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Article

Optimizing Pearl Millet-Groundnut Cropping System in the Sahelian Zone of Niger

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Abstract: A two-year study of pearl millet-groundnut cropping systems across two fertilizer levels was conducted at the INRAN/TARNA research station in Maradi, Niger in the Sahelian zone of West Africa. The objective of this study was to identify the best cropping system with and without fertilizer application to optimize pearl millet and groundnut yields, land use efficiency, and economics as measured by value-to-cost ratio. The experiment was conducted with three replications, and ten treatments combination of five pearl millet and groundnut cropping systems (pearl millet and groundnut sole crops, and three pearl millet – groundnut intercrops), and two fertilizer levels. Sole cropping produced the highest pearl millet grain by over 300 kg ha⁻¹ and groundnut pod yields by over 500 kg ha⁻¹, but all the intercropping systems had a LER above 1.0 with land use efficiency increased by 19 to 41%, also intercropping increased diversity, and reduced risk. Fertilizer application increased yields in all cropping systems by 200 to 600 kg ha⁻¹. Government subsidy increased the value-to-cost ratio by 0.5 to 2, 5 units, and was required for economic response for pearl millet sole and intercrops in 2022. The groundnut sole cropping system had the greatest economic response to fertilizer application. Based on the risky environment and multiple end uses needed by producers, the intercrop system M-G: 1:3:1 with fertilizer application is usually the best option to optimize pearl millet and groundnut production.

Keywords: grain yield; pod yield; intercrop; sole crop; land equivalent ratio; fertilizer land use efficiency; value to cost ratio

1. Introduction

Dryland cropping systems in Niger are produced on over 6 million ha with pearl millet (*Pennisetum glaucum* (L.) R. Br.) [1] and more than 85 % intercropped with groundnut [*Arachis hypogea* L.], cowpea [*Vigna unguiculata* (L.) Walp], and grain sorghum [*Sorghum bicolor* (L.) Moench]. The average yields are very low with grain yield of 349 kg ha⁻¹ for pearl millet and pod yield of 509 kg ha⁻¹ for groundnut in 2021. Low yields are due to drought (low and erratic rainfall), inherent low soil fertility, and infestations by pests and diseases, along with inefficient crop management practices and cropping systems.

The most appropriate cropping system is based on farmer's goal and existing environmental conditions. Only wealthy farmers who own large farms practice sole cropping systems of pearl millet and groundnut production in Niger. Traditional crop management systems used by farmers for diverse reasons including resilience to the incertitude of the region's climate, for more durable agriculture production, and to match efficiently crop demands to the available growth resources and labor [2]. The most common advantage of intercropping is increased land use efficiency [3] due to more efficient use of the available complementary growth resources using a mixture of crops of different rooting ability, canopy structure, height and nutrient requirements by the component crops. Presently, intercropping is widely practiced by small-scale farmers throughout Niger and West Africa to meet diverse needs for food and fodder in markets and in subsistence, and to increase farm income over that achieved by sole cropping. Intercropping system performance is commonly

measured using the Land equivalent Ratio (LER). LER is defined as the relative area needed in sole cropping system to produce what has been obtained with the intercropping system [4]. The production of pearl millet/groundnut can be significantly increased with use of appropriate cropping system, recommended fertilizer application rate, complementary genotypes, and use of best sowing dates, row spacing and plant population [5].

A review of groundnut production in India reported that groundnut performs well under intercropping system with short duration crops like pearl millet and sorghum due to the less shading and to enhanced pod development after the pearl millet harvest [6] especially in dryland production systems [7]. Sorghum and pearl millet intercropping with groundnut has been shown to increase productivity and profit from N and P application over sole crops ([8]; [9]; [10]; [11]).

Pearl millet intercropping systems research largely involves using diverse plant population applied to various plant arrangements based on the recommended plant population in sole cropping systems. The most common approaches are to apply one of the following

Replacement intercrop system [12], the plant population pearl millet is reduced and replaced by the plant population of groundnut along with increased pearl millet row spacing

Additive intercrop system [12] where the plant population of pearl millet crop remains constant at the recommended sole crop plant population and groundnut is added.

The objective of this study was to identify the best cropping system with and without fertilizer application to optimize pearl millet and groundnut yields, land use efficiency, and economics as measured by the value-to-cost ratio.

2. Materials and Methods

2.1. Experimental site

Trials on the pearl millet-groundnut cropping systems were conducted during the 2021 and 2022 growing seasons at INRAN/Tarna research station (13°27'33" N, 07°6'14" E). The soils of the site were classified as Arenosols [13] with low level of clay (3.2%) and loam (0.4%), and high level of sand (96.4%); 5.2 to 6.0 for soil pH, 1.0 to 7.8 g kg⁻¹ for organic C, 4.3 to 65.6 mg kg⁻¹ for Mehlich-3 P, 35 to 92 mg kg⁻¹ for exchangeable K. The climate of the site is Sahelian type with average rainfall of 600 mm between June and October.

2.2. Experimental design

The experimental design was a randomized complete blocks design with three replications.

Treatment structure

A. The pearl millet-groundnut trial has ten (10) treatments, combinations of:

- Five (5) cropping systems (Table 1) were S₁ pearl millet sole crop (**MSC**); S₂: groundnut sole crop (**GSC**); S₃: pearl millet/groundnut intercropped with one row of groundnut between two rows of pearl millet (**M-G : 1 :1 :1**); S₄: pearl millet/groundnut intercropped with two rows of groundnut between two rows of pearl millet (**M-G : 1 :2 :1**); S₅: pearl millet/groundnut intercropped with three rows of groundnut between two rows of pearl millet (**M-G : 1 :3 :1**); and

- Two fertilizer levels: F₀ no-fertilizer application and F₁ 100 kg/ha NPK (15-15-15) pre-plant applied and incorporated to the experimental area prior to planting and 50 kg/ha urea side-dress applied to pearl millet at 8-leaves stage.

For each treatment, plot size was 5m x 6m (30 m²).

2.3. Crop Management and Data Collection

The land was plowed to 15 cm depth and disk-harrowed. The varieties were pearl millet 'Zatib' with 80 to 85 days to maturity and groundnut variety Samnut24 with 80 to 90 days to maturity [14]. The seeds were treated with Calthio C chlorpyrifoséthyle 25%; Thirame 25%, W.S (20g/10 kg of seeds) for control of root and stem fungal diseases. The seeds were planted manually at a 5 cm depth. Pearl millet and groundnut were planted on the same day: 11 July 2021 and 18 June 2022. Two manual

hand-hoe weeding were done on 24 July 2021 and 16 July 2022, and the second at 8 Aug.2021 and 9 Aug. 2022. Pearl millet was thinned to 3 plants/ hill after the first weeding and groundnut was planted with 2 seeds/hill.

Pearl millet and groundnut distribution, row and intra-row spacing, and final plant population are presented in Table 1.

Table 1. Pearl millet –groundnut spacing and plant population.

Cropping System	Millet– Groundnut- Millet Distribution	Pearl Millet				Groundnut			
		Spacing		Plant Population		Spacing		Plant Population	
		Row	Intra- row	No./ha	%	Row	Intra- row	No. /ha	%
	Row	----- m -----			----- m -----				
Pearl Millet Sole (S1)		1.0	1.0	30,000	100				
Groundnut Sole (S2)		-	-	-	-	0.5	0.2	200,000	100
Pearl Millet – Groundnut Intercrop (S3)	1:1:1	1.0	1.0	30,000	100	0.5	0.2	75,000	37.5
Pearl Millet – Groundnut Intercrop (S4)	1:2:1	1.5	1.0	21,818	72.7	0.5	0.2	109,091	54.5
Pearl Millet – Groundnut Intercrop (S5)	1:3:1	2.0	1.0	16,000	53.3	0.5	0.2	120,000	60.0

3. Results

The two growing seasons of the experiment had divergent rainfall patterns with 500 mm in 2021 and 709 mm in 2022, one near-average and the other above the average of 598 mm, and the last five years average of 611 mm (Table 2). Rainfall was greater every month in 2022 than 2021, but especially more in September when pearl millet grain fill and groundnut pod fill occurred.

Table 2. Rainfall (mm) at INRAN/Maradi station in 2021, 2022 and average of last 5 years.

	2018-2022-Average	2021	2022
June	74	54	80
July	147	150	122
August	222	226	293
September	145	71	209
October	11	0	1
Total	598	500	704

3.1. Agronomic results

3.1.1. Grain and pod yields

The ANOVA for pearl millet and groundnut yields indicated that the interactions year*system*fertilizer, year*system, and year*fertilizer were not declared significant for both crops indicating that the crops respond similarly to these factors across years. However, the

system*fertilizer were declared significant $P = 0.04$ for pearl millet grain yield and at $P = 0.05$ for groundnut pod yield.

The lack of year*fertilizer interaction effect indicated that pearl millet and groundnut responded similarly to the applied fertilizer during the high and the near average rainfall years in this study. Fertilizer application increased average pearl millet grain yield by 54% and average groundnut pod yields by 52%.

Averaged across years and fertilizer applications, pearl millet grain yield and groundnut pod yields were 29 to 47% greater for sole crops than with intercropping (Table 3). Thus, if the farmer's goal is to maximize production of either pearl millet grain for subsistence consumption or peanut pods as a cash crop, the producer would select a sole crop. If the producer is interested in producing multiple products to meet diverse end uses and to reduce risk (Mason et al. 2015), then he would logically choose to intercrop the two species.

Pearl millet grain and groundnut pod yields were over 300 kg ha^{-1} higher during the higher rainfall season of 2022 compared the near-average rainfall season of 2021. This 13% increase for pearl millet grain yield and 10% for groundnut pod yield is consistent with previous studies [11]; [3]; [7]).

When the number of rows and the plant population combinations (Table 1) in the intercropping systems compared to sole cropping, the yield reductions with the intercropped pearl millet grain yield tended to decline with increasing number of groundnut rows and plant population (Table 3), likely due to increased groundnut competition with pearl millet for water and light [17]; [7]). Groundnut pod yields usually were similar for 1:1:1 and 1:2:1 row and plant population combinations, but increased with the 1:3:1 combination. Farmer perceived need for pearl millet grain or groundnut pods would influence which row spacing/plant population combination would be best.

Table 3. Influence of cropping system, fertilizer application, and year on pearl millet grain and groundnut pod yields.

Cropping system	Row distribution	Pearl millet grain			Groundnut pods		
		Without fertilizer	With fertilizer	Mean (across fertilizer rates)	Without fertilizer	With fertilizer	Mean (across fertilizer rates)
Pearl millet sole crop		828 Ba [†]	1338 Aa	1083 a	--	--	--
Groundnut sole crop		---	--	--	846 Ba	1408 Aa	1127 a
Pearl millet – groundnut intercrop	1:1:1	602 Bb	928 Abc	765 b	498 Bc	699 Acd	598 c
Pearl millet – groundnut intercrop	1:2:1	514 Bc	832 Abc	673 bc	560 Bbc	824 Abc	692 bc
Pearl millet – groundnut intercrop	1:3:1	498 Bc	658 Acd	578 c	683 Bb	1013 Ab	848 b
Mean (across cropping systems)		611 B	939 A		647 B	983 A	

[†]Capital letters indicate row differences and small letters indicate column differences at P≤0.05.

3.1.2. Land use efficiency

The performance of cropping systems was evaluated with the LERs coefficients (Table 4). All the intercropping systems had a LER above 1.0 indicating the intercropping systems used land better than sole cropping [4]. The LERs of the different intercrop systems for pearl millet and groundnut were similar except for groundnut in the 1:3:1 intercrop system that was 0.15 to 0.22 greater than other intercrop systems for groundnut. Across years and fertilizer levels, the LER indicated pearl millet – groundnut intercropping increased land use efficiency with large advantage over the sole crops. Although fertilizer application increased both pearl millet grain and groundnut pod yields (Table 3), fertilizer application tended to decrease the LER for all intercrop systems (Table 4) as fertilizer application increased sole crop yields by over 500 kg ha⁻¹ compared with increased yield of 160 to 412 kg ha⁻¹ for intercrop yields (Tables 3 and 4). Fertilizer application increased LERs for all intercropping systems over sole cropping systems. If the farmer's goal was to optimize land use efficiency, he would choose to intercrop the species and apply fertilizer.

Table 4. Influence of cropping system and fertilizer application on land equivalent ratio.

Cropping system	Row distribution	Cropping System without fertilizer			Cropping system with fertilizer			Fertilizer application for each cropping system		
		Pearl millet	Groundnut	Total	Pearl millet	Groundnut	Total	Pearl millet	Groundnut	Total
Pearl millet sole crop		1.0	--	1.0	1.00	--	1.00	1.62	--	1.62
Groundnut sole crop		--	1.0	1.0	--	1.00	1.00	--	1.66	1.66
Pearl millet - groundnut intercrop	1:1:1	0.73	0.59	1.32	0.69	0.50	1.19	1.54	1.40	2.99
Pearl millet - groundnut intercrops	1:2:1	0.62	0.66	1.28	0.62	0.59	1.21	1.62	1.47	3.09
Pearl millet - groundnut intercrop	1:3:1	0.60	0.81	1.41	0.49	0.72	1.21	1.32	1.48	2.80

3.2. Economic analysis

Groundnut pod prices were 30 to 50 FCFA kg⁻¹ greater than for pearl millet grain in both years, thus groundnut was of greater economic value than pearl millet in both years of this study. In all year and subsidy combinations, sole crop groundnut pods had the highest VCR, thus gave the greatest economic response to fertilizer application. All pearl millet-groundnut systems in 2021 had VCR's greater than 2 (Table 6) indicating that even with moderate rainfall the return to fertilizer investment was justified. The fertilizer subsidy increased VCR's by 0.4 to 0.7 units. In 2022 without fertilizer subsidies, despite the higher yields because of higher seasonal rainfall (Table 1), only the two cropping systems of groundnut sole cropping and the pearl millet-groundnut system (1:2:1) produced VCR's above 2 and warranted investment in fertilizer (Table 6). With fertilizer subsidy, all cropping systems produced VCR's greater than 2, thus justifying fertilizer application.

Table 6. Economic analysis for pearl millet-groundnut cropping systems with and without fertilizer subsidy.

Cropping system	2021 without fertilizer subsidy			2021 with fertilizer subsidy		
	Fert. CFA	VYi CFA	VCR	Fert. CFA	VYi CFA	VCR
S1: MSC	50000	131755	2.62	43500	131755	3.03
S2: GSC	35000	144716	4.13	30000	144716	4.82
S3: MGIC: 1:1:1	50000	160699	3.22	43500	160699	3.69
S4: MGIC: 1:2:1	44900	159119	3.55	38910	159119	4.09
S5: MGIC: 1:3:1	42500	151698	3.57	36750	151698	4.13
	2022 without fertilizer subsidy			2022 with fertilizer subsidy		
	Fert. CFA	VYi CFA	VCR	Fert. CFA	VYi CFA	VCR
S1: MSC	74000	102139	1.38	43500	102139	2.35
S2: GSC	50000	182500	3.65	30000	182500	6.08
S3: MGIC: 1:1:1	74000	106247	1.44	43500	106247	2.44
S4: MGIC: 1:2:1	65840	145849	2.22	38910	145849	3.75
S5: MGIC: 1:3:1	62000	112556	1.82	36750	112556	3.06

Fert. : Cost per ha of the fertilizers applied (F CFA/ha). VYi: Value of yield increase compared to plots without fertilizers (F CFA/ha). VCR: Value to cost ratio.

4. Discussion

4.1. Cropping system

Cropping system evaluation requires knowledge of farmer needs and priorities as well as agronomic and economic responses. In this study, it was clear that maximum pearl millet and groundnut yields would be a priority for benefits for some farmers as sole crops produced highest yields of both crops [8]; [9]), and if economic return was the only goal, then the sole crop of higher economic value groundnut crop would be best (Table 3). However, most poor farmers in the climate-risky Sahel zone have multiple end-use needs of food for consumption and economic return, and the felt-need to diversify to reduce production risk [5]. In addition, agronomic diversity through intercropping is scientifically desirable. Thus, evaluation of pearl millet - groundnut intercropping systems with the greatest grain and pod yields, and land use efficiency would be desirable.

In this study, all pearl millet – groundnut intercropping systems studied had LERs greater than the 1 for sole cropping systems (Table 4), and thus were superior in terms of reducing risk of crop failure and land use, as also found by others [3]; [5]). Based on yields (Table 3), and LERs (Table 4), the pearl millet – groundnut intercropping system of 1:3:1 was superior to other cropping systems.

4.2. Fertilizer application

Fertilizer applications increased grain yield of pearl millet and pod yield in groundnut in all cropping systems studied by more than 50% (Table 3) as previously reported by [8]: [9]), [10], [18] and [19] over a range of environmental conditions. However, fertilizer application slightly decreased LERs of intercropping systems, as the response to applied fertilizer was 100 to 400 kg ha⁻¹ greater in sole cropping than in intercropping systems. However, the fertilizer LER response was large for individual cropping systems, but especially for the intercropping systems, was very high, often more than doubling the LER. Agronomically speaking, fertilizer application was a best management practice for yield and LER optimization.

During the two growing seasons in this study, availability of government subsidy for fertilizer was present in 2021 but not in 2022. Fertilizer application increased the VCR of sole crop cropped groundnuts with and without subsidy in both years, supporting research of [20]. The greatest fertilizer application response was for sole cropped groundnuts, which should always receive fertilizer application. Fertilizer subsidy increased the VCR in all cropping system and with fertilizer application, with the increase greater in the high yield 2022 growing season than 2021 but the fertilizer subsidy was necessary for economic returns from most pearl millet cropping systems.

Usually, the VCR for intercropping systems was greatest for the treatment with the most rows and highest plant population of groundnut (i.e. MGIC 1:2:1 and MGIC 1:3:1). In 2021, the average rainfall year with the lowest yields, the fertilizer application always produced a VCR over 2.0 and was justified for farmer profit. In 2022, the high rainfall high yield year, the subsidized fertilizer produced VCRs greater than 2.0, so fertilizer application was justified. However, when fertilizer was not subsidized, the VCR was greater than 2.0 only for sole crop groundnut and MGIC (1:2:1). The reason for this response is not obvious. The VCR values in this study are based only on the economic value of grain and pod yields, thus are likely conservative as fertilizer application concurrently increases pearl millet [8] and [9] stover yields with grain yield. Stover of both crops is widely used as livestock feed and have considerable economic value.

5. Conclusions

A two-year study of pearl millet-groundnut cropping systems across two fertilizer levels was conducted in Niger. The objective of this study was to identify the best cropping system with and without fertilizer application to optimize pearl millet and groundnut yields, land use efficiency, and economics as measured by value-to-cost ratio. Based on grain yield, producers with goal to maximize grain yield of pearl millet to meet subsistence needs or groundnut to maximize economic return would plant sole crops and apply fertilizer if cost was subsidized. However, if diversity and reducing production risks were the goal then intercropping was best. Since groundnut was of greater value, the intercropping system with 1:3:1 arrangement was of greatest economic value with and without fertilizer application was best. Government fertilizer subsidies affected the economic performance of the cropping system, as did cropping system and year. Fertilizer subsidy increased the VCR in all cropping system and with fertilizer application, with the increase greater in the high yield 2022 growing season than 2021. Sole cropped groundnut should be fertilized in conditions similar to this study. If fertilizer subsidy is available, then application is merited to sole cropped pearl millet and to intercropped pearl millet-groundnut. Based on this production environment and multiple end use needs of farmers, the intercrop system M-G: 1:3:1 usually with fertilizer application can be considered as the best option to optimize pearl millet and groundnut production.

Author Contributions: For research articles with several authors, a short paragraph specifying their individual contributions must be provided. The following statements should be used “Conceptualization, Nouri Maman and Stephen C. Mason; methodology, Nouri Maman and Stephen C. Mason; software, Nouri Maman; validation, Nouri Maman and Stephen C. Mason; formal analysis, Nouri Maman; investigation, Nouri Maman; resources, Nouri Maman; data creation, Nouri Maman; writing—original draft preparation, Nouri Maman; writing—review and editing, Stephen C. Mason; visualization, Stephen C. Mason; supervision, Nouri Maman; project administration, Nouri Maman; funding acquisition, Nouri Maman. All authors have read and agreed to the published version of the

manuscript." Please turn to the CRediT taxonomy for the term explanation. Authorship must be limited to those who have contributed substantially to the work reported.

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