Agronomic evaluation of the effects of two green manure cover crops on maize (*Zea mays*) cultivation in four-agroecological zones of Benin

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Abstract
In Benin, approximately 90% of soils have poor fertility which hampers food production and nutrition security. We assessed the agronomic potential of two green manure cover crops (GMCCs) – *Cajanus cajan* and *Mucuna pruriens* – to increase soil fertility and yields of subsequent maize (*Zea mays)* crops in Northern (Kandi and Bembereke) and Central (Bante and Zagnanado) Benin. Participatory on-farm experiments were conducted with 51 farmers on plots planted with maize over 3.5 months and rotated with and without GMCCs at different levels of fertilization (urea, NPK). We observed improvements in soil pH (by 0.03), nitrogen (by 0.01%), organic matter (by 0.2%) and water infiltration (29-66% in north and 33-51% in Center) with GMCC integration. Maize yields increased by 126% with GMCCs and full fertilization, and yields were still 51% higher with GMCCs and half of the recommended mineral fertilization rate. Results suggest opportunities for farmers to reduce expenditure for fertilizers. Despite the potential of GMCCs to improve soil fertility and food security, seeds are still not readily available to smallholder farmers in Benin.
Keywords. *Cajanus cajan*, *Mucuna pruriens*, soil fertility, sustainable agriculture, West Africa.

Introduction
In sub-Saharan Africa, soils are characterized by low nutrient content (Saidou et al. 2018), resulting in low crop productivity, food insecurity and malnutrition. To improve soil productivity, mineral fertilizers are used by farmers (Diogo et al. 2017). However, their poor application rates and mismanagement (Diogo et al. 2018) have led to increased nutrient extraction rates and contributed to poor soil fertility.
In Benin, soil degradation and impoverishment are problems that affects all agro-ecological zones, where 90% of the soils have very low to low fertility (Igué et al. 2017). To improve soil health and ensure the sustainability of the production systems, various innovations that promote the natural functioning of biological processes are investigated. The use of green manure cover crops (GMCCs) constitutes a promising avenue to restore soil health and boost crop yields (Mukiri et al. 2019). In this study we tested the effects of two GMCCs: *Mucuna pruriens* and *Cajanus cajan*. Although several studies have been carried out on GMCC in Benin, none of them have revealed their simultaneous effects on soil parameters and crop yields. Here, we compare the use of GMCC on both soil health and maize yield from four agro-ecological zones that provide more than 80% of the national maize production. The study aimed at assessing how GMMCs can contribute to soil productivity and reduce dependency on mineral fertilization.

Materials and Methods
Experimental site and design

The trials were carried out between 2017 to 2018 in four districts each representing one agro-ecological zone (AEZ) of the eight AEZs across the country (Figure 1).
In 2017, the GMCCs (leguminous crops) were planted at spacing of 60 x 30 cm for *Mucuna* (55,555 plants/ha) and 100 x 100 cm for *Cajanus* (1,000,000 plants/ha) one year prior to maize trials on each farmer's plots (4 m x 4 m replicated plots similarly managed in each farm) and their biomass was harvested in a quadrat scale at the end of the growing season (about six months of rain-fed). No fertilization was applied to GMCCs. To standardize input application and regardless of how much biomass the GMCC produced per plot, 5 t dry matter/ha of aboveground biomass was chopped to fine materials of less than 5 cm pieces (leaves plus twigs and branches) using hammer technique and incorporated into the soil until the following cropping season (six months fallow period). At the beginning of the growing season, maize plots (flat plowing) were prepared on previous plots that received GMCCs. Sowing was made on plots of 10 × 10 m size with spacing of 80 cm between two rows and 40 cm on the rows corresponding to a seeding density of 62,500 plants/ha with two plants per pocket. The experiment was conducted using a randomized complete block design (RCBD) with four replicates per treatment at each farmer's field (two plots with GMCC and two without GMCC). A description of the treatments is given in Table 1.

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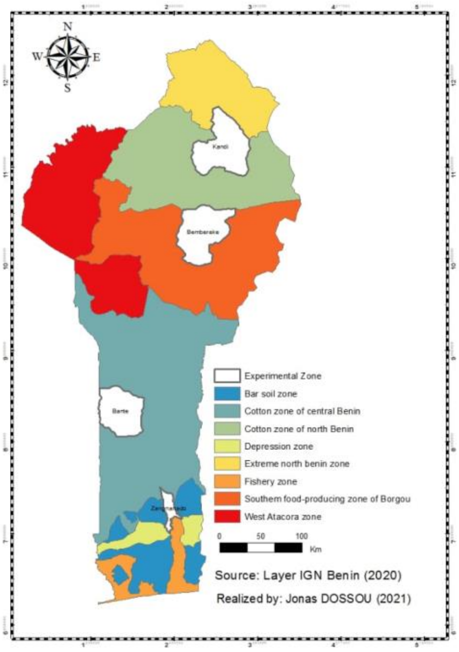

***Cotton zone of north Benin,* Kandi**
<u>Climate</u>: dry tropical with unimodal rainfall of 900-1000 mm.
<u>Soils</u>: washed ferruginous tropical soils
<u>Vegetation</u>: savannah and dry woodlands
Southern food-producing zone of Borgou, Bembèrèkè
<u>Climate</u>: dry tropical with unimodal rainfall pattern of 1100 mm.
<u>Soils</u>: ferruginous tropical
<u>Vegetation</u>: wooded savannah
Cotton zone of central Benin, Bantè
<u>Climate</u>: tropical sub-humid with bimodal rainfall pattern of 1100 mm. Transition zone between the south and the north of Benin. <u>Soils</u>: leached ferruginous tropical soils
<u>Vegetation</u>: woodlands and savannah
Bare soil area, Zagnanado
<u>Climate</u>: tropical sub-humid with bimodal rainfall pattern of 1100 to 1200 mm. <u>Soils</u>: ferrallitic
<u>Vegetation</u>: dense shrubby thickets

Sampling of producers per district: 51 maize producers across the four AEZ. 13 in each of Kandi, Bembèrèkè, and Bantè, and 12 in Zagnanado).

Figure 1. Location, description of the study sites and sampling in Benin.

Table 1. Description of the treatments used in the trial

Treatments	With GMCC	Without GMCC
T0	5 t DM biomass / ha	Absolute control (no fertilizer, no GMCC*)*
T1	Half rate of fertilizer recommendation : (75 kg NPKSBZn + 25 kg of 46% Urea) /ha + 5 t DM GMCC biomass / ha	Full rate of fertilizer recommendation (150 kg of NPKSBZn+ 50 kg of 46% Urea) / ha

DM= dry matter ; the NPKSBZn form applied was 13/17/17/0.5/6/1.5; GMCC= green manure cover crops.

Data collection and statistical analysis
Soil sampling and handling: soil samples were collected along the diagonals of each plot at 0-20cm depth and pooled as one composite before sowing (to assess baseline soil properties) and after harvest of maize to evaluate GMCC effect. Chemical analysis of pH, total nitrogen, total organic C and organic matter were performed using standard methods at the laboratory of soil science of the International Centre for Tropical Agriculture (CIAT, Nairobi). The C/N ration was then calculated.
Water infiltration and soil compaction: A minidisc infiltrometer was used to determine the hydraulic conductivity following Zhang (1997) coupled with Van Genuchten's mathematical model. Soil compaction measurements were done using a penetrometer. Both measurements were conducted at the end of the trial.
Maize yield: Data were recorded on corn ear weight. The grain yield was estimated following Akanvou et al. (2009). Yield = 0.75 P (100 - h) / (100 - 12) where, P is the weight of the ears, 0.75 is the coefficient representing the ratio of kernel weight to ear weight and h is the estimated moisture content of the kernels after harvesting.

Microsoft Excel software was used for data entry and processing. The yield data were analyzed with the R programming software version 3.5.1 (R Core development Team 2018) after checking the distribution of residuals. The Mixed Effect Linear Model with three fixed factors (AEZ, cropping system and treatment) was used for the analysis. Means separation was done at 5% using Student-Newman-Keuls tests with the agricolae package (de Mendiburu 2007).

Results and discussion

Effect of GMCCs on soil chemical properties
In general the soils are slightly acidic (before GMCCs application except in Bantè where the pH determined was neutral, Table 2). The nitrogen values determined are low and significantly different between Bantè and the other municipalities, which is one of the characteristics of ferruginous and ferrallitic tropical soils (Sanchez

and Jama 2002). These soils are known to be poor in nitrogen and phosphorus and the strategy to overcome this worrying situation is necessarily a rational management of agricultural land (Igué et al. 2017). The rate of organic matter is medium in Bantè and low in the other districts (without GMCCs application). This was slightly increased in all sites after GMCCs application (Table 2) The organic matter content obtained in Bantè corroborates the soil fertility status observed in Central Benin by Igué et al. (2018). The same authors concluded that the loss of soil fertility is generalized to all cultivated land in Benin and is due to poor land management as a result of inappropriate techniques used by the farmers. These include continuous cultivation without nutrient replenishment, poor use of organic amendment, poor rotation and short fallow periods, inappropriate timing of fertilizer or high rates of mineral fertilizer application.

Table 2. Chemical composition of soils at the end of GMCCs trial and start of maize trial

District Name	pH		% total Nitrogen		% total Carbon		% total Organic matter		C/N	
	Without GMCC	With GMCC	Without GMCC	With GMCC	Without GMCC	With GMCC	Without GMCC	With GMCC	Without GMCC	With GMCC
Bantè	7.37a	7.06ab	0.190a	0.20a	2.177a	2.316a	3.75	3.99	11.46	11.58
Bembéréké	6.37cd	6.41cd	0.050b	0.0632b	0.573b	0.582b	0.99	1.00	9.21	11.46
Kandi	6.69bc	6.26d	0.041b	0.050b	0.448b	0.640b	0.77	1.1	10.93	12.80
Zagnanado	6.48cd	7.07ab	0.020b	0.039b	0.247b	0.535b	0.43	0.92	12.35	13.72
P value	0.000		0.000		0.000		ns		ns	

Different letters within the same column indicate significant difference. Where no letters appear, the respective differences are insignificant with SNK 5%. ns = non significant.

Water infiltration and effects of GMCCs and mineral fertilization on maize yield

Without GMCC, soil hydraulic conductivity was low, indicating low water infiltration into the soil (Table 3). The K values recorded at Kandi and Bantè were significantly higher on GMCC plots than without GMCC.

Table 3. Hydraulic conductivity (K, in cm/s) on plots with and without GMCC in four agroecological zones of Benin

District Name	Hydraulic conductivity (K, cm/S)	
	Without GMCC	With GMCC
Bantè	0.0015 ± 0.0006b	0.003 ± 0.0005a
Bembèrèkè	0.0016 ± 0.0005a	0.0022 ± 0.0004a
Kandi	0.0014 ± 0.0002b	0.0038 ± 0.0006a
Zagnanado	0.0025 ± 0.006a	0.0038 ± 0.0006a

Different letters in rows indicate significant difference. Where no letters appear, the respective differences are insignificant with SNK 5%.

In general, hydraulic conductivity increased by 33-51% on the GMCC treated plots in the center (Table 3) compared to 29-66% on the same plots in the north compared to plots without GMCC (Table 3). The permeability of a soil depends on its texture and structure (homogeneous, cracks, etc.). The more permeable a medium is (high K), the more water infiltrates to it.

Concerning the effects of GMCCs and mineral fertilization on maize yield, significant differences were found between the different factors tested and their combinations (GMCC and mineral fertilization use (p = 0.000). The site has significant effect on the crop yield, reflecting the differences in soil fertility between the four agro-ecological zones under study. In general, maize yield increased with GMCC biomass application (Table 4). Interestingly, the yields obtained with GMCC and half rate of mineral fertilization were more than double the yields determined for sole GMCC application, but also outreach the results obtained for full fertilizer application rate.

Table 4. Maize yields (kg/ha) as affected by treatment in four agroecological zones of Benin

	T_0		T_1	
District Name	Without GMCC	With GMCC	Without GMCC	With GMCC
Bantè	699 ± 177 bA	1312 ± 181 aB	1342± 171 bB	2401 ± 209 aB
Bembèrèkè	510 ± 184 aA	881 ± 191 aBC	1667 ± 191 bB	2081 ± 184 aC
Kandi	739 ± 189 bA	2343 ± 176 aA	2238 ± 186 bA	3070 ± 174 aA
Zagnanado	406 ± 209 aB	767 ± 205 aC	1511 ± 207 bBC	2606 ± 161 aB
		(P=0.000)		

Notes : T0 without GMCC= Negative control (No fertilizer, no GMCC) ; T0 with GMCC =only GMCC biomass applied ; T1 without GMCC= Mineral fertilizer recommendation only: (150 kg NPK+50 kg Urea)/ha ; T1 with GMCC= Half rate mineral fertilization : (75 kg NPK+25 kg Urea)/ha + GMCC biomass. In rows, small letters compare cropping systems (with/without GMCC) within treatment (T0 or T1), while capital letters in columns compare agroecological zones within cropping system and treatment at 5% student-Newman-Keuls Tests.

The high yields obtained in Kandi corroborate those of Ziadi et al. (2006) who showed that nitrogen limitation is the main constraint to cereal production in sub-Saharan Africa. According to Brassard (2007), nitrogen is a major nutrient for crops; however, it is only fully utilized if sufficient amounts of P and K are available. The yield determined under GMCC treatment was 3-fold higher that the un-amended control plots and more than 4-fold higher than the same treatment when combined with half rate mineral fertilization in Kandi. These could be explained by the high rainfall of 1166 mm during the trial which favours GMCC mineralization and N, P and K availability under this drier climate. Hence, the need for green manure application is advised. These results indicate that there is huge potential for increasing maize production and food security while reducing expenses on mineral fertilizers. GMCC can be promoted in combination with microdose of mineral fertilizers. However, efforts should be made by research to provide seed banks to farmers and the central government should also facilitate this.

Conclusion

Our results indicate that there is great potential for increasing farmers revenue while saving on fertilizer purchase. Maize yield can triple with GMCC application only and even more if half rate recommended fertilizer is applied under good rainfall to favor GMCC mineralization. From the estimated yield gaps, it appears that the adoption of GMCC will increase farmers' profits and consequently ensure food nutrition security, environmental safety thereby reducing poverty. However, there is still a need to improve GMCC's seed value chain development and their availability to farmers.

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