m with two plants per hill (20,000 hills ha^{-1} or 40,000 plants ha^{-1}). The sowing density of millet in M/C intercropping was 1 × 1.5 m with three plants per hill (6666 hills ha^{-1} or 19,998 plants ha^{-1}). In M/C

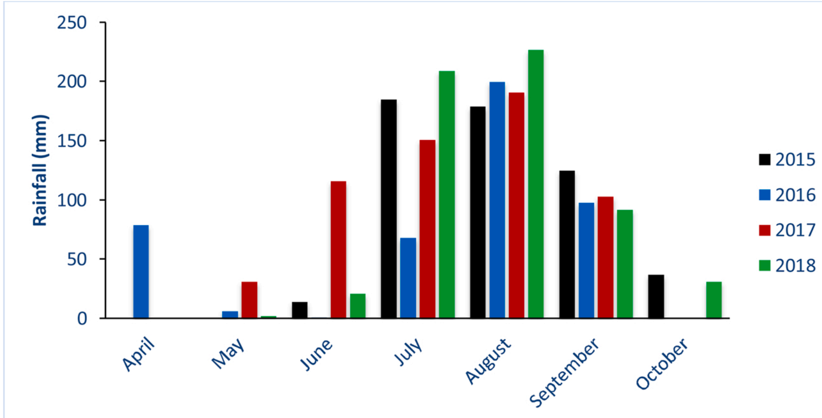

Fig. 1. Monthly and annual rainfall at the ICRISAT Sadoré research station in Niger over the experimental period (2015–2018).

Table 1
List of the treatments and doses of nutrients supplied to each crop in the three cropping systems (mono-cropping of millet, mono-cropping of cowpea, and millet/cowpea intercropping) tested at the ICRISAT Sadoré Research Station, Niger.

		Mineral nutrients supplied (kg ha^{-1})		
Cropping systems	Fertilizer Treatments	N	P	K
	F0: Control)	0	0	0
Mono cropping of Millet (MM)	F1: NPK fertilizer	9.0	3.9	7.5
	F2: Farm Yard Manure (FYM)	19.4	3.5	1.8
	F3: NPK + FYM	28.4	7.4	9.3
	F0: Control	0	0	0
Mono cropping of Cowpea (CC)	F1: NPK fertilizer	15	6.6	12.4
	F2: SSP1 fertilizer	0	11.8	0
	F3: SSP2 fertilizer	0	23.6	0
	F0: Control)	0	0	0
	F1: NPK (Millet and Cowpea)	21.0	8.2	17.4
Millet/Cowpea intercrop (M/C)	F2: FYM (Millet), SSP1 (cowpea)	12.9	14.1	1.2
	F3: NPK + FYM (Millet), SSP2 (cowpea)	18.9	28.5	6.2

The NPK fertilizer and FYM are applied on millet at 60 and 1000 kg/ha in MM, respectively. The NPK fertilizer and FYM are applied on M/C cropping at and 40 and 667 kg/ha, respectively. The NPK fertilizer is applied on cowpea at 100 and 40 kg/ha in CC and M/C cropping, respectively. The SSP fertilizer is applied on cowpea at 150 and 300 kg/ha (SSP1 and SSP2) in CC and at 50 and 100 kg/ha (SSP1 and SSP2) in M/C cropping.

Fig. 2. Field plot with previously pruned Ziziphus and sowing of millet (20 days after pruning) and cowpea (30 days after pruning) at the ICRISAT Sadoré research station, Niger.

cropping, two lines of cowpea were intercropped between the lines of millet (1.5 m spacing) with two plants per hill (6666 hills ha^{-1} or 13,333 plants ha^{-1}). For land preparation, the two blocks were plowed each season by animal traction at 15 cm depth. Millet was sown each year after the first 20 mm rain in the growing season. Several seeds were planted per hill to allow subsequent thinning one week after planting at three plants per hill. Cowpea was sown 15 days after millet, and it was also thinned one week later at two plants per hill. Similar to farmers' practices, mineral fertilizers and farmyard manure (FYM) were localized per hill of millet and cowpea at the recommended doses (known as the technique of nutrient micro dosing) (Aune and Bationo, 2008). Two mineral fertilizers, NPK (15 % N, 6.5 % P, and 12.5 % K) and single superphosphate (SSP) (7.8 % P), were used.

In MM cropping, the NPK fertilizer and FYM were applied on millet at 60 and 1000 kg/ha, respectively. The NPK fertilizer and FYM were applied on millet in M/C intercrop at 40 and 667 kg/ha, respectively. In CC cropping, the NPK fertilizer was applied on cowpea at 100 kg/ha. The SSP fertilizer was applied on cowpea in CC cropping at 150 and 300 kg/ha (SSP1 and SSP2), respectively. In M/C intercrop, the NPK fertilizer was applied on cowpea at 40 kg/ha. The SSP fertilizer was applied on cowpea in M/C cropping at 50 and 100 kg/ha (SSP1 and SSP2), respectively. Fertilizer treatments and nutrients supplied in each treatment are presented in Table 1.

Plots were kept weed-free by manual hoeing. Cowpea was protected against insects by spraying with insecticide (Abamectine 18 g/L and Deltaméthrine 25 g/L) at least twice during the cropping season. Ziziphus fruits were protected against insects and fruit flies by 3–4 sprayings of Deltaméthrine and harvested at maturity.

2.3. Sampling and analysis

At the start of the agronomic experiment in 2015, soil samples were taken from the top 0–20 cm depth in the two blocks (with and without Ziziphus). Each block was divided into four plots of 700 m^2, and each of the four plots was subdivided into 32 sub-plots. Six sub-samples were randomly taken from each sub-plot, and they were mixed to prepare a mean sample for laboratory analysis. At the end of the experiment in 2018, six soil samples were randomly taken from the sub-plots (fertilizer treatments) and mixed to prepare three mean samples per sub-plots for laboratory analysis. Six samples of FYM were taken each season (a total of 24 samples in four cropping seasons), dried at 60 °C for 72 h, and analyzed for C, N, P, and K. The FYM contained about 1.7 % N, 18.4 % C, 0.31 % P, and 0.16 % K. Soil pH was measured in 1 N KCl using a 2:1 solution: soil ratio, and exchangeable acidity was measured as described in McLean (1982). Organic C content was measured by the wet chemical digestion procedure described in Walkley and Black (1934). Total N was determined by the Kjeldahl procedure (Nelson and Sommers, 1980).

Exchangeable potassium (K^+) was determined using flame photometry, and available P was determined using Bray I method (Fixen and Grove, 1990). At crop maturity, the sample area of each sub-plot (56 m^2) under fertilizer treatments was harvested manually. Grain yield and total dry matter were determined by drying samples at 70 °C in a forced-draught oven for 48 h and weighing them. For cowpea, pods were hand-picked and the grain yields were determined after threshing. Water use efficiency (WUE; kg/ha^{-1} of plant biomass per mm of rainfall) was estimated as the ratio of total biomass produced by crops for each cropping system (MM, CC, and M/C intercropping) to the total rainfall during the season. The effect of ZT with and without Ziziphus fruits on the income was evaluated per year (for all treatments) on the block with Ziziphus (ZT) and compared with that in the control treatment (WZ). For this analysis, we used the prices in $US kg^{-1} from local markets (millet grain 0.32; millet Stover 0.03; cowpea grain, 0.53; cowpea fodder 0.16; Ziziphus fruits 1.75). Yearly data was subjected to analysis of variance as per Randomized Complete Block Design (RCBD). The test of Fisher-Newman Keuls was used for paired comparison of means. The Student-Newman-Keuls test was used for multi comparison of (more than two) means (Gomez and Gomez, 1983; GENSTAT 5 Committee, 1993).

3. Results

3.1. Soil properties

The data of the original soil in the two blocks (ZT and WZ) before (2015) and after the four years of cropping (2018) are presented in Table 2. Fig. 3 presents the distribution of data (boxplots) of the original soils in the two blocks. Before the cropping activities, the T-test did not reveal any significant differences between the two blocks (with and without Ziziphus) in N, K, pH, and SOC (Table 2), indicating that the soils of the two blocks were similar in these properties. Still, the ZT soil had less available P (6.4 ± 2.4 mg P/kg, median value of 2.8) than the control WZ (9.4 ± 3.5 mg P/kg, median value of 9.0). This difference in P-Bray1 could be linked to the spatial variability of soils properties and cropping activities that occurred before our experiment. Phosphorus is one of the stable nutrients in soils. Spatial variability and residual effects from cropping activities could have contributed to the difference in P content between ZT and WZ. Despite these differences, the P-Bray1 of the two blocks remained very low and can be classified as poor soils in which P deficiency is the main limiting factor for growth of cereal crops in upland soils. The critical limit of P-Bray1 is around 10–14 mg P ha^1 for most cereal crops in upland soils. Below this critical limit, soils are considered as very poor soils, which require the application of P-fertilizers (Sahrawat et al., 1997; Bado et al., 2009). So, the two blocks had almost the same constraint of P deficiency.

After four years of cropping (2015–2018), compared with that in the original soil, the SOC in ZT and WZ decreased by 15 and 21 %, and K decreased by 105 and 110 %, respectively. However, compared with that in the original soil, soil N decreased only in WZ by 19 %, and soil P decreased only in ZT by 35 %. These decreases in soil nutrients compared with the original soil (previously under fallow) indicated that the nutrient uptake by plants occurred, and different nutrients were lost with various cropping activities. The decreases in SOC have commonly been observed in upland soils as a consequence of the quick mineralization of organic carbon, which occurs as a consequence of cropping activities (Bado et al., 1997a,b; Whitbread et al., 1998; Bationo, 2008; Bationo et al., 2007; McNair Bostick et al., 2007; Bado and Bationo, 2018). However, fertilizer application did not affect soil N, P, K, SOC, and soil acidity (Table 2). Small doses of fertilizers applied on the hills according to farmer's practices were mainly absorbed by crops and could probably not be present in sufficient quantity to affect soil nutrients in this short period of four years of cropping. However, our results showed that different cropping systems affected soil nutrients. The soils of the MM cropping system had the highest pH, whereas those of the CC cropping had the lowest pH (Table 2). However, the pH of soils in M/C was lower than that of soils in MM. This could be explained by the quantities and nature of organic inputs. Higher quantity and higher lignin content of millet residues could explain the higher pH in MM and M/C cropping compared to that in CC cropping with the residues of cowpea. The low quantity and quick mineralization of residues from cowpea could explain the low impact on SOC and soil pH, compared with that of millet residues from MM and M/C systems. The MM and M/C systems had the highest levels of N without significant differences between the two systems (Table 2), whereas CC had the lowest levels of N. Regarding soil acidity, the low quantity and quick mineralization of residues from cowpea could explain the low impact on soil N compared with that of millet residues from MM and M/C systems. Nitrogen from the small quantity of residues in CC cropping was probably quickly mineralized and absorbed by crops or lost during the cropping seasons without significant impact on overall soil N status.

3.2. Crop yields

The results of the analysis of variance in millet and cowpea grain yields over the four years (2015–2018) are presented in Table 3. In three out of four years, the total dry matter (TDM) yields of millet were significantly affected by fertilizer applications (FA) and cropping systems (CS) ($p < 0.01$). However, we observed an interaction between CS and FA in 2017. In two out of four years, the presence of ZT also significantly affected millet TDM ($p < 0.05$). Cropping systems affected ($p < 0.01$) the TDM yields of cowpea over the four years of cropping (Table 3). The presence of ZT and FA affected cowpea TDM yields over two years (2015 and 2018). However, we observed an interaction between CS and FA in 2015 and between ZT and FA in 2017.

During the experimental period, millet was subjected to an attack by an insect species *Rhyniptia infiscata*, which drastically reduced grain

Table 2
Properties of the original soil at the start of cropping (2015) and effects of cropping systems on soil in 2018, after four years of cropping (2015-2018) with and without Ziziphus trees at the ICRISAT Sadoré research station, Niger. Ziziphus trees were planted at 80 plants ha^{-1}.

	pH-H_2O		pH-KCl		Organic Carbon (%)		Total N (mg/ kg)		Exchange K (cmol+ /kg)		P-Bray1 (mg/kg)	
	WZ	ZT	WZ	ZT	WZ	ZT	WZ	ZT	WZ	ZT	WZ	ZT
Original soil (OS)	5.0	5.2	4.0	4.1	0.21	0.21	173	163	0.13	0.14	9.4	6.4
t -test	ns		ns		ns		ns		ns		*	
Millet-Millet	4.8 a	5.3 a	4.0 ^{a}	4.2 ^{a}	0.17	0.19	144	167 ^{ab}	0.07	0.07	9.9	4.7
Cowpea-Cowpea	4.6 ^{c}	5.0 ^{c}	3.8 ^{c}	4.0 ^{c}	0.17	0.17	138	142 ^{c}	0.06	0.06	11.9	5.1
Millet/Cowpea intercrop	4.7 ^{b}	5.1 ^{b}	3.9 ^{ab}	4.1 ^{b}	0.18	0.19	154	169 ^{a}	0.06	0.07	9.6	4.4
Mean cropping (CS)	4.7	5.1	3.9	4.1	0.2	0.2	145	159	0.06	0.07	10.5	4.7
Variation with OS (%)	−6	−1	−3	0	−21*	−15*	−19*	−2	−105*	−110*	10	−35*

Values affected by the same superscripted letter in the same column are not significantly different at p<0.05, according to Student−Newman−Keuls test.; ns and *: not significant and significant at P<0.05, respectively for original soil (with and without zizphus) before cropping (year 2015) and variations of nutrients between original soil and after 4 years cropping according to the T−test of Student.

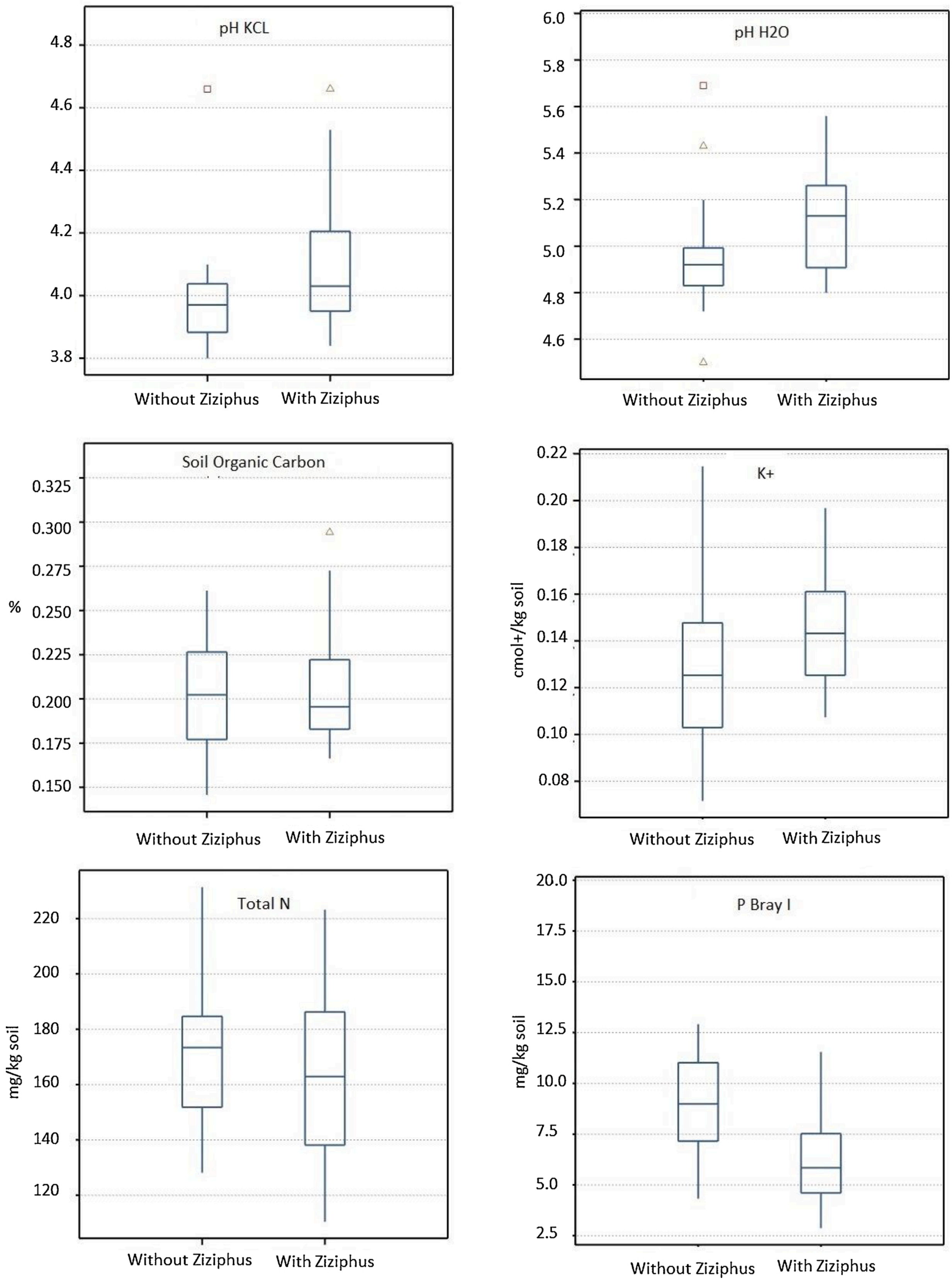

Fig. 3. Graphical distribution (by boxplots) of total nitrogen, available phosphorus (P-Bray1), exchangeable potassium (K+), organic carbon, and acidity (pH-KCl and pH-H_2O) of the soils from the two blocks (with and without Ziziphus trees) in 2015, before the cropping activities at the ICRISAT Sadoré research station in Niger.

Table 3
Analysis of variance of the effects of fertilizer application, cropping systems, and Ziziphus trees at 80 plants ha^{-1} on millet and cowpea yields (total dry matter and grain) over four years (2015–2018) at the ICRISAT Sadoré Research Station, Niger.

		Millet				Cowpea			
	Year	2015	2016	2017	2018	2015	2016	2017	2018
Total Dry Matter yields	Ziziphus Tree (ZT)	8.4^{a}	0.0	9.0^{a}	0.0	4.2^{a}	1.7	0.1	11.4**
	Cropping System (CS)	0.7	16.0**	55.4**	39.0**	151.1**	131.1**	28.4**	42.7**
	Fertilization application (FA)	2.1	14.4**	20.4**	52.0**	3.2^{a}	2.2	0.8	4.0^{a}
	ZT * CS	0.5	0.2	0.0	0.3	2.4	4.9^{a}	2.4	1.1
	ZT * FA	1.2	2.1	1.6	1.5	0.6	0.4	3.1^{a}	1.5
	CS * FA	1.2	0.6	3.0^{a}	1.1	3.2^{a}	2.3	0.4	2.3
	ZT * CS * FA	0.2	0.5	1.0	0.2	0.5	0.1	0.7	1.1
Grain yields	Ziziphus Tree (ZT)		2,9	12,2**	0,7	0.1	7.5^{a}	3.8^{a}	16.3**
	Cropping System (CS)		7.8^{a}	68.6**	42.3**	67.1**	73.7**	29.4^{a}	53.5**
	Fertilization application (FA)		7.9**	22.3**	58.6**	3.6^{a}	0.6	1.0	3.3^{a}
	ZT * CS		0.0	0.3	0.1	1.1	9.5^{a}	1.6	0.5
	ZT * FA		1.6	1.9	0.2	1.2	0.6	1.2	1.5
	CS * FA		0.8	3.4^{a}	2.3	2.8^{a}	0.6	0.2	1.7
	ZT * CS * FA		0.3	1.6	0.2	1.6	0.5	0.9	0.7

^{a} and ** : Significant at 005 and 0,01, respectively according to the test of Fisher-Newman Keuls. Grain data of year 2015 were not exploitable because millet was subjected to an attack by an insect Rhyniptia infiscata that drastically reduced grain yields in Niger.

yields (GY) across the whole Niger, which is why the data on millet GY in 2015 could not be used in this study. Regarding TDM yields; FA and CS affected GY of millet over three years of cropping (2016, 2017, 2018). The presence of ZT significantly affected millet GY in 2017 ($p < 0.01$), and we observed an interaction between CS and FA. Cropping systems affected ($p < 0.01$) the GY of cowpea over the four years of cropping (Table 3). The presence of ZT affected cowpea GY over three years (2016, 2017 and 2018). The application of fertilizer affected cowpea GY over two years (2015 and 2018). However, we observed an interaction between CS and FA in 2015 and between ZT and CS in 2016.

Because of the interactions between FA and CS and between ZT and CS, data could not be discussed by factor without taking account the other factors. So, we present the data of fertilizer treatments by CS in presence of Ziziphus (ZT) and without Ziziphus (WZ)

3.2.1. Mono-cropping of millet (MM)

Millet yields with MM cropping in the system with and without Ziziphus trees are presented in Table 4. In WZ, millet GY varied from 0.10 to 1.14 t/ha. The highest yields were obtained with mineral NPK fertilizer alone or with combined application of NPK and farmyard manure (FYM). Lowest yields were obtained with in the control treatment without fertilizer and with the application of FYM alone. In the ZT system, millet GY varied from 0.20 to 0.99 t/ha. The highest GY were obtained with NPK and with the combined application of NPK and FYM. The lowest yields were obtained in the control group without the use of fertilizer. Lower yields of millet in treatments with addition of FYM and in the control treatments without fertilizer were probably a consequence of the low quantities and availability of nutrients provided by these treatments. Compared with the WZ system, the presence of ZT increased millet yields by 41 % in the control treatment without fertilizer. Similarly, the application of FYM increased millet yields by 10 % in ZT compared with those in the WZ system. On the other hand, high impact of ZT on millet GY was observed in control and FYM treatments, which did not provide enough nutrients for the plants. Conversely, millet GY decreased in the ZT system with NPK fertilizer by 13 % compared with that in the WZ system. However, millet had the same GY in the two systems when NPK was applied along with FYM. The presence of ZT seemed to decrease millet yields in treatments that supplied more nutrients compared with those in the WZ system.

3.2.2. Mono-cropping of cowpea (CC)

Cowpea grain yield varied from 0.17 to 0.83 t/ha and from 0.19 to 1.08 t/ha in WZ and ZT, respectively. In both systems, cowpea yields were affected by fertilizer applications only during the first year of cropping (2015). The highest grain yields were obtained with NPK and SSP fertilizers, whereas the lowest yields were obtained with the control treatment without fertilizer. Compared with WZ, the presence of ZT decreased cowpea yields by 15 % in the control without fertilizer. This was an indication that cowpea was more negatively influenced, probably by the shadow from ZT. While ZT with SSP fertilizers did not affect

Table 4
The effect of fertilizer applications and mono-cropping systems of millet and cowpea with and without Ziziphus trees (at 80 trees ha^{-1}) on millet and cowpea grain yields (t ha^{-1}) over four years (2016–2018) at the ICRISAT Sadoré Research Station, Niger.

		Without Ziziphus (WZ)					With Ziziphus (ZT)					Effect of Ziziphus (%)
		Years					Years					
Cropping systems	Fertilizer Treatments	2015	2016	2017	2018	Mean	2015	2016	2017	2018	Mean	(ZT-WZ)/WZ*100
Mono cropping of millet (MM)	Control		0.61^{b}	0.10^{c}	0.21^{c}	0.34^{c}		0.76	0.47^{c}	0.20^{c}	0.48^{c}	41
	NPK fertilizer (NPK)		1.14^{a}	0.99^{a}	0.73^{a}	0.92^{a}		0.91	0.81^{ab}	0.70^{a}	0.80^{a}	−13
	Farmyard Manure (FYM)		0.95^{a}	0.50^{b}	0.42^{b}	0.62^{b}		0.83	0.77^{ab}	0.45^{b}	0.68^{a}	10
	NPK + FYM		1.13^{a}	0.82^{a}	0.57^{b}	0.84^{a}		0.99	0.92^{a}	0.53a^{b}	0.82^{a}	−2
	Mean		0.96	0.60	0.48	0.68		0.87	0.74	0.47	0.69	1
Mono cropping of cowpea (CC)	Control	0.63^{c}	0.38	0.65	0.17	0.46	0.33^{c}	0.23	0.75	0.27	0.39	−15
	NPK fertilizer	0.75^{b}	0.51	0.65	0.19	0.53	1.08^{a}	0.19	0.78	0.28	0.58	9
	SSP1 fertilizer	0.83^{a}	0.27	0.83	0.16	0.52	1.02^{a}	0.18	0.60	0.20	0.50	−4
	SSP2 fertilizer	0.75^{b}	0.40	0.82	0.24	0.55	0.88^{ab}	0.20	0.70	0.39	0.54	−2
	Mean	0.74	0.39	0.74	0.19	0.52	0.83	0.20	0.71	0.29	0.50	−4

Grain data of year 2015 were not exploitable because millet was subjected to an attack by an insect Rhyniptia infiscata that drastically reduced grain yields in Niger. SSP1 and SSP2: Sample Superphosphate applied at 2.8 kg P/ha and 5.8 P/ha, respectively. Values affected by the same superscripted letter in the same year for the same cropping system are not significantly different at p<0.05, according to Student−Newman−Keuls test.

cowpea yield, the presence of ZT with NPK fertilizer increased cowpea yield by 9% compared with that in WZ. The absence of N in the SSP fertilizer could explain the lower yields of cowpea in this treatment compared with that in the treatment with NPK. Cowpea plants partly fix N from the atmosphere, but a minimum quantity of N fertilizer is needed, particularly in poor soils, at the early growing stage in order to stimulate N fixation (Bado et al., 2006). The combined effects of N from the NPK fertilizer and N input from the residues of ZT could explain the higher yields of cowpea in this treatment compared with those in the treatment with SSP fertilizers (without N).

3.2.3. Millet/cowpea intercropping (M/C)

In M/C cropping system WZ, millet GY varied from 0.08 to 1.15 t/ha and from 0.13 to 1.10 t/ha, respectively (Table 5). Regarding MM cropping, the highest yields were obtained with NPK alone and with the combined application of NPK and FYM. Compared with GY in WZ, millet GY increased with ZT in the control and FYM by 8 and 11 %, respectively. The ZT system decreased millet yields by 4 and 11 % with NPK alone and with the combined application of NPK and FYM, respectively. Cowpea GY varied from 0.01 to 0.66 t/ha and from 0.03 to 0.47 t/ha in WZ and ZT, respectively (Table 5). In WZ, cowpea yields were not affected by fertilizer applications over the four years, whereas in ZT, cowpea yields were affected by fertilizer application only in 2015 (the first year of cropping). Compared with those in WZ, cowpea GY were 16–24% lower in ZT with SSP fertilizers. This result could be related to the absence of N in the SSP fertilizer.

3.3. Water use efficiency

Water use efficiency (WUE) in the three cropping systems (MM, CC, and M/C) is presented in Table 6. With MM cropping, WUE of millet varied from 1.1 to 11.8 kg/mm and from 2.2 to 11.2 kg/mm in WZ and ZT, respectively. Similar to millet yields in MM and M/C cropping, the presence of ZT increased the WUE of millet by 17 and 47 % with FYM and in the control treatment without fertilizer, respectively. With the addition of NPK alone or in combination with FYM, the presence of ZT did not affect the WUE in millet. With CC cropping, WUE in cowpea varied from 1.1 to 4.8 kg/mm and from 1.3 to 4.3 kg/mm in WZ and ZT, respectively, but significant differences were not observed between fertilizer applications in either ZT or WZ. However, the ZT system increased the WUE of cowpea by 11 % compared to WZ when NPK fertilizer was applied. Regarding cowpea yield, the presence of N as nutrient and stimulant for biological N fixation could explain the higher WUE in plants with NPK fertilizer than that in plants with SSP fertilizers. In M/C cropping, the WUE of WZ and ZT varied from 1.8 to 14 kg/mm and from 1.9 to 13.6 kg/mm, respectively. Fertilizer treatments significantly affected WUE in the two systems in two years (2017 and 2018). Similar to MM and CC cropping, ZT increased WUE in M/C cropping by 17 % in the control treatment without fertilizer, and it also increased WUE by 11 % with FYM (millet) and SSP1 (cowpea).

3.4. Incomes

The presence of ZT (with and without Ziziphus fruits) significantly affected the global income over two out of four years of cropping (Table 7). Without Ziziphus, the global incomes varied from $US414 to $US885/ha over the four years. In the presence of ZT (without the contribution of Ziziphus fruits), the global incomes varied from $US472 to $US980/ha. The presence of Ziziphus (without fruits) increased the incomes from 5 to 14 % compared with that in the control WZ. This could be considered as the consequence of the beneficial effects of ZT on crop yields. Depending of the cropping system and fertilizer treatments, ZT increased and sometimes decreased crop yield, but the global income increase without Ziziphus fruits indicated that ZT had a generally beneficial impact on the productivity of millet and cowpea. Moreover, the inclusion of Ziziphus fruits highly increased the incomes ($p < 0.01$) (Table 7), which varied from $US1058 to $US1791/ha. With the contribution of Ziziphus fruits, the ZT system increased the global incomes from 2 to 3 times compared with the control without Ziziphus.

4. Discussion

We have evaluated how Ziziphus that also provides high value fruits as source of food and incomes could be integrated in the traditional low input cropping systems of smallholder farmers. The goal was to propose an affordable agroforestry system that improved productivity and income generation and compatible with the limited resources of farmers. The significant increases in millet and cowpea yields in MM, CC, and M/C cropping systems with (ZT) and without Ziziphus (WZ) with small quantities of mineral and organic fertilizers reflected the original poverty of soils (Batioo and Mokwunye, 1991; Bado et al., 1997a,b; Bationo and Buerkert, 2001; Bationo et al., 2007; Bado and Bationo, 2018). Taking into account the limited resources of smallholder farmers, micro dosing or hill placement of fertilizers was developed by ICRISAT as an affordable option (Bielders and Gérad, 2015; Ibrahim et al., 2015a). The combined effect of the concentration of fertilizer nutrients close to plant roots and harvesting of water in small pits around plant hills created favorable conditions for biological activities. For example, Ibrahim et al. (2015b) observed an increase in root length density by 66 to 42 % with hill placement of manure. The combined effects of root density, water availability, and nutrient absorption contribute to improved crop responses to hill placement of fertilizers (Ibrahim et al., 2015a, c; Kermah et al., 2017).

One of the main goals of our study was to assess the impact of

Table 5

The effect of fertilizer applications in the millet/cowpea intercropping system with and without Ziziphus trees (at 80 trees ha^{-1}) on millet and cowpea grain yields (t ha^{-1}) over four years (2016–2018) at the ICRISAT Sadoré Research Station, Niger.

		Without ziziphus (WZ)					With Ziziphus (ZT)					Effect of Ziziphus (%)
		Years					Years					
Crop	Fertilizer Treatments	2015	2016	2017	2018	Mean	2015	2016	2017	2018	Mean	(ZT- WZ)/WZ*100
	Control		0.87	0.08^{c}	0.16^{c}	0.37^{c}		0.88	0.19^{b}	0.13^{c}	0.40^{c}	8
	NPK Fertilizer (NPK)		1.31	0.31^{ab}	0.48^{a}	0.70^{a}		1.10	0.47^{a}	0.49^{a}	0.67^{a}	−4
Millet	Farmyard Manure (FYM)		1.09	0.24^{b}	0.32^{b}	0.55^{bc}		1.08	0.47^{a}	0.29^{b}	0.61^{ab}	11
	NPK + FYM		1.15	0.41^{a}	0.39^{bc}	0.65^{b}		0.99	0.41^{a}	0.34^{b}	0.58^{ab}	−11
	Mean		1.11	0.26	0.34	0.57		1.01	0.39	0.31	0.57	
	Control	0.24	0.01	0.43	0.06	0.19	0.27^{b}	0.06	0.38	0.06	0.19	0
	NPK fertilizer	0.35	0.03	0.57	0.05	0.25	0.38^{a}	0.03	0.37	0.21	0.25	0
Cowpea	SSP1 fertilizer	0.24	0.01	0.54	0.07	0.22	0.19^{bc}	0.04	0.40	0.09	0.18	−18
	SSP2 fertilizer	0.38	0.02	0.66	0.06	0.28	0.19^{bc}	0.05	0.47	0.14	0.21	−25
	Mean	0.30	0.02	0.55	0.06	0.26	0.26	0.05	0.41	0.13	0.21	

Grain data of year 2015 were not exploitable because millet was subjected to an attack by an insect Rhyniptia infiscata that drastically reduced grain yields in Niger. SSP1 and SSP2: Sample Superphosphate applied at 2.8 kg P/ha and 5.8 P/ha, respectively. Values affected by the same superscripted letter in the same year for the same cropping system are not significantly different at $p<0.05$, according to Student−Newman−Keuls test.

Table 6
The effect of fertilizer applications and cropping systems with and without Ziziphus trees (at 80 trees ha^{-1}) on rainwater use efficiency by millet and cowpea (kg biomass of crop/ha/mm of rainfall) over four years (2015–2018) at the ICRISAT Sadoré Research Station, Niger.

		Without Ziziphus (WZ)					With Ziziphus (ZT)					Effect of Ziziphus (%)
		Years					Years					
Cropping systems	Fertilizer Treatments	2015	2016	2017	2018	Mean	2015	2016	2017	2018	Mean	(ZT-WZ)/WZ*100
Mono cropping of Millet	Control		5.7 ^{b}	1.1 ^{b}	2.1 ^{a}	3.0 ^{c}		8.4	2.6	2.2 ^{b}	4.4 ^{c}	47
	NPK fertilizer (NPK)		12.0^{a}	4.6^{a}	5.7^{c}	7.4 ^{a}		10.5	4.3	5.5^{a}	6.8 ^{a}	−8
	Farmyard manure (FYM)		9.3^{a}	2.8 ^{b}	3.5^{b}	5.2 ^{b}		9.9	3.9	4.4^{a}	6.1 ^{ab}	17
	NPK + FYM		11.8^{a}	4.6^{a}	4.9^{c}	7.1 ^{a}		11.2	4.7	4.6^{a}	6.8 ^{a}	−4
	Mean		9.7	3.3	4.1	5.7		10	3.9	4.2	6.0	5
Mono cropping of Cowpea	Control	2.5	2.8	2.1	0.8	2.1	2.5	2.0	3.0	1.2	2.2	5
	NPK fertilizer (NPK)	3.1	4.8	2.1	0.9	2.7	4.3	3.5	3.1	1.3	3.0	11
	SSP1 fertilizer (SSP1)	3.4	3.0	2.6	0.8	2.4	4.0	2.7	2.2	0.9	2.4	0
	SSP2 fertilizer (SSP1)	3.3	3.4	2.8	1.1	2.7	4.0	2.4	2.5	2.2	2.8	4
	Mean	3.1	3.5	2.4	0.9	2.5	3.7	2.6	2.7	1.4	2.6	4
Millet/Cowpea intercrop	Control)		8.7	2.2 ^{b}	1.8 ^{a}	4.2		9.8	3.1 ^{a}	1.9 ^{c}	4.9	17
	NPK fertilizer (Millet and Cowpea)		13.5	3.8^{a}	4.6^{a}	7.3		13.2	4.4^{b}	5.1^{a}	7.6	4
	Farmyard manure (Millet), SSP1 (Cowpea)		12.4	3.8^{a}	2.9^{b}	6.4		13.6	4.3^{a}	3.3^{b}	7.1	11
	NPK + FYM (Millet), SSP2 (cowpea)		14.0	4.7^{a}	4.1^{a}	7.6		11.9	4.4^{a}	3.7^{b}	7.6	0
	Mean		12.1	3.6	3.3	6.4		12.1	4.0	3.5	6.6	3

Grain data of year 2015 were not exploitable because millet was subjected to an attack by an insect Rhyniptia infiscata that drastically reduced grain yields in Niger. SSP1 and SSP2: Sample Superphosphate applied at 2.8 kg P/ha and 5.8 P/ha, respectively. Test Student-Newman-Keuls, Alpha = 0.05.

Table 7
Global revenues provided by the three cropping systems (mono-cropping of millet, mono-cropping of cowpea, and millet/cowpea intercropping) as affected by the presence (ZT) and absence of Ziziphus trees (WZ) with and without the contribution of the fruits from Ziziphus (ZTf and ZT, respectively) at 80 plants ha^{-1} over four years (2015–2018) at the ICRISAT Sadoré Research Station, Niger.

Year	Without Ziziphus (WZ)	With Ziziphus (ZT)	With Ziziphus and fruits (ZTf)	(ZT-WZ)/WZ*100 (%)	(ZTf-WZ)/WZ*100 (%)	ZTf/WZ Ratio
2015	449^{b}	490 ^{b}	1392^{a}	9	192**	3.1
2016	885 ^{c}	980 ^{b}	1791 ^{a}	11*	92**	2.0
2017	819 ^{b}	857 ^{b}	1713 ^{a}	5	104**	2.1
2018	414 ^{c}	472 ^{b}	1058 ^{a}	14*	136**	2.6
Mean	642^{c}	700^{b}	1489 ^{a}	9*	121**	2.3

Incomes of MM system did not include grain of year 2015 because of the lost of grain due to an attack by an insect Rhyniptia infiscata that drastically reduced grain yields in Niger. The prices in $US kg^{-1} on local market (millet grain 0.32; millet Stover 0.03; cowpea grain, 0.53; cowpea fodder 0.16; fruits of ziziphus 1.75) were used. Values affected by the same superscripted letter on the same line are not significantly different at $p<0.05$, according to Student-Newman-Keuls test; * and ** : Significant increase of income at 005 and 0,01, respectively according to the test of Fisher-Newman Keuls.

Ziziphus on low input cropping systems of smallholder farmers. Our data suggested that millet grain yield (GY) and water use efficiency (WUE) in both MM and M/C cropping systems were affected by planting of Ziziphus. Considering these two factors, fertilizer treatments could be classified into two groups. FYM alone and the control without fertilizer constituted the first group, whereas NPK fertilizer alone and NPK + FYM constituted the second group.

In the first group, nutrients from FYM and the control were slowly released (FYM) or very limited (control without fertilizer) to ensure plant needs. FYM and the control treatments (first group) could be considered as poor nutrient input systems. In the absence of Ziziphus (WZ), millet had the lowest yields as consequence of the low nutrient supply. The increase in millet yields with ZT in this poor nutrient input systems could partly be attributed to the improvement of WUE. This was confirmed by the WUE of millet in both MM and M/C cropping systems. The presence of ZT at the same time increased both millet yield and its WUE in these two cropping systems (MM and M/C) with low nutrient input treatments. Other factors may have contributed to this positive impact of ZT, but in these low nutrient input treatments, the improvement of WUE was probably the main factor affecting millet yield in this dryland ecosystem.

After four years of cropping, the soil with ZT contained from 5 to 10 % and from 10 to 15 % more SOC and N than the soil WZ, respectively. These differences were not significant. However, the combined effects of organic inputs and N from ZT system on soil properties (pH) could have contributed to the improvement of nutrient availability (Bado et al., 1997a,b; Bayala et al., 2006; Bationo et al., 2007) as well as WUE, which is why we concluded that it had a significant impact on millet yields (0.50 to 0.70 t/ha) in low nutrient input treatments. The reduction of run-off and water loss through the windbreak along with the increase in soil water holding capacity with the organic inputs from ZT and the impact of ZT on solar radiation and air temperature have probably contributed to the improvement of both nutrient availability and WUE (Tilander et al., 1999; Ndoli et al., 2017). For example, Zhang et al. (2018) reported that maximum light area index (LAI) of millet was 17 % higher in agroforestry than in sole millet system, and Breman and Uithol (1984) noted a loss of up to 50 % of rainfall through soil evaporation in the Sahelian drylands.

In our experiment, the second group of fertilizer treatments (NPK and NPK + FYM) could be considered as higher nutrient release systems. Under these treatments, the presence of ZT did not affect millet yield in the same way in MM and M/C cropping. In the absence of Ziziphus (WZ), millet produced the highest yields in both MM and M/C cropping as a consequence of higher levels of nutrients supplied to the plants from NPK and NPK + FYM. Conversely, the presence of Ziziphus (ZT) did not affect or even decrease millet yields. The WUE of millet was not significantly affected by ZT. While WUE and millet yields increased from 17 to 47 % and from 10 to 41 %, in ZT with low nutrient input treatments (FYM and control) compared to that in WZ, respectively; with higher nutrient input treatments, ZT did mostly not affect WUE and millet yield, and sometimes it decreased millet yield. By supplying more nutrients, NPK alone or associated with FYM offered better conditions for crop growth, but it also led to more competition for light, reducing the impact of ZT or decreasing crop yields. This is in accordance with many controversies in literature about the impact of trees in agroforestry systems on nutrients and water use (Tilander and Ong, 1999; Wallace, 1996; Young, 1997; Tilander et al., 1999). Competition for water is often reported, but there are also ways of water conservation in agroforestry systems. Still, direct competition between trees and crops for nutrients has rarely been demonstrated in dry agroecology (Young, 1997).

Because of their impacts on biomass production, nutrient recycling, reduction of run-off, windbreak, and soil protection, agroforestry systems could be considered as sustainable land use options with a promising potential for sequestering atmospheric carbon into the soil (Abbas et al., 2017). Bayala et al. (2020) noted that increase vegetation cover in the Sahel is associated with an increase in soil total carbon and this trend is more pronounced on sandy soils. Increasing biomass production with multi cropping agroforestry systems that include legume crops could contribute to the input of good quality organic carbon to the soil (Bado et al., 2006). In a literature review, Lorenz and Lal (2014) indicated that useful carbon sequestration in agroforestry systems for climate change mitigation must slow or even reverse the increase in atmospheric concentration of CO_2 by storing parts of SOC for millennia. In a study on degraded drylands in Ethiopia, Chiemela et al. (2018) provided evidence on how agroforestry systems can contribute to carbon sequestration and decrease in atmospheric CO_2 rates as a result of conversion of intensively cultivated agricultural lands to agroforestry systems.

From our data, growing ZT alone provided 2–3 times higher incomes compared with the system without Ziziphus. The productivity of the proposed agroforestry system with Ziziphus could be improved through future research to adjust the density of Ziziphus with the doses of fertilizer by crop and cropping system. This high contribution of ZT to income suggested that growing ZT alone and using the additional income to grow millet and cowpea could be a better option than the traditional low yields cropping systems. In such crop-free systems, the density of ZT could even be increased to make more income than the traditional systems. This is certainly a more profitable and technically realistic option. But getting the smallholder farmers to adopt this option could be difficult for two main reasons. Firstly, cereals (millet and sorghum) are staple food crops. Particularly, millet is one of the most important drought resistant crops, which really contributes to food security in the harsh environment of West Africa Sahel. In most social cultures, ensuring food security with one's own household production of cereal is an honor and an important factor of dignity and respect within the community, which is why producing cereal is the first priority of the farmers from this region. Sometimes, farmers buy supplemental cereals in exceptional crisis situations, such as seasonal droughts. Secondly, around 90 % of the farmers of this region are agro pastoralists, legume crops (cowpea and groundnut) are the second priority crops that provide food, incomes, and feed for livestock. For these reasons, growing only Ziziphus to make more revenue has a lower chance for being adopted by smallholder farmers. In the socio-economic context, our proposed agroforestry system with millet, cowpea, and ZT systems offers an interesting option, which could really improve agricultural productivity. Beyond the strong contribution of Ziziphus to the productivity and incomes, Ziziphus trees also provided wood through annual pruning at the start of each cropping season. In the present study, we did not quantify this additional value of wood, and it should be considered because as a source of energy in the difficult socio-economic conditions of these rural populations, it is an important contribution to traditional farming systems.

5. Conclusion

Our study showed that the association of Ziziphus trees at the density of 80 plants ha^{-1} with the low input mono-cropping of millet or millet/cowpea intercropping by smallholders improved agricultural productivity and incomes. The proposed agroforestry system has many advantages. It is an affordable and manageable system for the farmers, and it can be incorporated into the low input farming systems of smallholder farmers while ensuring sustainable management of soil fertility, land resources, and ecosystem services. However, future research could contribute by identify the optimal combinations of the density of Ziziphus trees, cropping systems and the doses of fertilizer on crops to optimize the productivity of the propose agroforestry system.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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