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Increasing Agricultural Productivity with Dual-Use Crops: An Agriculture-Livestock-Environment Integration Strategy in Niger

Ibrahim Kasso A. Rahamane[1,*], Massaoudou Moussa[2], Zounon Christian Serge Félix[2], Baragé Moussa[3], Mahamane Larwanou[1]

[1]Department of Rural Engineering and Water and Forestry, Faculty of Agronomy, Abdou Moumouni University of Niamey, Niamey, Niger
[2]Department of Natural Resource Management (DGRN), National Institute of Agronomic Research of Niger (INRAN), Maradi, Niger
[3]Department of Plant Production, Faculty of Agronomy Abdou Moumouni University of Niamey, Niamey, Niger

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Abstract Agriculture and livestock are the main sources of food for both humans and animals. However, soil poverty, high fertilizer costs, land degradation and deforestation are major challenges in the fragile ecosystems of semi-arid areas. A study on the integration of agriculture and livestock was conducted in the Maradi region of Niger. The objective of this study is to develop integrated farming models that will improve crop productivity, livestock production and soil fertility at the lowest cost. The experimental set up is a factorial 2 x 7 x 3 in 4 Fisher blocks according to a split-split plot arrangement of 112.5m x 76m or 8 550m2. Measurements were made on stem/fan biomass and grain yield. The results of this study show that the development of crops associated with cereals and legumes (cowpeas and/or groundnuts) in alternating strips or in rotation have increased the yield of stem biomass and grain and the level of soil fertility. The effect of alternating strip cropping induced an increase in grain yield in 2020 compared to 2019. Microdose organo-mineral fertilization had positively modified ($P<0.000$) the yields of millet and legumes (groundnut and cowpea).

Keywords Cereal, Legume, Strip cropping, Yield, CERRA-Maradi, Niger

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1. Introduction

In Sahelian countries such as Niger, 80-90% of rural populations derive their livelihoods from rain-fed agriculture and livestock. The Sahelian producer is both a farmer and a herder or agropastoralist. Livestock production plays a crucial role in income generation, providing access to diversified diets and meeting the costs of education, health and other basic household needs. These products (meat, milk, hides, etc.) now constitute a value chain that enables the survival of many households. Many technologies have been developed for agriculture and livestock. These include technologies for improving varieties (selection and varietal multiplication work), managing crop pests (work of entomological researchers), managing soil fertility and adding value to dairy products. However, agriculture and livestock production face enormous challenges and the socio-economic situation of producers remains precarious. It is characterized by a low income and a high rate of illiteracy. These factors make it difficult for producers to adopt new technologies. Niger is one of the countries south of the Sahara that have a low rate of mineral fertilizer use, with an average of less than 4kg/ha (Pandey et al., 2001; Autfray et al., 2012; Bationo et al., 2012). The development of agriculture-livestock integration systems is a way to reduce the vulnerability of producers and to respond to the main development constraints of agriculture and livestock. This theme must be a concern for all given the context of climate change that the developing world is experiencing. The integration of agriculture and livestock has been proposed since the 1990s to intensify production systems through the virtuous tripods of animal traction, organic manure and fodder production (Dugué 1989; Landais and Lhoste, 1990). The coexistence of livestock and agriculture is becoming the rule, and the problems related to their relations are clearly problems of the future (Caudron, 1989). Vermersch, (2007); Bell and Moore, (2012) report that the combination of crops and livestock is indeed recognized to secure the farm from the fluctuations of agricultural markets. Integrated farming provides resilience for producers in the face of fluctuating commodity or livestock prices. It is also an agronomic model proposed by agronomists to intensify the agricultural and livestock system. It proposes to use the by-products provided by one system as inputs for the other system. It is based on the use of traction, the production of organic manure and the

* Corresponding author:
ibrahimkassoa@gmail.com (Ibrahim Kasso A. Rahamane)
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production of fodder (Landais and Lhoste, 1990). The potential advantages of a close linkage between agriculture and livestock production have long been recognized by technicians, who have made it possible to enhance complementarities and limit competition between these two activities (Londais and Lhoste, 1990). However, there are very few technologies or systems for the integration of agriculture and livestock that have been developed in this area. The main objective of this study is to develop integrated farming models that will improve crop productivity, livestock production and soil fertility at the lowest cost.

2. Materials and Methods

2.1. Trial Site

The study was conducted at the Regional Agricultural Research Center of Maradi Niger (CERRA / Maradi) station located southwest of the urban community of Maradi (capital of the region) at an altitude of 380 m between 13° 30' north latitude and 7°06'06" east longitude. The soil is sandy with a low level of fertility. The climate of the area is Sahelo-Sudanese, characterized by a long dry season from October to May and a rainy season from June to September. The annual wind regime is characterized by alternating monsoon and harmattan winds. The first one, coming from the southwest, brings humid air masses. The second is a hot and dry wind, blowing from the North-East to the South-West during the dry season. Sandstorms are also observed at the beginning of the rainy season. Rainfall varies between 350 and 650 mm per year. The average annual rainfall over the past 30 years in the area is between 378 and 535 mm. During the two years of experimentation 2019 to 2020, the annual rainfall is 520 and 668 mm respectively.

2.2. Plant Material

The plant material is composed of six plant species, three of which are improved and three local (Table 1). The table shows the species used in the experiment.

Table 1. List of millet, groundnut and cowpea varieties used in the experiment

Variety	Millet	Peanut	Cowpea
Dual purpose variety	Siaka	JL-24	TN5-78
Local variety	HKP	55-437	TN/2780

2.3. Device and Experimental Treatments

The first experimental design is a 2 x 7 x 3 factorial in 4 Fisher blocks in a split-split plot arrangement with an area of 112.5m x 76m = 8,550m2. The 3 factors of the design include: 2 cereal varieties, including a local variety and a dual-purpose variety in the main plot, 7 cropping systems, including 4 cereal/legume association systems and 3 pure cropping systems in subplots, and 3 fertilization techniques: (Manure, manure + NPK fertilizer and a Control without fertilizer) for the cereal and (NPK, SSP and a Control) for the legume in the sub-subplot. Manure was applied to the cereal only by the micro-dosing technology at a rate of 200g (two handfuls) per packet. NPK (15-15-15) was applied at micro-doses in the plot during the weeding process and lightly plowed in at a rate of 6g for millet, 4g for cowpea, and broadcast for peanuts after the first weeding at a rate of 90g per sub-plot in the association system and 400g per sub-plot in the pure system Super Simple Phosphate (SSP) was used at 8g/pack for cowpea, 180g per subplot in the combination system and 800g per subplot in the pure system for groundnut. Cereals and cowpeas were sown at 0.75mx0.50m (26,600 bunches per hectare) and disked at 2 plants per bunch (53,200 plants per ha). Groundnuts were sown at 0.25m x 0.20m (200,000 bunches per hectare), i.e. 200,000 plants per ha.)

First main plot (CL: Local cereal in pure culture, AL: Local groundnut in pure culture, NL: Local cowpea in pure culture, CL-AL: Local cereal /Local groundnut, CL-AA: Local cereal /Local groundnut, CL-NL: Local cereal /Local cowpea, CL-NA: Local cereal /Local cowpea in dual use) and second main plot (CA: Pure-crop dual-use cereal, AA: Pure-crop dual-use peanut, NA: Pure-crop dual-use cowpea, CA-AL: Dual-use cereal/Local peanut, CA-AA: Dual-use cereal/Dual-use peanut, CA-NL: Dual-use cereal/Local cowpea, CA-NA: Dual-use cereal/Dual-use cowpea.

2.4. Measurements and Observations

Observations and measurements (growth and yields) were made on all plots. To better ensure follow-up from sowing to harvest, yield squares (1m x 1m) were selected and labeled with different colored stacks. Each color corresponds to a pile. In each plot, 6 yield squares were randomly selected with 6 stacks per yield square for millet and cowpea and 30 stacks per square for groundnut (336 yield squares or 2016 stacks monitored). Growth measurements were made on the height and number of tillers and/or stems respectively by measuring with a 4 m long graduated ruler and by counting the tillers and/or stems each week.

For the yield, the grains were separated from the tops and dried for 30 days in the sun. For the tops, the total biomass of all the bunches in the yield square was weighed, then a sample of the tops was taken, weighed fresh and placed in an oven for 72 hours at 100°C and weighed for dry weight. The dry weight was used to determine the total dry biomass per yield square according to the formula:

$$BST = BFT \text{ x Conversion rate}$$

With:

$$\text{Rate} = \frac{\textit{Dry biomass of the sample}}{\textit{Fresh biomass of the sample}}$$

And BST = total dry biomass and BFT=total fresh biomass.

2.5. Soil Sampling Methods

Soil samples were augered in 2019 and 2020 from each plot to a depth of 0-20 cm at all four corners and the center of the plot. A total of 30 composite samples were formed by mixing the collected samples. A quantity of 500g was taken per composite sample and then packed to determine the physicochemical characteristics of the soils. The analyses were carried out in the laboratories of Umar Mussa Yar'Adua University, Katsina and Ahmed Bello University, Zaria, Nigeria. The parameters to be determined were particle size (Clay, Silt, Fine Sand and Coarse Sand), pH, organic carbon, organic matter, total nitrogen, available phosphorus, exchangeable bases (Calcium, Magnesium, Potassium and Sodium), sum of exchangeable bases and Carbon to Nitrogen ratio (C/N).

2.6. Physicochemical Characteristics of Soils

Particle size was determined using the Robinson pipette method which separated and measured the following particle size fractions: clays (Exchangeable bases (Ca, Mg, K and Na) were obtained using Thermo Fisher Scientific Energy Dispersive X-ray Fluorescence (EDXRF) according to the International Atomic Energy Institute (IAEA) reference standard. The analysis was performed using the standard method which is 80% accuracy compared to the standard method less than 50% accuracy. The soil sample with a weight of 2g was ground into a fine powder using a mortar and pellet gun and then poured into a sample holder and covered with cotton to prevent pulverization. The bottom of the sample holder is made of polypropylene which is a thermoplastic. The sample holders containing the sample were run under vacuum or air for 10 minutes and inserted into the XRF spectrometer for elemental analysis. The method was calibrated using a geological or biological calibration. The analysis was performed in elemental form. The samples were allowed to run in the EDXRF spectrometer for 10 minutes each, after which the results were obtained.

pH-water was measured with a pH meter in a ratio of 1/2.5 by direct reading using an electronic electrode in a distilled water diluted soil suspension (Mathieu and Pieltain, 2003).

Organic carbon was determined by the method of Walkley and Black (1934) and organic matter content was determined by the following formula: OM (%) = [(Pi-Pf)/Pi]X 100 and C (%) = OM (%) /1.724 with: Pi= the initial weight of the test sample, Pf: the final test weight after calcination.

Total N was determined first by mineralizing soil samples with H2SO4-Se-H2O2 mixture at 450℃ for 4 h (Bremner, 1965). Then, the N content in the mineralization was determined using an automatic colorimeter (Skalar SANplus Segmented flow analyzer, Model 4000-02, Breda, Holland).

Assimilable phosphorus was determined by the Bray1 method (Bray and Kurtz, 1945); the soil was attacked with Bray1 solution (xNH4F + y HCl) at pH 1.5; the filtrate was mixed with boric acid, ascorbic acid, and sulfomolybdic solution; this mixture placed in a water bath at 85℃ for 10 minutes stained blue; it was read with a colorimeter at 665nm.

The results of the soil characterization showed that the experimental site soils are sandy-clay textured. These soils are strongly acidic with pH ranging from 4.1 to 5.1 in 2019 and 4.8 to 5.3 in 2020. The physicochemical parameters are significantly different between the different experimental plots from 2019 to 2020 except for pH in 2020. The overall levels of these elements are mostly low across the site (Table 2 and 3). A regression and an increase of some elements (C.org, P-Braye1, N-Total) were observed from 2019 to 2022 in some plots respectively of the cereal plots and of the league plots (in pure culture and in strip).

Table 2. Physical characteristics of soils in the experimental site

Treatments	Clay (%)	Silt (%)	Fine sand (%)	Coarse sand (%)
			2019	
AA	2,4abcde	4,5cde	36,9a	56,2b
AL	1,9def	4,9abcd	35,6ab	57,6ab
CA	2,8a	4,2^{e}	33,3ab	59,7ab
CA-AA	2,5abcd	4,7abcde	34ab	58,8ab
CA-AL	2,7ab	4,9abcd	31,3b	61,1a
CA-NA	2,1bcdef	5,3a	34,2ab	58,4ab
CA-NL	2,6abc	4,3de	31,9ab	61,2a
CL	2,6abc	4,5cde	31,6ab	61,3a
CL-AA	1,7f	5,2ab	35,8ab	57,3ab
CL-AL	2,1bcdef	4,9abcd	32,9ab	60,1ab
CL-NA	2cdef	5,1abc	32,2ab	60,7ab
CL-NL	1,8ef	4,7abcde	36,2ab	57,1ab
NA	2,2abcdef	4,6bcde	33,4ab	59,8ab
NL	2,3abcdef	4,7abcde	33,1ab	59,4ab
Probability	0,000	0,000	0,015	0,010
Treatments			2020	
AA	2,8ab	4,1cde	37,9abc	55,2bc
AA-B	2,6abc	3,6ef	34,3bcde	59,5ab
AL	2,6abc	4,4bcd	38,5ab	54,5bc
AL-B	2,9a	3,9def	33,3cde	59,9ab
CA	2,8ab	4,2bcde	34,1bcde	58,9ab
CA-B	2,7abc	3,3f	41,7a	52,3c
CL	2,4abcd	5,1a	35,8bcd	56,7bc
CL-B	2,2abc	4,7abc	30,3^{e}	62,8a
NA	1,9d	5,1a	29,9^{e}	63,1a
NA-B	2,7abc	4,5abcd	32,7de	60,1ab
NL	2,1cd	4,8ab	38ab	55,1bc
NL-B	2,7abc	4,3bcd	30,3^{e}	62,7a
Probability	0,001	0,000	0,000	0,000

CL: Local cereal in pure culture, AL: Local groundnut in pure culture, NL: Local cowpea in pure culture, CL-AL: Local cereal /Local groundnut, CL-AA: Local cereal /Local groundnut, CL-NL: Local cereal /Local cowpea, CL-NA: Local cereal /Local cowpea in dual use, CA: Pure-crop dual-use cereal, AA: Pure-crop dual-use peanut, NA: Pure-crop dual-use cowpea, CA-AL: Dual-use cereal/Local peanut, CA-AA: Dual-use cereal/Dual-use peanut, CA-NL: Dual-use cereal/Local cowpea, CA-NA: Dual-use cereal/Dual-use cowpea, AA-B: Dual-use Peanut Band, AL-B: Local Peanut Strip, CA-B: Dual-use Cereal Band, CL-B: Local Cereal Band, NA-B: Dual-use Cowpea Band, NL-B: Local Cowpea Band.

Table 3. Chemical characteristics of the 0-20cm soil horizon in the experimental sites from 2019 to 2020

Treatments	pH water	C.org (g/kg-1)	P-Bray1 (g/kg-1)	Total-N (g/kg-1)	M.O	C/N	Ca (ppm)	K (ppm)	Mg (ppm)	Na (ppm)	S (Ca, K, Mg, Na)
						2019					
AA	5,1ab	0,098cd	2,1g	0,858ab	0,114jk	0,169cd	0,69a	2,876a	1,51abc	0,237a	5,629a
AL	4,8abc	0,254abc	2,7efg	0,792ab	0,321h	0,437abc	0,075ef	0,756a	0,76f	0,237d	1,828h
CA	5,1ab	0,33a	3,7bcde	0,768bc	0,43g	0,568a	0,062f	0,635a	1,39abcd	0,272d	2,359fg
CA-AA	5,1ab	0,079d	6,3a	0,57cde	0,139ij	0,136d	0,064a	3,075a	1,19bcde	0,242d	4,571b
CA-AL	5,2a	0,276ab	4,5b	0,195gh	1,415d	0,475d	0,543b	2,543a	1,543ab	0,262ab	4,891b
CA-NA	5,1ab	0,319a	2,41fg	0,196gh	1,628c	0,549d	0,43g	0,041a	1,77a	0,254ab	2,108gh
CA-NL	4,2bc	0,383a	3,9bcd	0,198gh	1,934b	0,659a	0,117c	1,117a	1,54ab	0,275cd	3,049c
CL	5,1ab	0,027d	3,2cdef	0,035h	0,771e	0,046d	0,52def	0,82a	0,98ef	0,271ab	2,891cd
CL-AA	4,9abc	0,143bcd	2,5fg	0,706bcd	0,203i	0,246bcd	0,597cde	0,975a	0,95ef	0,238ab	2,76cde
CL-AL	5,2a	0,366a	2,3b	0,268fg	1,366d	0,63a	0,043cd	1,043a	1,11def	0,25d	2,446b
CL-NA	4,9abc	0,279ab	3,3cdef	0,035h	7,971a	0,48ab	0,35g	0,035a	0,94ef	0,221bc	1,231i
CL-NL	4,6abc	0,054d	3,1defg	0,985a	0,055k	0,093d	0,119c	1,108a	1,13cdef	0,245cd	2,702def
NA	5,1ab	0,076d	5,6a	0,426ef	0,178ij	0,131d	0,057f	0,655a	1,17bcde	0,222d	2,104gh
NL	4,1c	0,274ab	4,2bc	0,52de	0,527f	0,471ab	0,508def	1,008a	1,04def	0,233ab	2,689def
Probability	0,004	0,000	0,000	0,000	0,000	0,000	0,000	0,985	0,000	0,000	0,000
Treatments						**2020**					
AA	5,3a	0,012i	5,1a	0,389g	0,021i	0,031i	0,108b	2,08b	0,108e	0,16c	2,456de
AA-B	5,3a	0,62a	5,1a	0,244h	1,067a	2,541a	0,043d	0,02b	0,56de	0,283c	0,906h
AL	5,3a	0,226f	4,2bcd	0,566e	0,389f	0,399e	0,037c	0,69b	1,33bc	0,347c	2,404de
AL-B	4,9a	0,35d	4,4abc	0,761c	0,602d	0,46d	0,053a	2,42b	1,87a	0,365c	4,698a
CA	5,3a	0,098gh	3,2ef	0,494f	0,169gh	0,198g	0,5c	0,52ab	1,25c	0,412ab	2,682c
CA-B	5,2a	0,564b	4,1bcd	0,341g	0,970b	1,654b	0,26b	2,076a	0,93cd	0,654abc	3,92b
CL	5,2a	0,286e	2,8f	0,553e	0,492e	0,517c	0,204c	0,547ab	1,4abc	0,38bc	2,582de
CL-B	4,9a	0,224f	3,7cde	0,75c	0,385f	0,299f	0,51c	0,51b	1,32bc	0,31ab	2,65d
NA	4,9a	0,36d	3,6de	0,845b	0,619d	0,426de	0,56c	0,408b	1,77ab	0,288a	3,026c
NA-B	4,8a	0,416c	4,6ab	0,992a	0,716c	0,419de	0,053d	0,052b	1,01cd	0,33cc	1,445g
NL	5,1a	0,077h	4,3bcd	0,676d	0,133h	0,114h	0,48c	0,46b	0,63d	0,341ab	1,9605f
NL-B	5,1a	0,13c	4,5ab	0,972a	0,224g	0,134h	0,05c	0,525b	1,37bc	0,297cc	2,242ef
Probability	0,106	0,000	0,000	0,000	0,000	0,000	0,000	0,004	0,000	0,000	0,000

C.org: Organic Carbon, P-Bray1: Phosphorus Bray1, Total-N: Total Nitrogen, M.O: Organic Matter, Ca: Calcium,: Potassium, Mg: Magnesium, Na: Sodium, S(Ca,K,Mg,Na): Sum of exchangeable bases, CL: Local cereal in pure culture, AL: Local groundnut in pure culture, NL: Local cowpea in pure culture, CL-AL: Local cereal /Local groundnut, CL-AA: Local cereal /Local groundnut, CL-NL: Local cereal /Local cowpea, CL-NA: Local cereal /Local cowpea in dual use, CA: Pure-crop dual-use cereal, AA: Pure-crop dual-use peanut, NA: Pure-crop dual-use cowpea, CA-AL: Dual-use cereal/Local peanut, CA-AA: Dual-use cereal/Dual-use peanut, CA-NL: Dual-use cereal/Local cowpea, CA-NA: Dual-use cereal/Dual-use cowpea, AA-B: Dual-use Peanut Band, AL-B: Local Peanut Strip, CA-B: Dual-use Cereal Band, CL-B: Local Cereal Band, NA-B: Dual-use Cowpea Band, NL-B: Local Cowpea Band.

3. Analysis of the Data

The data collected was entered with Excel 2013. The latter was also used to analyze certain data and to develop graphs. Then, the yield components were analyzed with MiniTAB 16 software by an analysis of variance (ANOVA) associated with General Linear Model (GLM) to compare the means of the different treatments at the 5% threshold.

4. Results

4.1. Effect of Cropping System and Treatments on Average Millet Stalk Yield

The effect of cropping system and fertilizer application on average millet stalk yield for the entire system are presented in Table 4. The factors years, cropping system and fertilizer all had a highly significant impact on average millet stem yield from 2019 to 2020 with probabilities of P=0.000, P=0.027 and P=0.000 respectively. The results show that 2020 stem yields are higher than 2019 stem yields. Also, manure + NPK tends to give the best stem yield in both years of experimentation. Indeed, in 2019 the maximum stem yield is recorded with the variety Siaka (4141±907Kg/ha) while in 2020 it is 8738±224 kg/ha for the same variety. Manure + NPK tends to favor the development in stems than the contribution of Manure alone. The highest overall stalk yield from 2019 to 2020 is obtained with improved millet in pure cultivation (6439±2923kg/ha) with Manure + NPK input.

Table 4. Effect of cropping system and treatments on average millet stem yield

		Average dry weight of stems (kg/ha)									
Treatments	Years	CA	CL	CA-AA	CL-AA	CA-AL	CL-AL	CA-NA	CL-NA	CA-NL	CL-NL
Manure	2019	3261±115	2408±223	2953±147	3464±306	3388±653	3139±563	4141±119	2760±438	3383±877	2760±380
	2020	5795±108	5167±123	5097±216	5770±296	4888±117	4563±161	4336±163	4067±678	6075±157	5166±217
Manure +NPK	2019	4141±907	3491±240	3951±472	3978±223	3377±951	3500±101	4087±741	3789±606	3166±615	3735±929
	2020	8738±224	5975±722	4915±188	7174±157	5732±114	5487±543	7443±330	5800±215	5791±198	6103±983
Witness	2019	3139±378	2003±699	2544±628	2463±311	2631±378	2436±271	2598±106	2408±205	2084±533	2977±758
	2020	3637±158	3132±941	3364±774	4663±258	3843±521	3283±536	3365±107	3439±168	5213±197	3560±156
Manure	2019-2020	4528±170	3788±169	4025±206	4617±231	4138±119	3851±864	4238±132	3414±876	4729±186	3963±193
Manure +NPK	2019-2020	6439±292	4733±142	4433±136	5576±200	4555±159	4494±131	5765±285	4795±182	4478±195	4919±155
Witness	2019-2020	3353±989	2630±990	2954±786	3563±207	3237±770	2859±600	2982±107	2924±124	3648±214	3269±595

Analysis of variance	Df	P_Value
Years	1	<0,000
System	9	<0,027
Treatment	2	<0,000
Years*System	9	<0,340
Years*Treatments	2	<0,004
System*Treatments	18	<0,763
Years*System*Treatments	18	<0680

CL: Local cereal in pure culture, CL-AL: Local cereal /Local groundnut, CL-AA: Local cereal /Local groundnut, CL-NL: Local cereal /Local cowpea, CL-NA: Local cereal /Local cowpea in dual use, CA: Pure-crop dual-use cereal, CA-AL: Dual-use cereal/Local peanut, CA-AA: Dual-use cereal/Dual-use peanut, CA-NL: Dual-use cereal/Local cowpea, CA-NA: Dual-use cereal/Dual-use cowpea.

4.2. Effect of Cropping System and Fertilizers on Grain Yield

Table 5 presents the effects of cropping system and fertilizer on grain yield. The cropping system and fertilizers had highly significant effects on grain yield (P=0.000). Thus, the effect of strip cropping induced an increase in grain yield in 2020 compared to that in 2019. The highest grain yield is recorded in 2020 with the improved millet in pure cultivation 3426±112 kg/ha. Manure +NPK tends to give the highest grain yield in both years of experimentation. Also, the overall results from 2019 to 2020 indicate that the highest average yield is 2413±406kg/ha for the improved millet compared to 1304±675kg/ha for the local millet control associated with local groundnut.

Table 5. Effect of cropping system and treatments on grain yield

		Average grain yield (kg/ha)									
Treatments	Années	CA	CL	CA-AA	CL-AA	CA-AL	CL-AL	CA-NA	CL-NA	CA-NL	CL-NL
Manure	2019	1308±387	1281±440	1260±279	1556±77	1669±431	1285±729	1447±577	1301±216	1294±479	932±319
	2020	3033±876	2789±271	1733±364	1739±782	1645±568	2273±901	1846±326	1828±103	2459±786	1985±406
Manure +NPK	2019	1399±619	1360±319	1619±357	1880±402	1708±443	1617±748	1674±577	1426±330	1287±581	1138±461
	2020	3426±112	2929±821	1985±801	1716±627	2260±824	2302±265	2566±921	1871±821	2474±545	2504±904
Witness	2019	1349±442	1241±271	1201±340	1437±325	999±265	1138±527	1309±290	1159±136	924±199	1167±318
	2020	2107±687	2443±416	1530±630	1333±990	1716±797	1470±226	1900±830	1674±917	2135±556	1818±752

		Average grain yield (kg/ha)									
Treatments	Années	CA	CL	CA-AA	CL-AA	CA-AL	CL-AL	CA-NA	CL-NA	CA-NL	CL-NL
Manure	2019-2020	2170±1114	2035±874	1496±393	1648±524	1657±475	1779±912	1647±484	1564±743	1877±866	1458±657
Manure +NPK	2019-2020	2413±137	2144±102	1802±606	1798±495	1984±688	1959±627	2120±857	1648±626	1881±821	1821±987
Witness	2019-2020	1674±648	1909±718	1365±500	1385±684	1358±675	1304±406	1604±657	1416±667	1529±754	1492±638

Analysis of variance	Df	P_Value
Years	1	<0,000
System	9	<0,013
Treatments	2	<0,000
Years*System	9	<0,000
Years*Treatments	2	<0,350
System*Treatments	18	<0,999
Years*System*Treatments	18	<0,960

CL: Local cereal in pure culture, CL-AL: Local cereal /Local groundnut, CL-AA: Local cereal /Local groundnut, CL-NL: Local cereal /Local cowpea, CL-NA: Local cereal /Local cowpea in dual use, CA: Pure-crop dual-use cereal, CA-AL: Dual-use cereal/Local peanut, CA-AA: Dual-use cereal/Dual-use peanut, CA-NL: Dual-use cereal/Local cowpea, CA-NA: Dual-use cereal/Dual-use cowpea.

Effect of cropping system and fertilizers on legumes

Effect of cropping system and fertilizers on stem yield

Year and cropping system factors significantly affected peanut stem yield in both years of the experiments (P=0.000) (Table 6). But fertilizer application did not have a significant effect on stem yield (P=0.105). Nevertheless, the maximum stem yield was obtained with the local groundnut variety (1776±354kg/ha) in 2019 against the minimum which is 580±120 kg/ha of the control treatment obtained with the local variety in 2020. Thus, the NPK fertilizer tended to give the best stalk yield compared to the SSP and the control in both years of experimentation. Overall for the two years of experimentation, the highest yield was recorded with the local groundnut in pure culture (1375±524g/ha) with NPK fertilizer.

Table 6. Effect of cropping system and fertilizers on stem yield

		Average total stem dry weight (kg/ha)					
Treatments	Années	AA	AL	CA-AA	CA-AL	CL-AA	CL-AL
Manure	2019	1534±301	1776±354	1117±371	969±356	1080±331	823±55
	2020	866±452	974±294	587±234	1036±406	792±297	1109±265
Manure +NPK	2019	1455±121	1692±446	1092±581	872±348	665±171	1126±432
	2020	942±342	1056±497	671±229	847±132	1154±881	831±68
Witness	2019	1373±189	1337±198	915±291	865±257	824±276	879±256
	2020	809±271	580±120	828±244	775±177	946±505	796±244
Manure	2019-2020	1200±504	1375±524	852±403	999±361	936±329	995±246
Manure +NPK	2019-2020	1199±363	1374±554	881±467	861±260	910±643	949±274
Witness	2019-2020	1091±371	958±432	872±253	824±219	885±382	829±219

Analysis of variance	Df	P_Value
Years	1	<0,000
System	5	<0,000
Treatments	2	<0,105
Years*System	5	<0,000
Years*Treatments	2	<0,801
System*Treatments	10	<0,836
Years*System*Treatments	10	<0,582

AL: Local groundnut in pure culture, CL-AL: Local cereal /Local groundnut, CL-AA: Local cereal /Local groundnut, CA-AL: Dual-use cereal/Local peanut, CA-AA: Dual-use cereal/Dual-use peanut.

Effect of cropping system and fertilizers on pod yield

Table 7 shows the effect of cropping system and fertilizer on pod yield. The results show that the cropping system and fertilizer application had a significant effect on pod yield (P=0.000). The year factor did not have a significant effect on pod yield (P=0.960). However, the year 2019 recorded the highest pod yield with the local variety in pure culture (1238±275kg/ha) with the SSP fertilizer. Also for both years, it was always the local variety in pure culture (1150±367 kg/ha) but this time if with NPK fertilizer.

Table 7. Effect of cropping system and fertilizers on pod yield

		Average dry pod weight (kg/ha)					
Treatments	Années	AA	AL	CA-AA	CA-AL	CL-AA	CL-AL
Manure	2019	1109±226	1232±309	768±188	588±288	810±233	781±79
	2020	944±241	1069±448	699±202	782±270	910±259	847±151
Manure +NPK	2019	1072±102	1238±275	761±255	549±232	660±268	691±136
	2020	873±346	1035±553	726±193	675±227	813±107	838±230
Witness	2019	924±173	853±137	737±178	581±169	676±155	586±62
	2020	886±277	766±272	643±219	664±146	723±149	690±62
Manure	2019-2020	1026±233	1150±367	733±184	676±285	860±234	820±119
Manure +NPK	2019-2020	972±259	1137±418	744±210	606±228	736±206	780±194
Witness	2019-2020	905±215	810±205	690±192	619±157	699±143	649±78

Analysis of variance	Df	P_Value
Years	1	<0,960
System	5	<0,000
Treatments	2	<0,014
Years*System	5	<0,134
Years*Treatments	2	<0,997
System*Treatments	10	<0,769
Years*System*Treatments	10	<0,999

AL: Local groundnut in pure culture, CL-AL: Local cereal /Local groundnut, CL-AA: Local cereal /Local groundnut, CA-AL: Dual-use cereal/Local peanut, CA-AA: Dual-use cereal/Dual-use peanut.

Effect of cropping system and fertilizer on peanut seed yield

Table 8 shows that all factors (years, cropping system and fertilizers) significantly affected peanut seed yield in both years of the experiments. Thus, local groundnut in pure cultivation recorded the highest seed yield in 2019. SSP and NPK fertilizer inputs increased groundnut seed yield compared to the control with 835±212Kg/ha, 743±177kg/ha and 336±114Kg/ha respectively.

Table 8. Effect of cropping system and fertilizer on peanut seed yield

		Average seed weight (kg/Ha)					
Fertilizer	Années	AA	AL	CA-AA	CA-AL	CL-AA	CL-AL
Manure	2019	743±177	826±189	394±124	364±195	547±152	565±2
	2020	635±178	770±276	458±98	440±81	590±32	528±98
Manure +NPK	2019	617±220	835±212	488±108	366±124	444±206	474±126
	2020	608±224	695±366	448±90	468±113	556±31	447±81
Witness	2019	691±266	657±195	474±88	359±95	416±35	439±141
	2020	611±185	469±188	336±114	452±98	466±105	443±43
Manure	2019-2020	689±174	798±221	426±109	398±152	568±104	543±72
Manure +NPK	2019-2020	612±205	765±287	468±94	412±125	500±149	458±86
Witness	2019-2020	651±216	563±204	405±120	401±104	441±77	442±77

Analysis of variance	Df	P_Value
Years	1	<0,057
System	5	<0,000
Fertilizer	2	<0,040
Years*System	5	<0,132
Years* Fertilizer	2	<0,783
System*Fertilizer	10	<0,530
Years*System*Fertilizer	10	<0,992

AL: Local groundnut in pure culture, CL-AL: Local cereal /Local groundnut, CL-AA: Local cereal /Local groundnut, CA-AL: Dual-use cereal/Local peanut, CA-AA: Dual-use cereal/Dual-use peanut.

Effect of cropping system and fertilizer on dry cowpea haulm yield

Table 9 presents the effect of cropping system and fertilization on cowpea haulm yield. There was no significant effect of cropping system on cowpea haulm yield. However, fertilizer application had a significant effect on cowpea haulm yield (P=0.000). The highest mean haulm yield was obtained with the improved cowpea in pure cultivation 2427±160 kg/ha with NPK application in 2019. The lowest cowpea haulm yield is obtained in 2020 with the control treatment of local cowpea in combination with local millet (770±398kg/ha).

Table 9. Effect of cropping system and fertilizer on cowpea haulm yield

		Average dry haulm weight (kg/ha)					
Fertilizer	Années	NA	NL	CA-NA	CL-NA	CA-NL	CL-NL
Manure	2019	2427±160	2155±231	2242±322	2007±762	2374±373	2242±751
	2020	2207±790	1509±69	1656±231	1848±1193	1579±405	1733±704
Manure +NPK	2019	2423±292	1972±215	2130±405	1540±748	2068±198	2374±1149
	2020	2156±924	2064±1201	1309±154	1656±1017	1502±553	1694±933
Witness	2019	1156±205	1740±163	1838±217	1186±294	1887±388	1913±646
	2020	1283±235	1232±154	1040±317	963±646	886±385	770±398
Manure	2019-2020	2333±485	1796±372	1907±399	1927±931	1976±557	2016±735
Manure +NPK	2019-2020	2309±589	2023±861	1661±509	1598±829	1785±490	2072±1056
Witness	2019-2020	1210±210	1458±306	1382±498	1074±479	1386±644	1405±794

Analysis of variance	Df	P_Value
Years	1	<0,000
System	5	<0,371
Treatments	2	<0,000
Years*System	5	<0,135
Years*Treatments	2	<0,641
System*Treatments	10	<0,791
Years*System*Treatments	10	<0,967

NL: Local cowpea in pure culture, CL-NL: Local cereal /Local cowpea, CL-NA: Local cereal /Local cowpea in dual use, NA: Pure-crop dual-use cowpea, CA-NL: Dual-use cereal/Local cowpea, CA-NA: Dual-use cereal/Dual-use cowpea.

Effect of cropping system and fertilizers on cowpea pod yield

Cowpea pod yield was significantly affected by the effect of cropping system and fertilizer application (Table 10). The results show that the maximum yield is obtained in 2020 with the improved cowpea in pure culture (1494±322kg/ha). On the other hand, the minimum yield is recorded in 2019 with the combination of local cowpea and local millet (175±40Kg/ha). The addition of NPK seems to favor cowpea pod yield.

Table 10. Effect of cropping system and fertilizers on cowpea pod yield

		Average Pod Weight (kg/ha)					
Treatments	Années	NA	NL	CA-NA	CA-NL	CL-NA	CL-NL
Manure	2019	1330±121	398±260	418±256	553±250	490±0	315±185
	2020	1494±322	1016±352	700±318	616±214	341±106	715±257
Manure +NPK	2019	893±184	695±709	379±219	373±176	537±202	229±183
	2020	1268±236	868±383	606±310	498±243	380±97	563±271
Witness	2019	630±375	185±164	191±99	175±40	270±137	148±120
	2020	1107±554	794±364	623±418	399±250	385±116	398±171
Manure	2019-2020	1412±235	741±440	579±308	584±218	405±109	515±298
Manure +NPK	2019-2020	1054±276	791±520	509±280	444±210	447±159	396±279
Witness	2019-2020	835±487	523±424	438±380	287±205	327±133	259±188

Analysis of variance	Df	P_Value
Years	1	<0,000
System	5	<0,000
Treatments	2	<0,008
Years*System	5	<0,006
Years*Treatments	2	<0,314
System*Treatments	10	<0,448
Years*System*Treatments	10	<0,684

NL: Local cowpea in pure culture, CL-NL: Local cereal /Local cowpea, CL-NA: Local cereal /Local cowpea in dual use,
NA: Pure-crop dual-use cowpea, CA-NL: Dual-use cereal/Local cowpea, CA-NA: Dual-use cereal/Dual-use cowpea.

Effect of cropping system and fertilizers on cowpea seed yield

The effect of cropping system and fertilizer on cowpea seed yield are presented in Table 11. The results show that the factors years, cropping system and fertilizer had a significant effect on cowpea seed yield in both years of the experiments. Indeed, the best average seed yield was obtained in improved cowpea (871±184kg/ha) with NPK input in 2020. In general, grain yields in 2020 were found to be higher than those in 2019.

Table 11. Effect of cropping system and fertilizers on cowpea seed yield

		Average seed weight (kg/ha)					
Treatments	Années	NA	NL	CA-NA	CA-NL	CL-NA	CL-NL
Manure	2019	294±228	61±41	174±101	225±128	212±56	139±70
	2020	871±184	665±254	521±241	403±144	240±73	428±144
Manure +NPK	2019	181±106	87±59	149±82	213±123	267±33	102±69
	2020	738±195	570±170	387±157	338±163	251±86	399±175
Witness	2019	88±63	34±30	96±51	94±38	114±42	49±35
	2020	506±89	389±121	282±144	274±108	235±60	266±87
Manure	2019-2020	583±367	396±366	372±258	314±158	228±63	283±186
Manure +NPK	2019-2020	420±328	355±284	285±176	284±151	258±64	251±201
Witness	2019-2020	267±234	231±207	202±145	184±122	174±81	145±129

Analysis of variance	Df	P_Value
Years	1	<0,000
System	5	<0,000
Treatments	2	<0,003
Years*System	5	<0,000
Years*Treatments	2	<0,755
System*Treatments	10	<0,949
Years*System*Treatments	10	<0,968

NL: Local cowpea in pure culture, CL-NL: Local cereal /Local cowpea, CL-NA: Local cereal /Local cowpea in dual use,
NA: Pure-crop dual-use cowpea, CA-NL: Dual-use cereal/Local cowpea, CA-NA: Dual-use cereal/Dual-use cowpea.

5. Discussion

Year, cropping system, and fertilizer factors all had a significant effect on average millet stem yield from 2019 to 2020 (P=0.000). Also the stem biomass yield of 2020 is significantly higher than that of 2019. These results are similar to those of Hamidou *et al*. (2018) who showed that millet grown in rotation with groundnut increases millet biomass by 20% than in non-rotation and that this increase indicates soil enrichment especially in N by groundnut. The highest yield of stems in this study was obtained for the millet variety Siaka in pure culture with manure + NPK. This result is higher than the one obtained by Ali (2018) who used the HKP variety in an ANR field with phospho-compost input (2737.5kg/ha); then the one obtained by Zounon *et al.* (2020) in an ANR field with manure+NPK input on the HKP variety (2126kg/ha) in the Sahelo-Sudanese zone. This shows that the dual-purpose variety Siaka favors fodder production with manure + NPK fertilizer more than the HKP variety.

Finally, the average dry weight of grains which is the most sought after parameter by the producers, conditions the choice of the variety to be used among the producers in terms of grain yield. Grain yield motivates growers more, as they look for not only the early and resistant variety but also the one that can give more grain yield. Cropping system and fertilizer had significant effects on grain yield (P=0.000). Thus, the effect of strip cropping induced an increase in grain yield in 2020 compared to that of 2019. This increase is due not only to the fertilizer input but also to the nitrogen input by the legumes in the strips. The work of Toudou *et al.*, (2016) specified that the atmospheric nitrogen fixed by cowpea in the first year was therefore only beneficial in the second year, especially for grains. As for Bado, (2002) and Bationo *et al*. (2002), legumes through their ability to fix atmospheric N can improve soil N availability and increase the yield of subsequent and associated cereals. However, Garba and Renard, (1991) reported that the positive effect of the cereal/legume association on the cereal is rarely obtained in the next year (Garba and Renard, 1991). Indeed, the results of this study are superior to those obtained by Mahamane (2012) with the varieties HKP, Zatib and CT6 in association with groundnut JL-24 and 55-437 with organic manure followed by DAP and NPK in the department of Aguié villages of Guidan Bakoye and El Guéza with values of 500kg/ha, 412kg/ha and 375kg/ha respectively. It is also higher than that obtained by Gaptia (2014) with the HKP variety in pure culture with the addition of organic manure in a farmer's school field in Dogo village (Magaria department) with 1233.33kg/ha. It is also higher than that obtained by Zounon *et al*. (2020) with the HKP variety in a RNA field with the addition of manure+NPK (464.1kg/ha) in the Sahelo-Sudanese zone. It is also higher than that obtained by PASADEM (2014) in Guidan Roumdji, Mayahi, Madarounfa and Tessaoua with values of 1302kg/ha, 1030kg/ha, 1600kg/ha and 1116kg/ha, respectively; and even higher than that of Rahilatou (2014) with the HKP variety (1520.83kg/ha) for a varietal test in a farmers' school field. The HKP variety is more productive in grain than the zatib and CT6 varieties on the one hand, and on the other hand the manure+NPK treatment has more effect than manure followed by DAP, in addition the pedoclimatic conditions strongly influence the grain production of the HKP variety. However, grain production is lower than that obtained by Bouzou (2009) with the variety Zatib (3000kg/ha) under compost-enriched treatment. In this context, the difference is more related to soil and climatic conditions, as we know from experience that manure + NPK has a greater effect than enriched compost, and the Zatib variety produces less grain than the HKP variety. Soil and climate conditions influence grain production in millet varieties.

Year and cropping system factors significantly affected peanut stem yield in both years of the experiments (P=0.000). But fertilizer application did not have a significant effect on stem yield (P=0.105). However, the NPK fertilizer tended to give the best stem yield compared to the SSP and the control in both experimental years. Overall for both years of experimentation, the highest yield was recorded with the local groundnut in pure culture (1375±524g/ha).

With regard to peanut seed yield, statistical analysis showed that the factors years, cropping system and fertilizers significantly affected peanut seed yield (P=0.000). Thus, the local variety of groundnut under pure cultivation recorded the highest grain yield in 2019. The application of SSP fertilizer increased peanut seed yield better than NPK and control. This could be due to the more soluble nature of SSP fertilizer. Indeed, the yields of SSP and NP were not significantly different. These results corroborate those of Hamidou *et al*. (2016) who reported that the SSP technology did not result in significantly different results than those obtained with the average NPK technology applied to the poquet. These results are superior to those obtained by Bello et al. 2019 in the Zinder region where he found a yield of 800kg/ha with the same variety. However, these results are inferior to those obtained by Bangata *et al*., 2013.

Fertilizer application had a significant impact on cowpea haulm yield in contrast to the cropping system which did not significantly affect cowpea haulm yield. However, the highest average haulm yield was obtained with the improved cowpea under pure cultivation with NPK application in 2019. Ouedraogo and Hien (2015) reported that better aboveground biomass production is observed with the application of organo-mineral fertilizer. Several others reported that phosphorus plays a determining role in legume and cereal production (Dakora & Keya., 1997; Twomlow *et al*., 2004; Valluru *et al*., 2010). Regarding sheath yield, year, cropping system and fertilizer factors had a significant effect on cowpea seed yield in both years of experiments. This study showed a positive effect of fertilizer use on increasing cowpea yields. Indeed, the best average grain yield was obtained in improved cowpea (871±184kg/ha) with NPK application in 2020. In general, grain yields in 2020 are higher than those in 2019. The low cowpea yields in

2019 may be explained by low soil fertility. Some *et al*. 2014 indicates that application of compost increases seed yield. The work of Bado (2002) shows that the effects of organo-mineral fertilizers on crop yields are more pronounced in the second year. All the high vines and grain yields of cowpea were obtained with the improved variety. This is explained by the dual-use characteristics of this variety, including the production of seeds for human consumption and tops for animal feed. Toudou *et al.* (2016) reported that dual-purpose varieties allow seed production for human consumption and for agriculture-livestock integration in the Sahelian zone, as cowpea haulms are an important source of protein for livestock. Microdose organic and mineral fertilizers positively affected millet and legume (groundnut and cowpea) yields. All of the significant yields were obtained on the plots that received microdose fertilizer in contrast to the control plots. This performance of the microdose would be linked to the concentration of nutrients at the level of the root systems, which would improve accessibility and efficiency of use (Muehlig-Versen *et al*., 2003) and would reduce losses. Several studies have shown the positive impact of microdosing on both yield increase and income increase for producers, as it allows to decrease the defense to organic and mineral fertilizers. The work of Tabo *et al.* (2005), Aune *et al.* (2007) and Taonda *et al*. (2008) showed the positive effect of microdose in increasing the income of producers. Microdose NPK (6g of NPK applied per packet at sowing) and 30kg N/ha (applied in two fractions) also showed a positive result (Hamidou *et al.*, 2016). Microdosing technology has induced an increase in cereal yield of more than 120% in Burina-Faso, Mali and Niger (Tabo *et al.*, 2011).

6. Conclusions

This study evaluated the effect of cereal-legume crop succession, alternate strips and microdosing on millet, groundnut and cowpea yields. Microdosing of organic and mineral fertilizer increased biomass and grain yields of millet, cowpea and groundnut. Indeed, the improved cereal (Siaka) and legume (TN5-78) varieties would be better for seed and stalk biomass production.

The results show that the development of crops associated with cereals and legumes (cowpeas and/or groundnuts) in alternating strips or in rotation, as opposed to farmers' practice where cowpeas and groundnuts are scattered in the millet field, has made it possible to increase human and animal nutrition and the level of soil fertility. The cultivation of legumes improves the level of soil fertility in the cereal/legume cropping system and would increase the yield of stalk biomass and grain. The contribution of mineral (NPK) and organic (manure) fertilizer in microdose in the cereal/legume cultivation system allows to reduce the defense for the purchase of fertilizer on the one hand. On the other hand, it allows to obtain a better biomass and grain yield. It would be important to sensitize producers to adopt the technique of combined cereal/legume strip cropping (improved varieties) and microdose mineral and organic fertilization in order to improve soil fertility, crop yields and income.

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