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Combined effect of fertilizer micro-dosing and intercropped millet/cowpea effect on agronomic and economic advantages in prone Sahel area, Niger

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Abstract
Climate change is affecting crop production in the West Africa Sahel. Farmers develop many adaptation strategies However, few of them have been tested to find their climate smartness, primarily their agronomic and economic benefits. Therefore**,** this study aimed to evaluate the field experiment in two successive years, 2020 and 2021, in rainy conditions, the combined effect of millet/cowpea intercropping and fertilizer microdosing on the yield and their economic advantages. Two genotypes of cowpea (ISV128 and Tiligré) and a variety of millet, Heini Kirey Précoce (HKP), were intercropped. At the treatment level, there is a net benefit of the crop association compared to the pure cultivation of each of the millet and cowpea species with total LERs, an average of 1.48 in 2020, and 1.43 in 2021 for microdose treatment and 1.55 in 2020 and 1.13 in 2021 for the control. However, there is no significant difference in cowpea genotype on LER and millet yields in the 2 years (P = 0.65 in 2020 and 0.29 in 2021). Yields of millet and cowpea were higher in the sole crop than in intercropping. The intercropping showed a significantly higher monetary advantage than the sole millet crop in both years. ISV128 is the most profitable because it is less competitive and less aggressive in intercropping with millet and offers a considerable monetary advantage. The findings are invaluable in implementing resilience strategies for smallholders who must be encouraged to adopt these cultural practices due to global warming.

Keywords Fertilizer microdosing · Intercropping · Sustainable farming · Adaptation · Yields · Monetary advantage

1 Introduction

In Niger, only 12% of the country's total land area is suitable for agriculture [1]. The main cereal crops are millet and sorghum. But millet is the most important cereal grown intercropping with cowpea or groundnut. Millet is produced on sandy and deep soils relatively poor in phosphorus [2]. However, phosphorus is one of the first-factor limiting production in West Africa [3]; nitrogen only becomes necessary when humidity and phosphorus are not limited [4].

With recurrent droughts and declining soil fertility, yields are low, 415 kg/ha for millet and 298 kg/ha for cowpea, and agricultural production can no longer nourish a population with strong demographic growth, 3.9% [5]. However, national and international research institutes have proposed several technologies relating to soil fertilization management and improving productivity, including using organic manure or organo-minerals [6, 7]. But these technologies are poorly

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adopted by farmers because of the high cost of fertilizers, their low availability on the market [8, 9], and the lack of means of transporting manure, particularly in fields far from the village [10]. Other, less expensive, and easy-to-apply technologies have been proposed, such as the use of agroforestry [11], fertilizer microdosing developed by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) in the 1990s [12], and the intercropping of cereals and legumes, and crop rotation [13, 14]. Intercropping cereals with legumes are known to increase the yield of both crops compared to their sole crop and is a way to diversify crops [15]. These mixed crops, millet/cowpea, are widespread in Niger [16].

Studies have shown that millet yields can be increased using the fertilizer microdosing technique, which involves the application of small amounts of mineral fertilizer per pocket at sowing or after the emergence of about 0.3–6 g according to sowing densities [17–20].

The previous studies carried out in the Sahelian zone and particularly in Niger have been based on improving millet productivity by focusing on fertility management techniques, including microdose. Most of the work has been based on the pure culture of millet [17, 21]. None of these works have addressed the economic profitability of the use of the microdose. In other regions, particularly in West Africa Sahel, a region which is one of the most vulnerable to the effects of climate change as its main cropping system is rainfed, for example [19] showed that microdosing alone does not give sufficient economic returns on millet sole crop. However, those studies demonstrated the risk in economic terms of applying the microdose in the form of NPK particularly in sole millet as shown by [20] in Fakara in Niger. One of the available options for addressing this problem could be the combination of microdose and millet/cowpea intercropping.

In Niger, most farmers prefer to grow millet intercropping with cowpea. Inclusion of appropriate cowpea and millet genotypes was known to increase millet-cowpea intercrop productivity [22], also the choice of date and density of sowing [23], and the application of mineral fertilizers [24]. Very few studies have evaluated the combined effect of mineral fertilizer microdosing and intercropping with cowpea on millet yields and its economic advantage. Mainly in West Africa Sahel, where agricultural production is one of the most vulnerable to climate change due to most of the farmers remaining poor. Therefore, this study tries to determine the effects of fertilizer microdosing and intercropping with cowpea on yield and land-use efficiency and monetary advantage in millet/cowpea intercropped. This study will provide baseline data for boosting the farmers' resilience regarding poverty reduction and agriculture failure consequences.

2 Materials and methods

2.1 Experimental site

A field experiment was carried out at the agricultural research farm of the Faculty of Science and Technique at Abdou Moumouni University in Niamey (Niger) during the rainy seasons of 2020 and 2021.

This site is located between 13° 30′ North latitude and 2° 05′ East longitude with an altitude of 204 m. This site is located in the south-western Sahelian biogeographic compartment characterized by a rainfall index (PI), 400 mm < PI > 600 mm, a relative humidity (RH) of 20% (February) < HR > 73.5% (August), a temperature (T) of 24° 35 (January) < T > 33° 64 (April) and a thermal amplitude of 9° 29. The soil is one of the leached tropical ferruginous types with a sandy texture. Table 1 gives the initial physicochemical characteristics of the soil at the study site.

The average precipitation from 2011 to 2021 was 535.71 mm. During the trial, the cumulative precipitation was 704.5 mm in 2020 and 436.7 mm in 2021. Figure 1 gives the monthly precipitation distributions for the two years of the experiment.

2.2 Experimental details

The HKP (Heini Kirey Précoce) millet variety, which has a 90-day cycle, created by INRAN (Niger National Institute for Agronomic Research), has been intercropped with two genotypes of cowpea. The cowpea genotypes used are ISV128 which has an average cycle (90 days) created by ICRISAT (International Crops Research Institute for the Semi-Arid Tropics) Niger, and Tiligré (75 days) created by INERA (Institute for Environment and Agricultural Research) Burkina Faso. The choice of these two genotypes is based on the fact that they provide many services to the farmers. Such as the mulches are used for animal feeding [13]. For instance, the leaves of cowpea are used for forage and human food in Niger [25]. The HKP was used because it is one of the most used millet varieties in Niger as its seeds are available throughout the year from urban to rural areas at an affordable price in the majority of the seed companies in Niger. The farmers in Niger appreciate also the taste of the HKP because it is near the local variety. The mulches of the HKP are used for diverse services such as

Table 1 Initial physicochemical characteristics of the site's soil

Parameters	Values
N-total (mg/kg)	152.8
C.Org (%)	0.11
P-Bray1 (mg/kg)	31.8
pH/H_2O (1:2.5)	6.4
pH/KCl (1:2.5)	6.0
Sand (%)	66.5
Silt (%)	29.2
Clay (%)	1.8

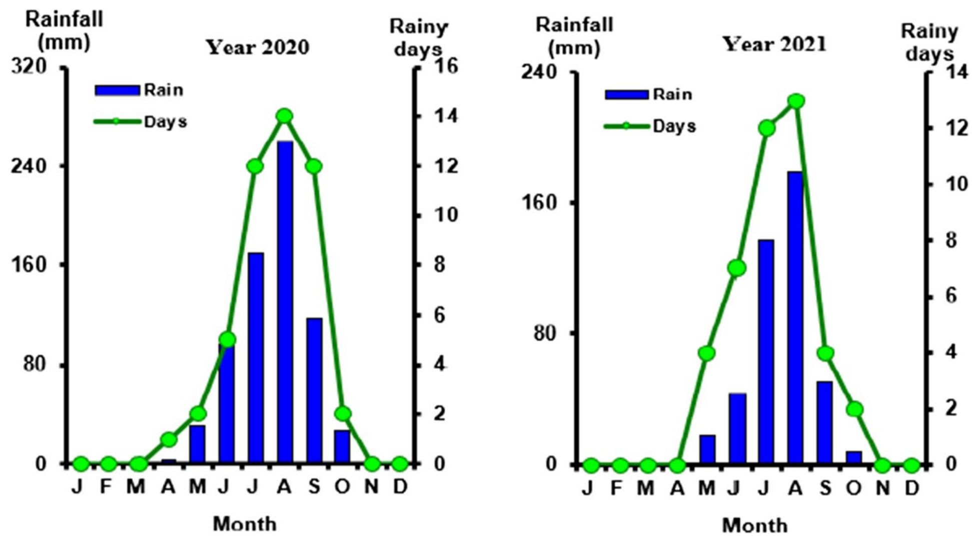

Fig. 1 Monthly rainfall distributions for 2020 and 2021

animal feeding, building huts, traditional beds and walls in Niger. The glumes of HKP are used for feeding animals and compost and mineral fertilizer for agricultural soil restoration [26]. The use of this HKP millet variety in rainfed farming systems in Niger has been reported to be a response to climate change [27].

The experimental design was laid out in a split plot with three replications. The main plot comprised cultural practices, (1) application of fertilizer microdosing i.e., 3.6 g of NPK (15-15-15) per pocket of millet both in intercropping and sole crop and supply 60 kg of NPK as basal dressing of cowpea in sole crop and (2) control without any fertilizer input. Each large plot is subdivided into 2 subblocks where millet and cowpea genotypes are distributed randomly in the intercropping and a sole crop in an elementary plot with an area of 12 m^2 (4 m × 3 m) each other. The successive elementary plots are spaced one meter apart and the replication two meters apart.

Millet was sown on 11th July 2020, and 5th July 2021 with a spacing between the pockets of 80 cm and spacing between the rows of 75 cm for a density of 16,666.66 plants/ha. In the intercropping, cowpea was sown on the same day as the millet at the rate of 5 seeds per pocket, alternating one row of millet with two rows of cowpea. The spacing between the cowpea pockets was 30 cm and 50 cm between rows i.e., a density of 106,666.67 plants/ha. After 21 days of sowing, millet was thinned at three plants and cowpea at two plants per pocket. Cowpea and millet were sown at the same density in the intercropping and sole crops. The same positions of cowpea varieties were kept in the plots in 2020 and 2021.

Fertilizer microdosing application for millet was made according to [18] which consists of the application of 60 kg/ha of NPK 15–15-15 (equivalent to 9 kg N/ha, 4 kg P/ha and 7.47 kg K/ha) at sowing, i.e., 3.6 g per pocket of millet in the intercropping and sole crop, and no fertilizer for the controls. In combination, no dose of fertilizer was applied to cowpea. For pure cowpea cultivation, micro-fertilization consisted of the application of 20 kg of equivalent DAP (18-46-0) (at 4 kg P/ha, and 3.6 kg N/ha) or 0.2 g per pocket and 0 g for controls. For sole cowpea, application of 60 kg of NPK (15-15-15) corresponding to the equivalent quantity of phosphorus (4 kg P/ha) provided as in intercropping and no fertilizer for the controls.

Tillage was carried out with a plow before the experiment was established, and after sowing, the land was plowed once during the millet tillering stage with a hand hoe weeding to eliminate weeds. TITAN insecticide was sprayed on cowpea trees to avoid insects attack just before floraison.

2.3 Measurement of yield and land use efficiency

The harvest was carried out on October 3 and 9, respectively, in 2020 and 2021. For each plot with the intercropping and sole crop, the harvest was carried out in a yield square (i.e., 1.5 m × 1.6 m). After separation of biomass (stems + leaves) and pods for cowpea and ears of millet, these were left to be sun-dried for two weeks.

The following parameters were calculated:

The yields of dry biomass and seeds after threshing were determined. The intercropping advantage was determined based on the land equivalent ratio (LER) according to [28]. The LER is used to assess the efficiency of intercropping during its development cycle. It compares the yields of intercropping with the yields of the sole crop. It is calculated as follows:

$$\mathrm{LER} = \frac{\mathrm{Y_{ab}}}{\mathrm{Y_{aa}}} + \frac{\mathrm{Y_{ba}}}{\mathrm{Y_{bb}}}$$

Y_{aa} et Y_{bb} are, respectively, the yields of species A and B in sole crop; Y_{ab}: yield of species A intercropped with species B; Y_{ba}: Yield of species B intercropped with species A; If LER = 1, there is no difference between intercrop and sole crop; If LER < 1, there is a loss of yield in intercrop; If LER > 1, there is a productive advantage of intercrop.

2.4 Competition index and monetary advantage

The competition index, the competition ratio (CR), and the aggressivity were calculated according to the method described by [29].

2.5 Competition ratio (CR)

The CR indicates the competitive capacity of one species (a) compared to another (b) in intercropping. It is calculated by the following formula:

$$\text{For species A : } \mathrm{CRa} = \frac{\mathrm{LERa}}{\mathrm{LERb}} \times \frac{\mathrm{Z_{ba}}}{\mathrm{Z_{ab}}}$$

$$\text{For species B : } \mathrm{CRb} = \frac{\mathrm{LERb}}{\mathrm{LERa}} \times \frac{\mathrm{Z_{ab}}}{\mathrm{Z_{ba}}}$$

where Z_{ab} = sown proportion of species a grown in intercrop with species b. Z_{ba} = sown proportion of species b grown in intercrop with species a.

In the case of our study, the sowing proportions are 1: 2, i.e., 40:60.

When CRa $^{>}$ 1, it means that the species a is dominant. When CRa $^{<}$ 1, the species a is dominant.

The reverse is true for CRb, i.e., for species B.

2.6 Aggressivity (A)

Aggressivity indicates the difference between the competitive abilities of the different components of the intercropping. When one component's A value is positive, it is dominant; when it is negative, it is dominated; and when it is zero, neither species dominates the other. Aggressivity is calculated by the following formula:

$$\mathrm{A} = \frac{\mathrm{Y_{ab}}}{\mathrm{Y_{aa}Z_{ab}}} - \frac{\mathrm{Y_{ba}}}{\mathrm{Y_{bb}Z_{ba}}}$$

To assess the performance of the intercrop and the fertilizer microdosing in economic terms, two indices were calculated, namely the MAI (Monetary Advantage Index) according to [29] and the VCR (Value Competitive Ratio) according to [19, 30, 31].

$$\text{MAI} = \text{ Value of combined intercrop } \times (\text{LER} - 1)/\text{LER}$$

The formula below was used to calculate the VCR of sole cowpea and millet crops. It was calculated based on the increase in yield of each species depending on the amount of fertilizer used in microdosing and based on the type of fertilizer as well as the price per kg of each species on the local market.

The prices per kilogram of millet and cowpea on the market at that time were 200 West African CFA Franc (FCFA) ($ 0.33) and 450 FCAF ($ 0.74) respectively, and the prices per kilogram of NPK 15-15-15 were 300 FCFA ($0.49).

$$\text{VCR} = \frac{(X - X0) \times \text{ Product price at harvesting}}{\text{Fertilizer dose } \times \text{ Fertilizer price}}$$

where X = microdose treatment yield and X_0 = control yield.

To calculate the VCR of combined intercrops, this formula has been modified to consider the price of millet and cowpea simultaneously. This is reformulated as follows:

$$\text{VCR} = \frac{((X - X0) \times \text{ Product price at harvesting}) + ((Y - Y0) \times \text{ Product price at harvesting})}{\text{Kg fertilizer } \times \text{price per kg fertilizer}}$$

where $(X - X_0)$ is the increased yield of species an intercropped with species b and $(Y\text{-}Y_0)$ is the increased yield of species b intercropped with species a. The fertilizer microdosing is economically efficient if only its value is higher than two (VCR > 2) [31].

2.7 Statistical analysis

The analysis of variance (ANOVA) was carried out using the JMP version 9.0.0 software (SAS Institute, Cary, NC, USA). The separation of the means for the various parameters measured was carried out by the Student Newman Keuls test at the threshold of $\alpha = 5\%$. The generalized linear model was performed to assess the relationship between yield data, competition index, monetary advantage and cowpea genotypes, and treatment.

3 Results

3.1 Cowpea yield

Table 2 shows the effect of the microdose and intercrop with millet on seed yields, dry biomass yield, and weight of hundred seeds of cowpea genotypes studied. The ANOVA shows that the dry biomass yield, seed yields, and hundred seed weight are significantly affected by the cowpea genotypes in 2020 and 2021, as well as by the micro dose supply except for hundred seed weight, where there is no significant difference in 2020 and 2021 (Table 2). At the treatment level, we noted higher yields of cowpea genotypes in the sole crop, compared to the yields in intercropping. At the genotype level, ISV128 gave higher seed and biomass yields in 2020 and 2021 compared to Tiligré which, however, has the highest thousand seed weights.

Both cowpea genotypes had higher yields in intercropping and the sole crop with the microdose treatment compared to the control with clear advantages for the sole crops. We note with the microdose treatment in intercropping, an increase in seed yield of 43.30% in 2020 and 166.5% in 2021 for ISV128 and for Tiligré respectively, 42.02% and 168.75%. For the sole crop, compared to control without microdose, the increase was about 76.10% in 2020 and 29.31% in 2021 for ISV128 and, 79.12% and 98.4% for Tiligré.

Table 2 Effect of intercropping and fertilizer microdosing on cowpea yields

Treatment		Genotypes	Grain yield (kg/ha)		Biomass yield (kg/ha)		TSW* (g)	
			2020	2021	2020	2021	2020	2021
Fertilizer	Intercrop	ISV128/Millet	922.3a	541.1a	7472.0a	3645.8a	11.13b	11.35b
		Tiligré/Millet	583.7b	272.8b	5778.0a	3027.8a	18.50a	17.63a
		P value	*0.05*	*0.02*	*0.23*	*0.07*	*0.00*	*0.00*
		SE ±	143.90	86.87	1459.00	302.00	0.37	0.75
	Sole crop	ISV128	1680.0a	772.0a	8430.6a	4697.9a	11.17a	11.10b
		Tiligré	979.7b	695.6a	6472.2a	4354.6a	20.00a	18.06a
		P value	*0.05*	*0.33*	*0.20*	*0.24*	*0.00*	*0.02*
		SE ±	299.00	60.12	1547.00	207.50	1.04	1.09
Control	Intercrop	ISV128/Millet	643.6a	203.7a	4833.3a	1750.0a	10.00a	10.74b
		Tiligré/Millet	4110a	101.5b	2666.7b	1638.9a	18.23a	17.03a
		P value	*0.38*	*0.30*	*0.02*	*0.56*	*0.00*	*0.04*
		SE ±	285.90	106.00	721.70	212.10	1.54	2.66
	Sole crop	ISV128	954.0a	596.9a	6611.1a	3583.3a	10.60b	10.43a
		Tiligré	579.3b	350.6a	4944.5a	2614.6b	19.03a	14.97a
		P value	*0.04*	*0.11*	*0.27*	*0.01*	*0.00*	*0.13*
		SE ±	157.50	90.45	1593.00	98.30	0.44	1.83
Genotype (G)			***	**	**	*	***	***
Treatment (T)			**	***	**	***	ns	ns
G*T			ns	ns	ns	ns	ns	ns

*, **, ***Significant at the probability threshold of 0.05, 0.01, and 0.005, respectively; ns: Not significant ($p > 0.05$). Numbers with the same letter(s) in the same column are not significantly different at the $p < 0.05$ threshold

TSW: Thousand Seed Weight

3.2 Millet yield

The effects of intercrop and microdose on millet yields are presented in Table 3. The results indicated that there was no significant effect of cowpea genotype on grain yields, biomass, and thousand-seed weight of millet both in 2020 and 2021. The treatment effect was only significant in 2021 on grain yield and in 2020 on dry biomass yield.

Indeed, the grain and dry biomass yields obtained in the sole millet crop were higher than those obtained in intercropping with cowpea. By comparing the two treatments, microdose and control, the grain yields of millet in intercropping have increased by 14.4% in 2020 and 101.5% in 2021 for ISV128, and respectively by 2.7% and 113.18% for Tiligré. This increase was 18.84% in 2020 and 78.38% in 2021 for sole millet.

3.3 Yield advantages

Table 4 shows that there was no significant effect of intercropping and microdose on total LERs in 2020 and 2021. The intercrop compared to the sole crops with or without the microdose are more advantageous in terms of LER with values greater than 1 in both years.

3.4 Competition index and mixed cowpea-millet monetary advantage

ANOVA shows that there is no significant effect of cowpea genotypes on the aggressivity and competition ratio of millet and cowpea in 2020 and 2021 (Tables 5 and 6).

Table 3 Effect of intercrop and microdose on millet yields

Treatment	Cultural practice	Grain yield (kg/ha)		Biomass yield (kg/ha)		TSW (g)	
		2020	2021	2020	2021	2020	2021
Microdose	ISV128/Millet	703.20a	639.30a	5277.80a	3465.00a	8.46a	8.02a
	Tiligré/Millet	515.60a	567.00a	4263.90a	3757.00a	8.20a	8.20a
	Sole Millet	906.90a	637.05a	5444.40a	4569.00a	8.42a	8.13a
	P value	*0.07*	*0.88*	*0.14*	*0.57*	*0.89*	*0.98*
	SE ±	161.30	195.20	662.50	1268.00	0.69	1.22
Control	ISV128/Millet	614.79b	317.27a	4265.00a	3424.00a	6.75a	7.84a
	Tiligré/Millet	501.74b	265.96a	3381.90a	3472.00a	8.02a	7.75a
	Sole Millet	763.13a	357.13a	4270.80a	3688.00a	6.86a	8.12a
	P value	*0.01*	*0.39*	*0.52*	*0.98*	*0.17*	*0.90*
	SE ±	69.85	75.36	1030.00	1644.00	0.79	1.00
Genotype (G)		ns	ns	ns	ns	ns	ns
Treatment (T)		ns	**	*	ns	ns	ns
G*T		ns	ns	ns	ns	ns	ns

*, **, ***Significant at the probability threshold of 0.05, 0.01, and 0.005, respectively; ns: Not significant (p > 0.05). Numbers with the same letter(s) in the same column are not significantly different at the p < 0.05 threshold. ISV128/Millet = intercropping millet with ISV128 and Tiligré/Millet = intercropping millet with Tiligré

Table 4 Partial and total LER of millet and cowpea as affected by intercropping and microdose fertilizer in 2020 and 2021

Treatment	Cultural practice	Partial LER				Total LER	
		Millet		Cowpea		LER	
Microdose		2020	2021	2020	2021	2020	2021
	ISV128/Millet	0.78	0.82	0.65	0.78	1.43	1.60
	Tiligré/Millet	0.56	0.81	0.97	0.44	1.53	1.25
	P value	*0.27*	*0.98*	*0.06*	*0.13*	*0.65*	*0.29*
	SE ±	0.20	0.36	0.16	0.12	0.24	0.25
Control	ISV128/Millet	0.95	1.01	0.71	0.20	1.66	1.21
	Tiligré/Millet	0.71	0.8	0.716	0.25	1.43	1.05
	P value	*0.22*	*0.579*	*0.95*	*0.49*	*0.85*	*0.705*
	SE ±	0.19	0.32	037	0.06	0.52	0.37
Genotype (G)		ns	ns	ns	ns	ns	ns
Treatment (T)		ns	ns	ns	**	ns	ns
G*T		ns	ns	ns	*	ns	ns

*, **, ***Significant at the probability threshold of 0.05, 0.01, and 0.005, respectively; ns: Not significant (p > 0.05). ISV128/Millet = intercropping millet with ISV128 and Tiligré/Millet = intercropping millet with Tiligré

At the microdose treatment, there is no significant difference in the aggressivity of millet and cowpea in 2020 and 2021. The results show that in intercropping, regardless of the treatment and cowpea genotype, millet is more dominant than cowpea in 2020 and 2021.

Regardless of the cowpea genotype intercropped, the monetary advantage index is higher with the microdose compared to the control. At the genotype level, the monetary advantage is greater in intercropping with the ISV128 genotype in 2020 and 2021 with or without microdose.

In 2020, the microdose induced a gain of 24,913 FCFA ($40) and 134,092 FCFA ($212.54) in 2021 compared to the control in the combination with ISV128, while it was only 12,614 FCA ($19.99) and 16,422 FCFA ($26.03) respectively in 2020 and 2021 for Tiligré. The analysis of the results of the VCR shows higher values in sole cowpea than in the intercropping with millet on one hand and the VCR of the millet /cowpea intercropped is higher than the VCR of sole millet in 2020 and 2021 (Tables 5 and 6) on the other hand.

Table 5 Competition index of combined cowpea millet and economic advantage under microdose fertilizer and intercropping in combined crop and sole crop in 2020

Treatment	Cultural practice	Aggressivity (A)		Competition ratio (CR)		MAI	VCR
		Cowpea	Millet	Cowpea	Millet		
Microdose	ISV128/Millet	− 0.79	0.79	0.53	2.21	137,626	10.57ab
	Tiligré/Millet	− 0.43	0.43	0.78	1.42	69,250	5.66ab
	SoleISV128						18.15a
	Sole Tiligré						9.18ab
	Sole Millet						1.142b
	P value	*0.29*	*0.29*	*0.37*	*0.27*	*0.29*	*0.014*
	SE ±	036	0.36	0.3	0.76	56,824	5.77
Control	ISV128/Millet	− 1.06	1.06	0.38	2.72	112,713	
	Tiligré/Millet	− 0.69	0.69	0.53	1.93	56,636	
	P value	0.12	0.12	0.06	0.06	0.359	
	SE ±	0.23	0.23	0.07	0.39	20,638	
Genotype (G)		ns	ns	ns	ns	ns	
Treatment (T)		ns	ns	ns	*	ns	
G*T		ns	ns	ns	ns	ns	

*, **, ***Significant at the probability threshold of 0.05, 0.01, and 0.005, respectively; ns: Not significant (p > 0.05). Numbers with the same letter(s) in the same column are not significantly different at the p < 0.05 threshold. ISV128/Millet = intercropping millet with ISV128 and Tiligré/Millet = intercropping millet with Tiligré

Table 6 Competition index of combined cowpea millet and economic advantage under microdose fertilizer and intercropping in combined crop and sole crop in 2021

Treatment	Cultural practice	Aggressivity (A)		Competition ratio (CR)		MAI	VCR
		Cowpea	Millet	Cowpea	Millet		
Microdose	ISV128/Millet	− 1.37	1.37	0.75	1.69	155,767	14.76a
	Tiligré/Millet	− 1.25	1.25	0.41	2.94	47,339	8.38b
	Sole ISV128						4.38bc
	Sole Tiligré						8.62b
	Sole Millet						2.155c
	P value	*0.68*	*0.68*	*0.47*	*0.48*	*0.07*	*0.001*
	SE ±	0.25	0.25	0.38	1.45	30,917	1.40
Control	ISV128/Millet	− 1.24	1.24	0.13	7.6	21 ?675	
	Tiligré/Millet	− 1.04	1.04	0.21	4.6	10,830	
	P value	*0.75*	*0.75*	*0.15*	*0.18*	*0.624*	
	SE ±	0.56	0.56	0.035	1.47	8911	
Genotype (G)		ns	ns	ns	ns	*	
Treatment (T)		ns	ns	*	*	**	
G*T		ns	ns	ns	ns	*	

*, **, ***Significant at the probability threshold of 0.05, 0.01, and 0.005, respectively; ns: Not significant (p > 0.05). Numbers with the same letter(s) in the same column are not significantly different at the p < 0.05 threshold. ISV128/Millet = intercropping millet with ISV128 and Tiligré/Millet = intercropping millet with Tiligré

4 Discussion

4.1 Yield and yield advantage

The results showed the millet-cowpea intercrop was relatively more productive than the corresponding sole crops in 2020 than in 2021, despite a solid response to seasonal variation in rainfall. Millet and cowpea showed the best performance in 2020 resulting in better rainfall conditions, mainly their better distribution over time (Fig. 1). According to [17], better rainfall favored better plant growth and biomass production.

In both years, the results indicated that there was no significant effect of cowpea genotype on grain yields, biomass, and thousand-grain weight of millet both (Table 3). The small yield penalty in maize-cowpea intercropping has been reported by [32]. This can be explained according to [33], by the absence of interspecific competition for the two species having different growth habits. However, there is a slight advantage in the yield of millet in the sole crop compared to intercropping with cowpea.

The low performance of millet in yield in intercropping with cowpea has been reported by [23]. Ghosh [30] observed a decrease in millet yields in intercropping with groundnut due to high planting densities. According to [23], in the millet/cowpea intercropped, the late planting of cowpea allows for better production of millet. Other work carried out within millet/cowpea intercropped has shown a decrease in the yields of the two combined crops due to competition for environmental resources (nutrients, water and light) [34].

The millet yield penalty both with the microdose and control in intercropping compared to the sole millet was less significant in the subsequent year. This can be attributed to the additional nitrogen cowpea provides to soil following symbiotic fixation [22]. So, thanks to the complementarity of the root architecture of two plants in intercropping, the cereal can benefit from a better acquisition of nitrogen from the soil [35]. Increasing the density of cowpea in simultaneous sowing can contribute to improving yields in the Sahelian zone subject to recurrent droughts and low soils. According to [36], the simultaneous sowing of cowpea with millet makes it possible to maximize the yield of cowpea.

Intercropping is a common practice, practiced by 87–96.6% of farmers depending on the regions of Niger [37, 38]. In general, farmers are not in favor of simultaneous sowing and increased sowing densities of cowpea, because it can reduce millet yields. Farmers, therefore, seek to minimize intraspecific competition for environmental resources [39].

In this study, we had opted for simultaneous sowing and our results clearly showed that with intercropping, farmers can produce more using the same amount of fertilizer or even less than required in a sole crop. In intercropping, only millet has benefited from the microdose, this will allow farmers to save money for the purchase of fertilizers. Cowpea has a major economic interest for farmers who can immediately sell it after harvesting for family needs.

In intercropping, cowpea genotypes grain yields are low compared to sole crop both in fertilizer and control treatment the two years contrary to the trends observed with millet. This could be explained by the simultaneous sowing as observed by [32], which obtained a reduction of cowpea yield in the same date intercrop with maize by between 20 and 63%.

Increasing in cowpea sowing density was followed by high production of dry biomass both for the microdose and for the control treatment (Table 2). These results were different from the findings reported by [21] under the same conditions. This can be explained by an increase in the density of cowpea seedlings in our study (106,666.67 plants/ha) against (90,000 plants/ha) for cowpea Sadoré local which is late and spread in the study [21].

The significant development of biomass can be an important asset in the efficient use of water for rainfed crops in arid zones. Indeed, global climate change can lead to significant potential evapotranspiration and a decrease in precipitation in the arid zones. In these conditions, cowpea-millet intercrop can contribute to covering the soil surface reducing the proportion of the total water that is evaporated and increasing water use efficiency [40]. According to [41], when LER > 1, water can have been used more effectively because more water has been used by crops by transpiration that was lost by evapotranspiration.

The gains in yields and efficient use of land in the millet /cowpea intercropped compared to their reference in sole crop clearly showed the advantage of intercropping with LER values greater than 1 with or without the microdose. Similar results were obtained by [32, 41] in the maize/cowpea intercropped. Intercropping is more beneficial and profitable when the resources of the environment are exploited to the maximum by the intercropping crops.

4.2 Analysis of the competition index

Aggressivity and competition ratio (Tables 5 and 6) show that millet is dominant in the cowpea genotypes when intercropped with it. These results are consistent with those obtained by [28] showing the dominance of millet and sorghum over groundnuts.

Due to the higher competitiveness of millet for the use of soil nitrogen and light, it can reduce the growth of cowpea which results in the reduction of dry matter yield due to shading [42]. Solar radiation is one of the main resources determining the growth and yield of crops when sown simultaneously, especially when other resources are not limiting to growth [43].

At the genotype level, ISV128 is less aggressive and offers less competition to millet compared to Tiligré. It is, therefore, the most suitable for intercropping with millet. At the treatment level, millet is less competitive and less aggressive with the microdose treatment than with the control (Tables 5 and 6), unlike cowpea genotypes which are more competitive with the microdose treatment and less with the control. This can be explained by the fact that cowpea in the intercropping took advantage of the phosphorus supplied to millet in the form of NPK and developed to oppose strong competition to millet. Sime and Aune [32] Observed positive response of cowpea to the application of nitrogen and phosphorus in the maize /cowpea intercropped.

4.3 Socio-economical potential and resilience attribute of cowpea-millet intercropping

Regardless of the cowpea genotype intercropped, the monetary advantage index is higher with the microdose compared to the control. At the genotype level, the monetary advantage is greater in intercropping with the ISV128 genotype in 2020 and 2021 with or without microdose.

In 2020, the microdose induced a gain of 24,913 FCFA and 134,092 FCFA in 2021 compared to the control in combination with ISV128, while it was only 12,614 FCA and 16,422 FCFA respectively in 2020 and 2021 for Tiligré. This demonstrates that the microdose combined with intercropping millet/cowpea can be a compensating solution for the loss of investment for small farmers who can produce more and cheaper in the context of climate change. This may help to build the farmer's resilience and promote the sustainability of this practice. Other research also indicated the economic benefits of intercrops over monocrops. For example, [44] showed that the maize/cowpea intercropping appeared to be the most productive and economic intercrop combination than the maize sole crop. Sime and Aune [32] demonstrated that the within-row maize-legume intercropping could be a more profitable and acceptable crop production option for farmers.

The analysis of the results of the VCR shows higher values in sole cowpea than in the intercropping with millet on one hand and the VCR of the millet /cowpea intercropped is higher than the VCR of sole millet in 2020 and 2021 (Tables 4 and 5) on the other hand.

The intercrop with ISV128 gave more monetary advantage and also shows a higher VCR, than with Tiligré (Tables 4 and 5). Indeed, ISV128 is less competitive, less aggressive and more productive in intercropping than Tiligré. The VCRs are higher in sole cowpea crops because of the high cost of cowpea on the market (450 FCFA). However, the sole millet crop gives VCRs that are largely below (Tables 5 and 6) the VCRs in intercropping. This demonstrates the risk in economic terms of applying the microdose in the form of NPK as shown by [20] in Fakara in Niger. Economically, we can also say that millet/cowpea intercropping was more advantageous than the sole crop of millet.

5 Conclusion

In this study, we noticed a clear advantage of intercropping in all treatments from an agronomic and economic point of view compared to the sole millet crop. Microdose fertilizer led to a gain in the yield of millet and cowpea in two successive years. However, it did not give promising results from a profitability point of view for the sole millet crop. The intercropping reduced the yields of both crops compared to their reference in the sole crop. In terms of cowpea genotypes, in the sole crop and intercropping, ISV128 is the most suitable from an agronomic and economic point of view in the Sahelian context which the study recommends being vulgarized to be used massively by the farmers for reducing the farmers' vulnerability. The combination of microdosing fertilizer and cereal-legume intercropping could prove to be a strategy of resilience and the fight against famine for farmers in the context of climate change. Farmers would then be advised to use the microdose combined with a grain legume crop to compensate for losses due to the purchase of inputs in their field. The study should be extended to other improved cowpea and millet genotypes for intercropping to be attractive to farmers, access to fertilizers where improved varieties must be facilitated by the government and other relevant agencies. Our study recommends further studies on the combined effect of fertilizer microdosing and intercropped millet/cowpea effect on agronomic and economic advantages in prone Sahel area at large scale farming with a focus on population demography and gender perspective.

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Data availability The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Consent for publication Not applicable.

Competing interests The authors declare no competing interests.

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