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Improvement of the productivity of millet (*Pennisetum glaucum* (L.) R. Br.) Intercropped with the Arabic gum tree (*Acacia senegal* (L.) Willd.) in agroforestry parkland in Niger

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ABSTRACT

In Niger, *Acacia senegal* species is used in agroforestry parklands in association with several cereals including millet. However, the performance of these associations is not optimal since the techniques applied lack expertise. The objective of this work is to promote the intercropping system *Acacia senegal* - millet to improve millet productivity. We compared millet production in different areas in an agroforestry parkland based on *Acacia senegal* in a Sahelian agro-ecological zone in Niger. Over two successive rainy seasons, concentric crowns are designed around *A. senegal* trees. Millet growth and yield parameters are measured on millet plants inside each crown under cover and out of cover of *A. senegal* canopy. In the second year, the experimentation was completed with some plots of 5 m x 5 m designed in two pure millet fields. Physico-chemical soil characterization of both cropping systems was also performed in the second year of the trial. The results of this study showed that growth and yield parameters are higher out of cover than under cover of *A. senegal*. However, these parameters are higher in the whole parkland compared to the pure millet culture system. The levels of mineral elements such as carbon and nitrogen are higher in the parkland than in fields of pure millet. These results show that the parkland with *A. senegal* has increased soil fertility, and improved yield of millet, so this system could be disseminated at the level of agricultural producers to improve the production of this cereal.

Introduction

Agriculture in Niger is a subsistence farming with little fertilizer and manure. It evolves in a context of low fertility of soils and under a very unfavorable climate characterized by insufficient rainfall and its bad spatiotemporal distribution. As a result, land degradation is rising while agricultural production is declining (Wezel, 2000) and this situation is exacerbated by climate change. Some options exist to overcome the declining soil fertility and the low agricultural production, but often these options cannot be implemented. Manure or fertilizer application is one of these options, but household economic constraints limit their adoption (Wezel, 2000). Options that do not require any monetary exit would therefore constitute alternatives that are more suited to the socio-economic conditions of farmers. One of these kinds of option is agroforestry, integrating of multipurpose natural woody vegetation into cropping systems. Several authors have demonstrated the advantage of this integration in agricultural production systems (Maïga, 1987; Boffa, 2000; Liagre *et al.*, 2005). When implemented properly, agroforestry systems lead to higher productivity than pure crop rotation systems and there is an income gain on the plot when considering the entire production cycle (Liagre *et al.*, 2005). In addition, agroforestry systems can improve soil fertility by mineralization of leaf litter on the surface (Ong, 1996) and by the deep degradation of the roots of dead trees in the soil after pruning (Dupraz, 2002). Woody species also play a role in controlling water erosion by increasing the content of organic matter and soil macroporosity (Ong, 1996), thereby slowing the flow of water and promoting its infiltration into the soil, limiting runoff and soil departure, especially if tree alignment is perpendicular to the slope. Another advantage of agroforestry system is that trees grow faster than afforestation because they have more resources and can benefit in part from crop fertilization (Liagre *et al.*, 2005). In general, they are also more resistant. In fact, agroforestry trees function as isolated trees, therefore, root more firmly than their congeners in the actual afforestation.

So, agroforestry can be one of the options to solve the problem of low soil fertility with the promotion of sustainable development (N'garbaroum, 1994). In Niger, *Acacia senegal* species is used in agroforestry parklands in association with several cereals including millet. *A. senegal* is a species of major importance in the Sahelian zone because it adapts perfectly to low rainfall and high temperatures (Wickens *et al.*, 1995). Its excellent adaptation to arid conditions makes it one of the most widely used species in dry land reforestation programs (Soloviev *et al.*, 2009). *A. senegal* belongs to the Mimosaceae and therefore has the property of fixing atmospheric nitrogen and it produces Arabic gum, making it a good candidate for use in agroforestry system of agriculture.

Millet (*Pennisetum glaucum* (L.) R. Br.) is a staple cereal in the semi-arid tropics. In Niger it is the main food crop and occupies more area than all rainfed crops. In 2014, millet production in Niger was estimated at 3,321,753 tons (MDA, 2015). It constitutes the basic food of the Nigerien population. About 16 million hectares are cultivated each year in Niger for food crops and millet occupies 46.20% of this area and represents 69.56% of the national cereal production (MDA, 2015). However, despite the size of the area sown, the increase in production remains low and yields tend to peak, rarely exceeding 500 kg/ha in peasant areas (MDA, 2015). It would therefore be necessary to find cultivation methods that will make it possible to increase its production sustainably. The objective of this work is to highlight the contribution of agroforestry parklands system based on *A. senegal* in improving millet productivity in the context of climate change in Niger. We analyzed differences in biomass gains between an agroforestry system and a pure cultivation system of millet and we characterized the level of soils fertility to explain the observed differences.

Methods

Experimental site

The study was conducted in the agroforestry parkland (14°31'41.5"N and 06°42'59.1"E) dominated by *A. senegal* located at 4 Km from the town of Dakoro in Niger. Two pure millet fields (*field 1*: 14°31'24.9"N and 006°44'16.7"E and *field 2*: 14°31'25.1"N and 006°44'26.3"E) located in the same area, were used as controls for the comparison of millet productivity. The climate is tropical dry,

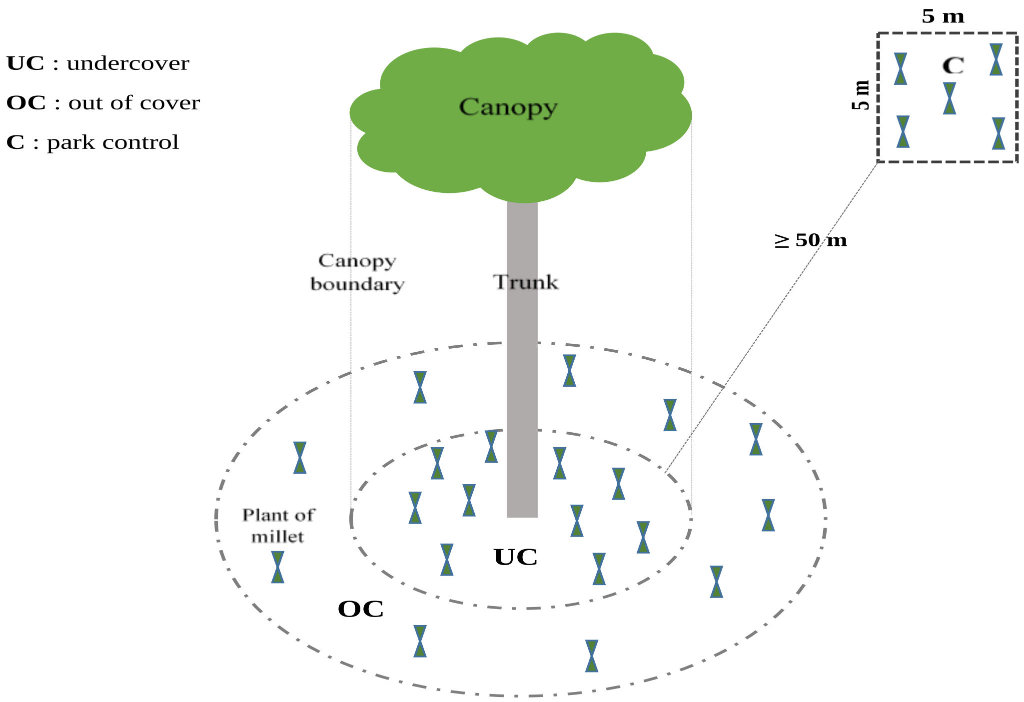

Figure 1. Experimental design in two concentric circles around *A. senegal* tree in an agroforestry parkland in Niger.

Sahelian type. The rainy season is from June to September with a dry period from October to May. The average annual rainfall over 20 years is 377.59 mm (MDA, 2015). The average annual temperature is 28.3°C. The most cultivated speculations are millet, sorghum, cowpeas and groundnuts. Cassava, roselle and maize are also grown but at a small scale. Millet and sorghum are either cultivated alone or intercropped with *A. senegal* or with legumes (cowpeas and groundnuts). The vegetation is a thorny steppe pricked with trees and shrubs. The herbaceous stratum is composed of annual grass-dominant species. The tree stratum is essentially composed of: *Acacia senegal*, *Faidherbia albida*, *Acacia tortilis*, *Balanites aegyptiaca and Ziziphus mauritiana*. The density of the tree stratum per hectare is 80 individuals. Tropical sub-arid soils are made of sandy materials with low clay content. This locality was chosen because it is naturally populated by the *A. senegal* species.

Plant material

The study was conducted in tow replicates over two consecutive years from July to October 2015 for the first trial and from July to October 2016 for the second trial. The plant material of the first trial is composed of 10 trees of *A. senegal*, 176 plants of millet distributed around these ligneous trees and 30 plants of millet in 6 control plots inside the same parkland. At the second year, millet plants that were planted by farmers around the same *A. senegal* trees were considered. The second trial is composed of 161 plants around the tree, 30 millet plants in 6 control plots in the same parkland and 60 millet plants in two pure crop fields. Five millet poaches per 25 m² was retained during the two rainy seasons. The millet monitored is an early local variety called “Haini Kirey Precoce” (HKP). Trees of *A. senegal* were selected for the study based on criteria such as the size of the tree and the volume of the canopy. A minimum distance of 50 meters is respected between 2 selected trees. The others tree species present in the parkland are also at least at 50 meters away from the monitored millet plants to avoid any influence.

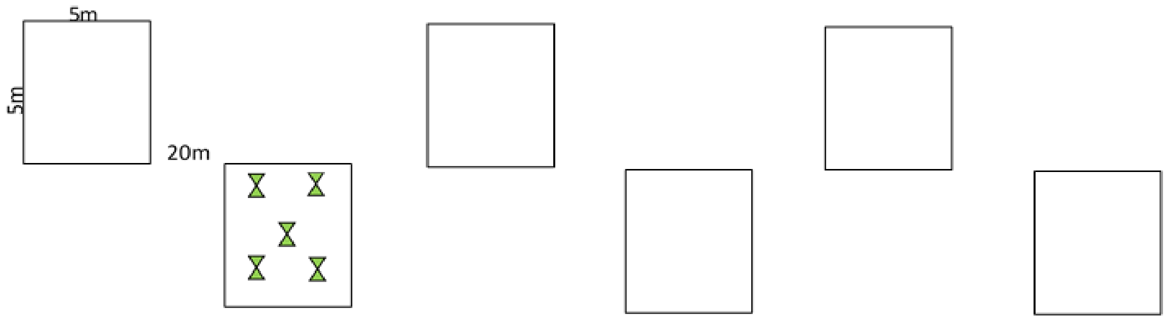

Figure 2. Experimental device designed in the pure culture system of millet.

Experimental design

The design used in the parkland is in concentric rings around the trunk of *A. senegal* (Figure 1). It includes two (2) circles delimiting the crowns around each tree. Rings are formed according to the diameter of the canopy of each tree. The first ring called UC (undercover) covers the canopy and the second ring enveloping the previous one over a distance corresponding to the radius of the canopy, is OC (out of cover). Six control plots were delimited each 50 m from the nearest tree. These control plots were used to control the influence of the *A. senegal* tree on millet production. In each ring and control plot, 10 millet plants are randomly selected for growth and yield parameters measurement.

This approach (Guillet *et al*., 1996) is widely used in crop performance monitoring in agroforestry parklands in the Sahelian part of West Africa (Abdou *et al.*, 2014; Bayala *et al*., 2002; Boffa *et al*., 2000; Boffa, 1999).

Two fields of pure local millet without *A. senegal* tree were selected in which 12 plots (Figure 2) were installed (6 plots per field). The shape and heterogeneity of the field were respected. The size of each plot is 5m*5m. Five millet poaches were randomly selected from each plot and monitored by measuring growth and yield variables**.**

Growth parameter measurements

Monitoring of millet phenology in the agroforestry system and in the pure-cropped fields was carried out by measuring the following variables:

- Height of the main stem measured with a tape measure. This parameter was evaluated until the emergence of the ear;
- Number of leaves on the main stem, the last leaf is marked to facilitate the next reading and reduces the risk of error;
- Length of internodes by measuring three internodes of the main stem then their average.

Measurements of these variables were taken every 14 days up to the millet heading stage. Survey sheets have been prepared for this purpose.

Harvesting and yield assessment

Harvesting was carried out at the stage of maturity of the ears. The ears of a single poaches are grouped together and tied by a negligible mass cord. For yield assessment, the following variables were measured:

- Weight of ears of corn by weighing on the scale the heap of ears of corn from the same poaches;
- Weight of the grains by weighing after deseeding and purification;

- Weight of dry biomass by weighing after three days of sun drying.

These yield parameters were evaluated at poaches. Thus, four poaches were randomly selected from each control plots in the parkland and in the pure cropping fields.

Soil Sample Collection

Soil sampling was carried out using an auger in each ring around *A. senegal* tree trunk (UC and OC), in the parkland control plots and in the two pure millet fields. The sampling was carried out following the four directions of orientation (East, West, South and North). The sampling depth is 0-25 cm. In total, under each tree of *A. senegal*, 8 soil samples were taken, i.e. 1 vertical sample × 4 directions × 2 rings. In each of the 6 control plots of the parkland, 4 samples are also taken in the 4 directions. The same procedure was used to collect samples from the plots of the pure cropping system. Composite samples were taken by mixing separately the samples taken in the 4 directions in each ring and in each control plot and in outside of the parkland. These soil samples were analyzed at the Soil Science Laboratory of the Faculty of Agronomy of Abdou Moumouni University, to determine the content of chemical elements (N, C and P_{ass}) characterizing the soil fertility level.

Data analysis and statistical testing

The statistical analysis was performed using XLSTAT software (Addinsoft**,** 2016). An analysis of variance (ANOVA) was performed to verify the existence of significant differences between means of variables at 5% threshold of Fisher test. Variables analyzed by ANOVA concern all millet growth and yield parameters measured in the parkland and in the millet fields. In addition, a Principal Component Analysis (PCA) was performed to estimate the correlation between millet yield parameters and soils chemistry characteristics.

Results

Number of leaves and plant height of millet

Over the two test years, the difference in leaf count was not significant ($P=0.407>0.05$) between the millet plants located in the different interaction zones in the parkland (Figure 3). In the first year, the average number of leaves per plant at 92nd DAS (days after sowing) was 8.93 ± 1.49 in the UC zone (under trees canopy); 8.11 ± 0.73 in the OC zone (out of the canopy but at a distance corresponding to the radius of the crown) and 9.91 ± 1.58 in the control zone of parkland C. In the second year, the same variable is 13.89 ± 1.07 in UC; 14.01 ± 1.94 in OC and 14.27 ± 1.26 in C. The difference between the parkland and the pure-crop system was not significant either for this variable.

Over the two years, the mean plant height was significantly higher ($P=0.033<0.05$ and $P=0.037<0.05$ respectively for the first and the second year) at 78 DAS in the OC zone compared to that recorded in UC. The pure cropping (PC) system records the smallest average size (Figure 4).

Evolution of the length of internodes

The mean internode length of millet stems (Figure 5) in the interaction zones with *A. senegal* (UC and OC) and in the parkland control plots are not significantly different ($P=0.461$) at the 5% Fischer threshold. However, a significant difference can be observed with the pure cropping system ($P<0.05$). In the second year, this variable is 15.52 ± 1.73 cm in UC; 17.10 ± 1.96 cm in OC and 15.85 ± 1.45 cm in the parkland control plots, while it is 12.35 ± 1.2 cm in the pure crop plots.

Yield comparison

Over the two years, assessed variables for yield comparison (the weight of the spike, the weight of the seeds and the weight of the dry biomass) were higher in OC zone than in UC zone in the parkland

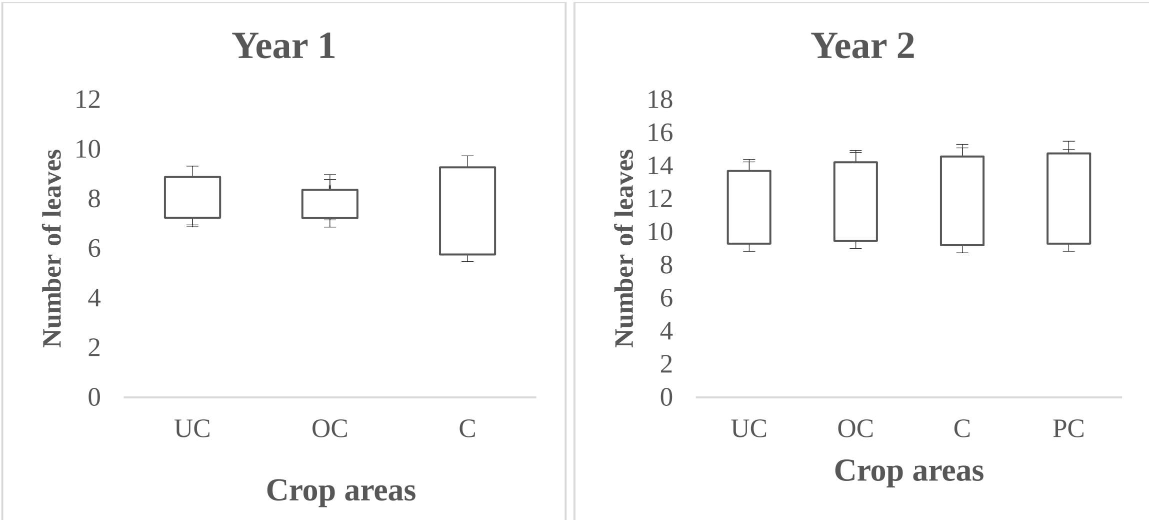

Figure 3. Evolution of the number of leaves during millet growth in the defined cultivation areas in the park with *A. senegal* and in pure millet cultivation fields. Study was carried out over two years. UC: undercover; OC: out of cover; C: park control; PC: pure crop system

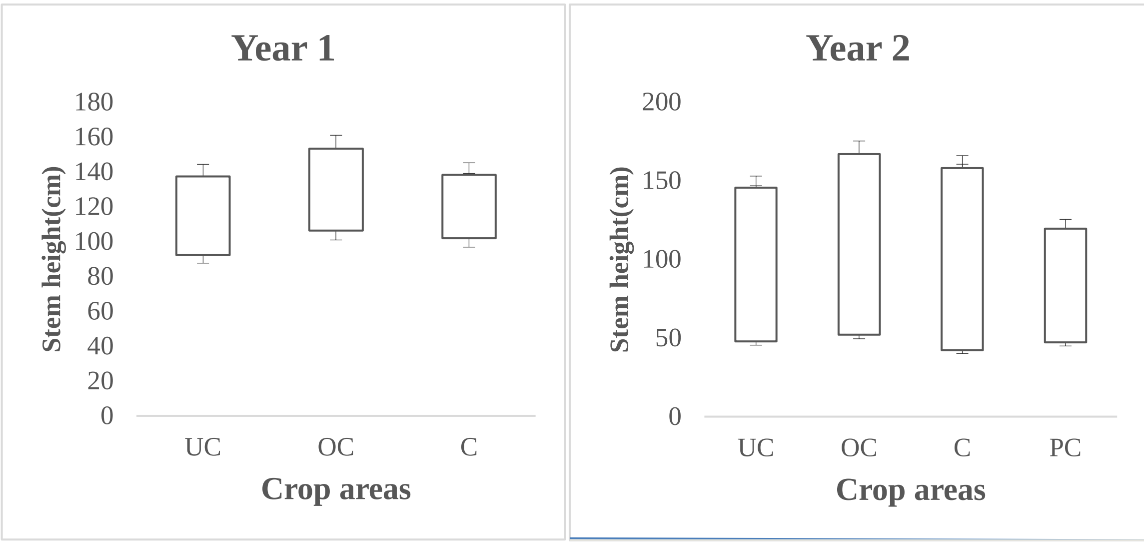

Figure 4. Change in the height of millet plants at 78 DAS in the defined cultivation areas in the parkland with *A. senegal* and in pure millet cultivation fields. Study was carried out over two years. UC: undercover; OC: out of cover; C: park control; PC: pure crop system.

(Table 1). In the table 1, values followed by the same letter are not statistically different at the 5% threshold of the Fisher test. The OC interaction zone had the highest cob, followed by C, and SC. For dry biomass, the highest yield is also obtained in the OC zone. Of the areas in the parkland, only the crowned (UC) area showed spike yields close to those obtained in the pure crop system at year two. The pure cropping system (PC) had the lowest value for this variable. The same situation was observed for grain yield. Overall, the average grain yield increased from 253.13 kg / ha in pure cropping to 416.52 kg / ha in parkland, an increase of 64.55%.

Comparative analysis of soil chemical components in the different interaction zones

Table 1. Yield in grains, spike and dry biomass of millet in the interaction and non-interaction zones with *A. senegal* in an agroforestry park and in two pure crop fields. Comparative measurements carried out over two successive rainy seasons.

Crop areas	**Spike yield (kg/ha)**		**Grains yield (kg/ha)**		**Biomass yield (kg/ha)**	
	year 1	year 2	year 1	year 2	year 1	year 2
UC	829,44**b**	636,25**b**	548,79**b**	327,08**b**	1395,83**ab**	1425,00**b**
OC	1329,96**a**	1135,00**a**	930,65**a**	583,75**a**	1835,45**a**	2777,50**a**
C	1153,50**ab**	766,67**ab**	891,75**a**	338,75**b**	1399,01**ab**	2050,00**ab**
PC		493,75**b**		253,13**b**		987,50**b**

On a column, the values followed by the same letter are not statistically different at the 5% threshold of the Fisher test. *UC: undercover; OC: out of cover; C: park control; PC: pure crop system*

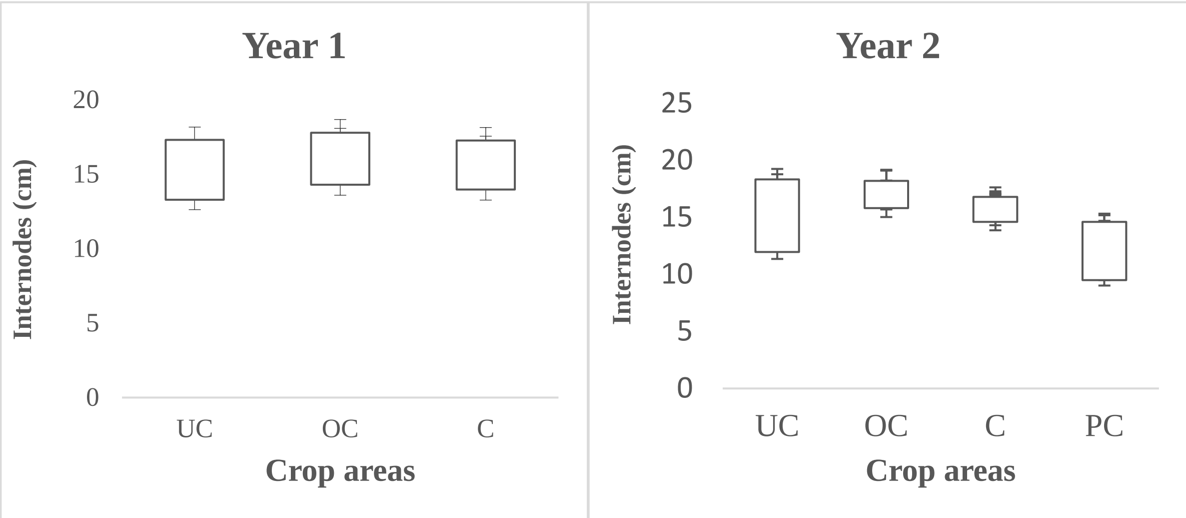

Figure 5. Average internode lengths of millet stalks in the interaction zones of *A. senegal* and in pure millet cultivation. Measurements carried out on two rainy season. UC: undercover; OC: out of cover; C: park control; PC: pure crop system.

The levels of carbon, nitrogen and available phosphorus in soils were compared in the different interaction zones of *A. senegal*, and in the control plots in the parkland and in the pure cropping system (Figure 6). The graphs plotted based on ANOVA analysis, show that nitrogen and carbon levels are higher in the interaction zones (UC and OC) than in the parkland control (C) and in the pure cropping system (PC); P<0.05 for N and C comparison among UC-OC and PC. As far as available phosphorus (P_{ass}) is concerned, the levels are statistically identical in the different interaction zones and in the pure millet culture.

Relationship between soil chemical parameters and yield components in different crop zones

PCA results linked crop areas, major soil chemicals (N, C and P_{ass}) and yield parameters (Figure 7). The information contained in the variables is controlled at 97.87% for the first test year and 91.13% for the second year by axes F1 and F2. Variables C, N, yield in ears, yield in grains and biomass contributed to the formation of the F1 axis and are in the same projection as the out-of-coverage (OC) zone for both rainy seasons. This means that the presence of a high content of these 2 elements (C and N) would have

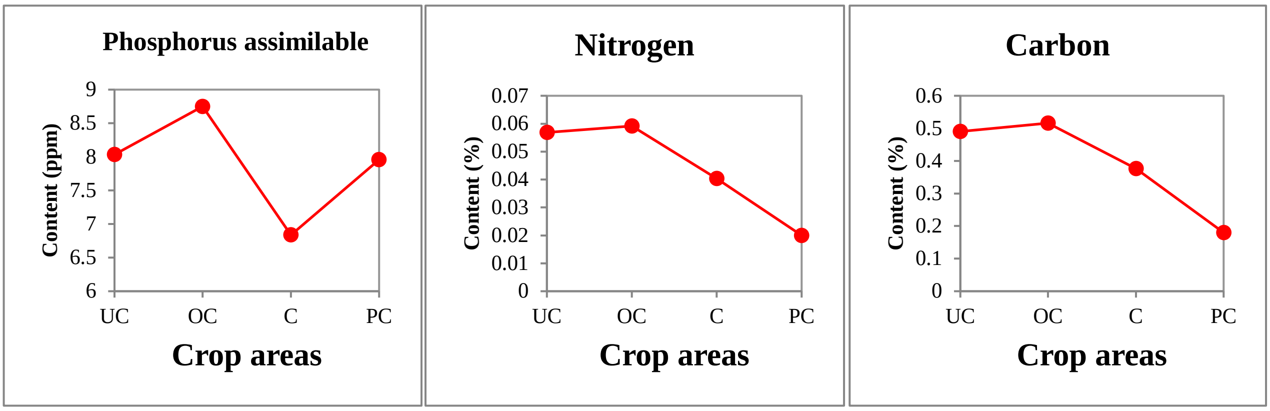

Figure 6. The contents of the 3 main soil chemical elements of soils in the *A. senegal* parkland and in the fields of millet. *UC: undercover; OC: out of cover; C: park control; PC: pure crop system.*

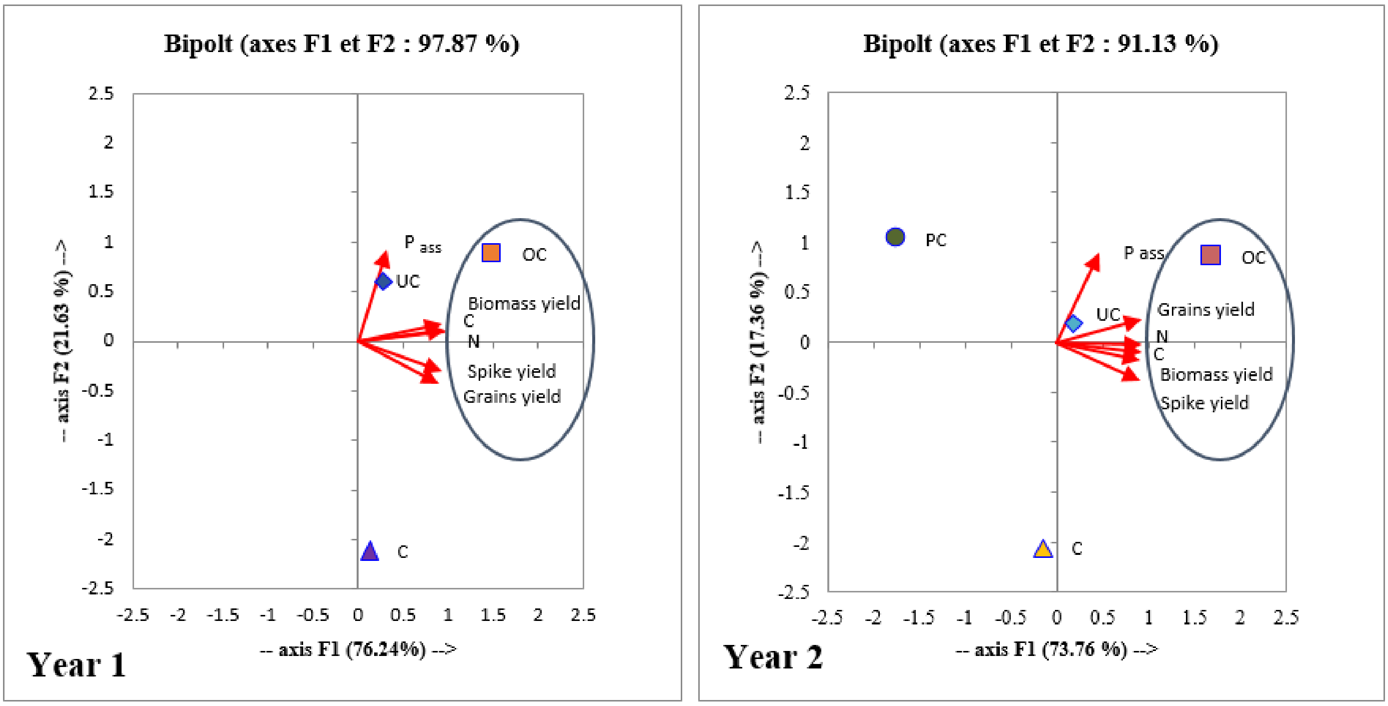

Figure 7. Plan of the Principal Component Analysis (PCA) among yield components and soil chemical parameters in different crop zones in the *A. senegal* parkland and in the fields of millet. UC: undercover; OC: out of cover; C: park control; PC: pure crop system; N: Nitrogen; C: Carbon; P_{ass}: Phosphorus assimilable.

led to higher yields in this zone (OC). In contrast, in the second year, the pure crop system has a negative correlation with these soil chemical characteristics. The undercover area (UC) and the parkland control (C) contribute to the formation of axis 2 as well as the P_{ass} but the parkland control shows a negative correlation which shows that the ground of the control is poor in P_{ass}.

Discussion

The results of this study showed that over two years, millet growth variables (number of leaves, plant height and internode length) were higher outside crown (OC) than under crown (UC) of *A. senegal* tree. This difference between the two cultivation areas around the tree can be explained in part by competition between the tree and the crop for the use of light and water. The decrease in light intensity under the trees canopy probably resulted in less development of millet plants in this area. Competition for water generally occurs at the beginning of the rainy season, when part of the rainfall is intercepted by the tree canopy (Abdou *et al.*, 2014). The amount of water reaching the ground under the tree canopy can be insufficient because together the tree and the underlying crop absorb water in the same area (under tree canopy) (Boffa, 2000). However, in this study, the height of the plants is significantly higher in the parkland than in the pure millet cultivation system. This significant difference can be explained by the richness of the soil in organic matter and nutrients in areas close to the tree caused by the fall of leaves producing litter. The C and N levels in soils near the tree (UC and OC) are always higher than those recorded in soils outside the influence of the tree (C and PC). Indeed, litter is an important source of nutrients (N, C, P, K *etc*) and their quality and quantity determine the different levels of these nutrients in soils. These results corroborate those of Dommergues (1995) who showed that the concentration of litter in agroforestry parklands with acacia makes soils richer in nutrients than in fields outside parklands. Fadl (2010) attributed the higher soil nitrogen content under the intercropping systems to both the mineralization of the soil litter and a direct nitrogen input from the trees to the soil.

As for growth variables, grain and ear yields are significantly higher in the OC zones followed by C, UC and PC respectively. These yield differences could be explained by the fact that soil nutrient levels near the tree are higher than in areas far from the canopy (C and PC). In addition, improved soil fertility made by trees would explain the higher yields in the parkland compared to pure cultivation. This improvement in fertility is achieved by various mechanisms: trees return to the soil a large quantity of nutrients that are often taken deep by deep rooting or fixed by photosynthetic means such as carbon (Young, 1986); or by the symbiotic fixation of nitrogen and phosphorus, by the decomposition of tree residues but also by atmospheric dust trapped by the tree (El Tahir *et al.,* 2009). In addition, the dry and wet deposits of organic matter on the foliage of the tree, the reduction of erosion through soil fixation under the tree, the absorption and recycling of nutrients, contribute to the improvement of soil fertility in the horizons near the tree (Fadl, 2013, Zomboudré *et al*., 2005). Animals often come to apprehend fallen leaves and pods or to rest under *A. senegal* tree and the concentration of their faeces also helps to improve soil fertility. This results in higher grain and ear yields in the areas of interaction with the tree. However, the UC interaction zone, although under the crown, showed low yields that are close to those of the PC system. The decrease in yield in the area near the trunk of the tree is strongly correlated with a steady decrease in light intensity which leads to poor development and a decrease in photosynthetic activity of the underlying crops (Sanou *et al.,* 2012; Fadl & Gebuaer 2005; Bayala *et al*., 2002; Kesler, 1992; Maïga, 1987). Fadl (2010) recorded a yield reduction of peanut, sesame and roselle in *A. senegal* agroforestry system and attributed this reduction to the underground competition between *A. senegal* trees and field crops for water and soil nutrients. Globally, in this study, yields observed in the parkland are significantly higher than in the pure-crop system and we highlighted the soil richness of the parkland in mineral elements (C and N) compared to the pure cultivated soil. Indeed, if no organic manure or mineral fertilizers are applied in fields with pure crops, their fertility continuously degrades, while in the parkland, falling leaves produce a litter that restores organic matter after each growing season. In addition, *A. senegal* is a legume which, through symbiosis with rhizobia and mycorrhizal fungi at the root level, can stimulate the development of a wide variety of microbial colonies source of nitrogen, and phosphorus in the soil (Manssour *et al.,* 2013).

Yields in ears and grains were greater in the first season than in the second one, while the opposite is observed for the biomass. This could be explained by a better temporal distribution of rains in the first year of experimentation while in the second-year, rainfall was abundant at the beginning of the season, but an early cessation of rainfall was observed at the heading stage. As a result, the crop gave many ears of corn, but very light ears because they contain little or no grain. So the difference in the temporal distribution of the rains caused a difference in biomass production over two years. However, yields obtained in the second year despite the drop-in rainfall are satisfactory in the agroforestry system. In addition, this intercropping system would increase the number of productions made on the same field and the production gain is reflected in a short-, medium- and long-term gain, if considering the increase in yields, the improvement of the ecological environment and the durability conferred by woody vegetation. So, *A. senegal*-millet intercropping system could help improve the resilience of vulnerable populations in Niger to meet the growing challenges of climate change through technology that increases production and diversifies agriculture.

In conclusion this work shows a clear increase in yield in the Agroforestry Parkland with *A. senegal* compared to pure millet cultivation. The low production in the UC zone of the parkland, most probably due to the shading effect, shows that millet is a heliophilous plant and is not suitable for cultivation in association with *A. senegal* in the area near the trunk. But the presence of satisfactory levels of mineral elements in areas close to the tree canopy, combined with the lack of influence of shade in this specific area, led to an average yield much higher than that of the pure crop system. So, the presence of *A. senegal* in the fields creates an agro-ecological environment suitable to millet production. The diversity of products of both species would provide farmers with diversified sources of income throughout the year, for example, the gum tree presents economic opportunities such as fodder and Arabic gum. This system can be adopted easily by farmers to cope with climate change.

Further experimentation is needed to precise tree to tree spacing of *A. Senegal* and tree to plant spacing between *A. Senegal* and a plot of millet plant population, and plant to plant spacing of millet plants in a plot, to harness maximum benefit from the interactions with increased grain yield and minimizing the negative effect on the millet crop.

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