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Combining soil fertilization, cropping systems and improved varieties to minimize climate risks on farming productivity in northern region of Burkina Faso

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Abstract

Background: In search of options to cope with climate change and variability, a trial combining fertilization and improved varieties of millet and cowpea (intercropped or as sole crop) was conducted on three sites (Lemnogo, Tibtenga and Ramdolla) in the northern region of Burkina Faso. The application of cattle manure (3 t ha^{-1}), micro-dose (3 g $hole^{-1}$ equivalent to 62 kg ha^{-1}) of a mineral fertilizer composed of 14 % N, 23 % P_2O_5 and 14 % K_2O (NPK), their combination and a control (no manure and no NPK) as four soil fertilization options, two improved varieties of millet (SOSAT-C88 and IKMP5), two varieties of cowpea (KVX 396-4-5-2D and KVX 61-1) and two cropping systems (millet–cowpea intercropping, sole crop) were tested on-farm for two seasons (2013 and 2014). During the third season a survey was conducted on the acceptability by farmers of the tested combinations as a way of buffering or coping with rainfall variability.

Results: Two-year trial revealed that the combination of manure and NPK applied to the intercropping of millet and cowpea significantly increased crop production (land equivalent ratio $= 1.83 \pm 0.18$ and 1.78 ± 0.20, intercropping millet variety IKMP5 with cowpea KVX 61-1 and intercropping millet variety SOSAT-C88 with cowpea KVX 396-4-5-2D, respectively). During erratic rainfall year, intercropping millet IKMP5 and cowpea KVX 61-1 performed the best, while under well-distributed rainfall conditions, intercropping millet SOSAT-C88 with cowpea KVX 396-4-5-2D displayed higher production, respectively, for millet and cowpea. Some varieties were not well accepted by most farmers (based on a survey of 36 farmers) mainly because of loss in grains before harvest for millet IKMP5 (97 %) and high grain attacks by insects in storage for cowpea KVX 61-1 (89 %). The alternative for farmers rejecting these varieties could be the intercropping of millet SOSAT-C88 and cowpea KVX 396-4-5-2D fertilized with manure.

Conclusions: Making weather forecasts and related agronomic advices available to farmers in this region will allow them to better plan their agricultural practices such as mineral fertilizer application and will also be a great move toward climate-smart agriculture. Developing more performant storage measures that drastically reduce insect attacks for some of the tested varieties (cowpea KVX 61-1, for instance) could contribute to promoting their adoption.

Keywords: Acceptability, Climate risks, Climate-smart agriculture, Soil fertilization

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Background

Agriculture in Burkina Faso is characterized by low yields primarily due to poor climate conditions and low soil fertility. This situation is worse in the northern region where rainfall is low and uncertain (630 mm per year) and the environment is much degraded as a result of recurrent droughts and human pressure. Soil degradation in that region is a consequence of high erosion and shortened period or even lack of fallow as a mean to restore soil fertility as in the past when population pressure on lands was lower [1]. Indeed, soils are Lixisol (leached ferruginous tropical soils) which have severe limitations such as poor structural stability and high erodibility of the topsoil [2, 3]. They have low organic matter, nitrogen, phosphorus and potassium contents and a strong tendency to acidification [3]. In addition, crusted soils locally called zipellé that need restoration before any crop production are common in the area [4].

In such conditions, farmers practice subsistence agriculture with millet (*Pennisetum glaucum*) and sorghum (*Sorghum bicolor*) as staple cereals and sesame as cash crop. The secondary crops are cowpea (*Vigna unguiculata*), groundnut (*Arachis hypogaea*) and Bambara groundnut (*Voandzeia subterranea*). The average yields of the main staple crop (sorghum and millet) are in the order of 400–500 kg ha^{-1} varying between years depending on rainfall amount and distribution [5]. Chemical fertilizer utilization is very low because of its cost, whereas manure application is common even though not at the recommended dose due to its limited availability. Cereals are often intercropped with cowpea or simply rotated in the same field [6, 7]. At harvest, crop residues are removed from the fields to feed livestock as animal husbandry is extensive and most animals are left to roam reducing manure production which is crucial for crop production in the region. Indeed, most farmers have livestock including sheep, goats and cattle. Donkeys are mostly used for traction, but few farmers use oxen.

Given these precarious climatic and environmental conditions farmers have opted for restoring their lands using locally adapted integrated soil and water management practices including the construction of stone bunds, half-moons and zaï pits [8–11]. Such techniques are adapted by each farmer to his own socioeconomic conditions. Besides, intercropping of cereals and legume crops (mainly cowpea) is also used to restore soil fertility as the latter fix nitrogen that can benefit the associated crop or leave some residuals of this nutriment in the soil for the next cereal crop [12]. Another advantage of cereal-cowpea intercropping for farmers is the double products from the two crops on the same plot [12] with the guarantee to harvest the early maturing one (cowpea) even in the case of an early end of the rainy season. Indeed, higher rainfall variability and shorter rainy season have forced farmers to seek and use early maturing and drought-tolerant crop varieties [13]. In line with farmers' needs for varieties adapted to changes in climate, researchers have developed early maturing and productive varieties for such conditions. Therefore, combining soil management practices and the use of improved varieties may prove to be a viable option to buffer or cope with risks associated with rainfall variability, thus making the agriculture in such harsh environment smarter. Thus, the present work aimed to investigate how the combined use of soil fertilization and improved varieties can help farmers cope with climate changes. The specific objectives were to analyze the effectiveness of combining soil fertilization and improved varieties in climate risk reduction and to identify the determinants of the acceptability by farmers of these combinations.

Methods

Study sites

The study was conducted in three villages in the province of Yatenga, namely Tibtenga in the rural commune of Koumbri, Lemnogo and Ramdolla in the rural commune of Barga (Fig. 1). The climate is Sahelian, characterized by two seasons: a hot and dry season from October to May and a rainy season from June to September. The duration of the rainy season varies from 1 year to another, with maximum precipitation recorded between July and August. The average annual rainfall is 630 mm with high variability for the last 30 years (data from Direction Générale de Météorologie, Burkina Faso). The highest rainfall deficits were recorded from 1970 to 1990 (Fig. 2).

Soils characteristics vary from gravelly soil on hilltops to sandy, clay or loamy soil in lowlands. Generally, they are shallow and have low organic matter content. Soils of the experiment fields in the three villages were Lixisol which are known to have low organic matter content, to be *P* limited and tend to have an acid pH. Currently, there are no longer fallows in the three villages as in the past because of the high pressure on lands for farming activities. The experiment fields were exploited for more than 10 years in a row before 2013. Crops grown during the last 2 years (2011 and 2012) before our experiment were successively groundnut and cowpea in Ramdolla, groundnut and Bambara groundnut in Tibtenga and 2-year continuous groundnut in Lemnogo.

Agriculture is still characterized by low productivity and high dependence on natural conditions. Because of its subsistence nature, food crops like millet, cowpea and groundnut are dominant as opposed sesame which is grown as cash crop. There is a rotation between cereals, cowpea and groundnut. In addition, millet is often intercropped with cowpea: sowing the two crops in the

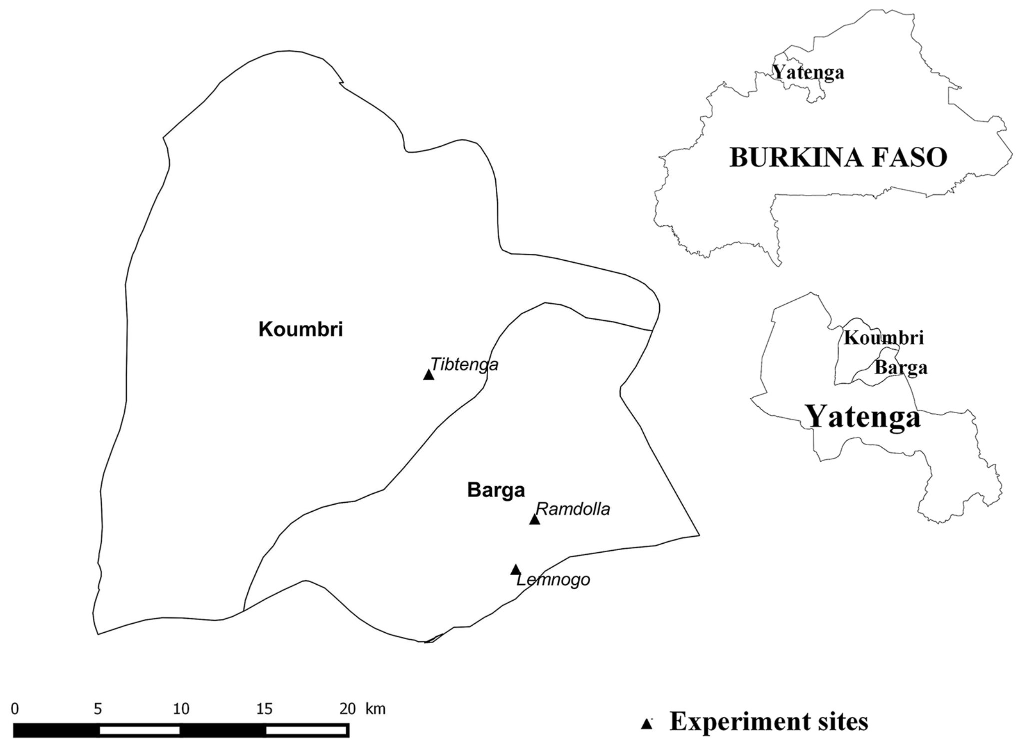

Fig. 1 Map of the experimental sites (Lemnogo, Tibtenga et ramdolla) in the northern region of Burkina Faso

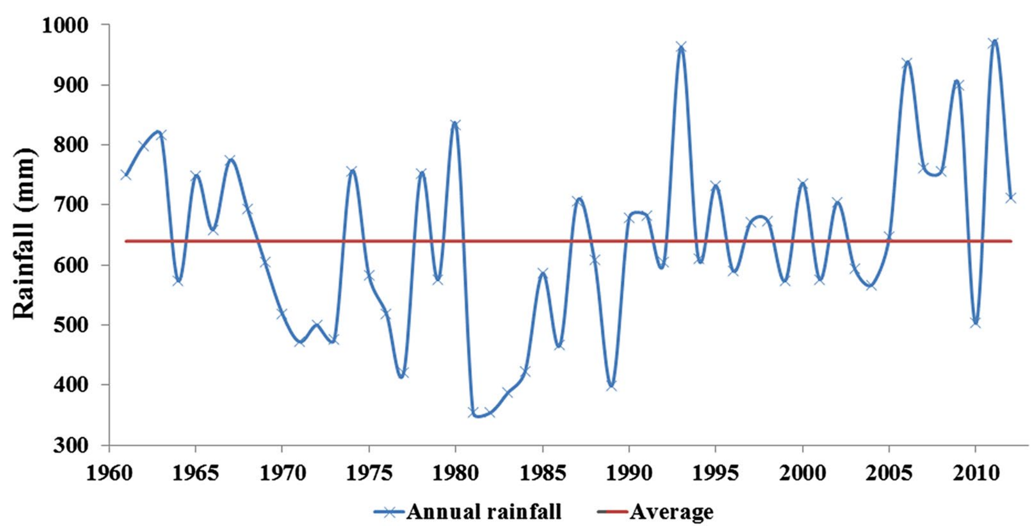

Fig. 2 Variability of rainfall from 1961 to 2012 at Ouahigouya in the northern region of Burkina Faso *Source*: Data from direction Générale de Météorologie, Burkina Faso

same sowing bed or rarely on the same line. Except the cash crop (sesame) for which an improved variety SR42 is provided for free by the national extension service, farmers use their own local varieties for the other crops. The maturing cycle of local varieties varies from 130 to 180 days for millet and 80–100 days for cowpea [14]. Most fields are sowed after a hand plowing or a ridging using a donkey. On crusted soils, zaï pits are dug before the rainy season (April) to be later used as sowing beds. Manure or compost of domestic organic wastes is applied in zaï pits and on some fields (cereal, sesame) depending on its availability. The average cattle manure application was estimated to be 2 t ha^{-1} by the extension service and an average 42 kg ha^{-1} of mineral fertilizer (14 % N, 23 % P_2O_5, 14 % K_2O) was applied mainly for sesame and in some zaï pits for millet, no matter of the soil content in these elements, which is usually very poor. The recommended dose by extension service for millet in Burkina Faso is 100 kg ha^{-1}, which is not applied by farmers because of the cost and also the availability in villages. Livestock that comes as second activity after agriculture is one of the main sources of income for the population, especially for women [15]. It provides for families' needs, especially in case of cereal deficit (poor production years) and lean periods [16].

Materials

The trial on soil fertilization and cropping systems was conducted with two improved varieties of millet (SOSAT-C88 and IKMP5) and two improved varieties of cowpea (KVX 396-4-5-2D and KVX 61-1) adapted to the climatic conditions of the northern region of Burkina Faso. SOSAT-C88 (M1) and IKMP5 (M2) are short maturing varieties of millet whose cycles are 90 and 110 days in length, respectively. These two varieties are drought tolerant with an average grain yield of 600 and 650 kg ha^{-1}, respectively [17]. The two cowpea varieties KVX 396-4-5-2D (C1) and KVX 61-1 (C2) have short maturity cycle (70 days) and an average yield of 1.2–2 t ha^{-1} [18]. These varieties have been introduced in the area as a response to farmers' queries for productive varieties adapted to the shorter rainy season and drought spells currently observed. The maturing cycle of local varieties from 130–180 and 80–100 days, respectively, for millet and cowpea constitutes a risk with regard to shorter rainy seasons and poorer rainfall distribution. Most of the local varieties have high biomass production because farmers need straws and haulms of crops for their livestock in addition to grains for their own food. Therefore, the introduced varieties, apart from their early maturity and drought tolerance, should combine good production of biomass and grains to fulfill farmers' needs.

Methods

The on-farm trial was conducted at three sites (Lemnogo, Ramdolla and Tibtenga) for 2 years (2013 and 2014). The trial was a combination of fertilization [application of cattle manure and mineral fertilizer composed of 14 % N, 23 % P_2O_5 and 14 % K_2O (NPK)], crops association and an introduction of improved varieties. Fertilization treatment had four levels, namely (1) manure + NPK, (2) manure, (3) NPK and (4) control (no manure and no NPK). The manure dose was set at 3 t ha^{-1} to reflect its availability from the producers. Cattle manure with moisture content of 15 % was used for the experiment. Mineral fertilizer application was a micro-dose of NPK at a dose of 3 g per hole (62 kg ha^{-1} at a sowing spacing of 80 cm × 60 cm) [19]. Varieties and cropping systems were combined to have 8 levels of treatment (M1, M2, C1, C2, M1C1, M1C2, M2C1 and M2C2). The association of millet and cowpea was made in interspersed rows of the two crops. The sowing spacing was 80 cm between lines for both crops and on a line 60 and 40 cm for millet and cowpea, respectively. Before sowing, plots were plowed using oxen traction and every 3 weeks the plots were manually weeded. No pesticide treatment was applied. The experimental design was a split plot with three replicates (the three villages). Each replicate was divided into four main plots to which the levels of fertilization were randomly assigned. Each main plot was then divided into 8 subplots to which the levels of combination "variety × cropping systems" were randomly assigned (Fig. 3). The experimental unit was a plot of 5 m × 10 m (50 m^2). At harvest, total aboveground crop biomass was weighed after drying and grain production of each crop was weighed to estimate yield.

Two parameters were calculated to evaluate crop performances: the rainfall use efficiency (RUE) and the land equivalent ratio (LER). RUE was calculated as follows: $\mathrm{RUE} = \frac{\text{Grain yield}}{\text{Total rainfall}}$. RUE (kg mm^{-1}) is the efficiency of rainfall use by a crop to produce grains. Then the total rainfall (mm) used for calculation is the sum of rainfall from sowing time (1st–15th July) to crop maturity (mid-October). According to the rainfall data from 1965 to 2015 of the national meteorological service, the rainy season in the experiment area starts in the second half of June and ends in first half of October in average. Total rainfalls were 378 and 476 mm in 2013 and 2014, respectively.

LER is defined as the total land area required for single crop to give the yields obtained in the intercropping mixture [20]. LER value was estimated using the following equation [21]:

$$\mathrm{LER} = \frac{\text{Yield of millet under intercropping conditions}}{\text{Yield of millet under sole crop conditions}} + \frac{\text{Yield of cowpea under intercropping conditions}}{\text{Yield of cowpea under sole crop conditions}}$$

LER is the sum of partial LERs of the two crops and its value should be 1 in theory if the agro-ecological characteristics of each crop under intercropping conditions are exactly the same while the partial LERs should be 0.5 for each [21, 22]. Then LER <1 means crops perform better in sole cropping and if LER >1 it means there is more advantage in intercropping [22]. The LER value

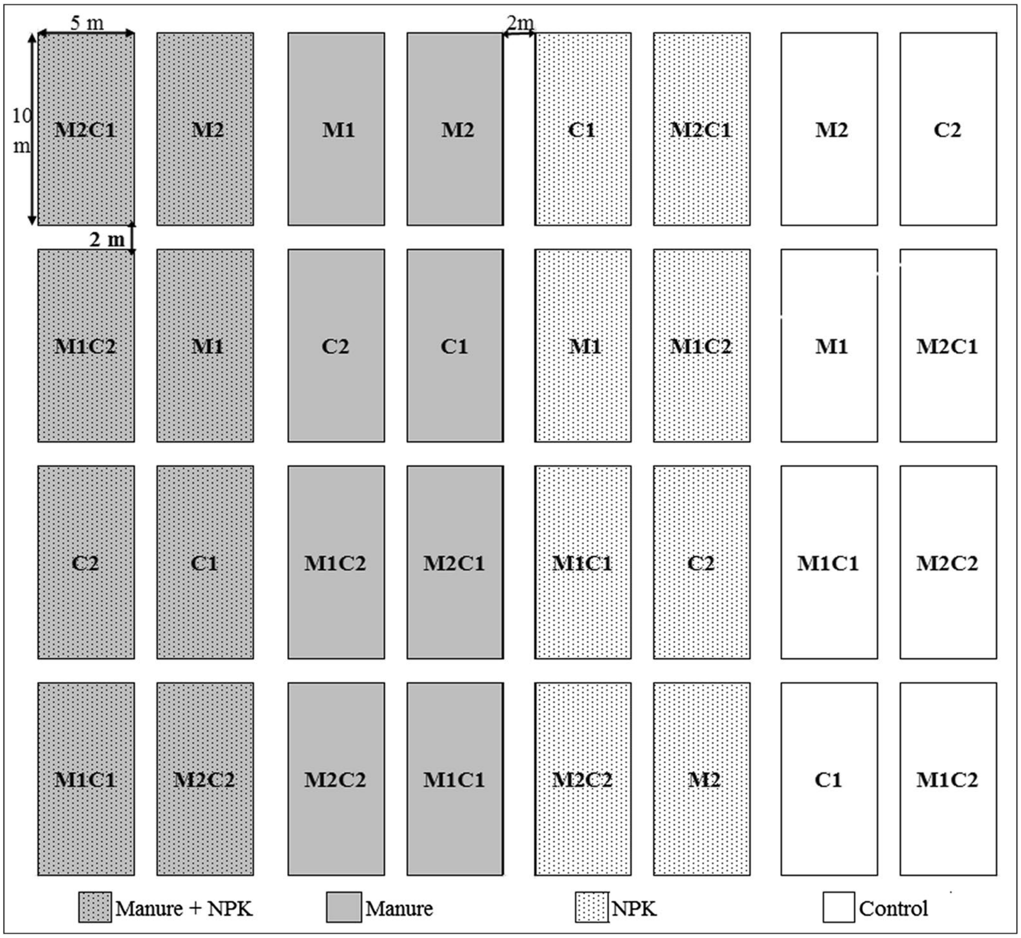

Fig. 3 Main block of the experimental design showing fertilizer applications and crop combinations repeated in three sites (Lemnogo, Tibtenga and Ramdolla) in the northern region of Burkina Faso. M1 = Millet 1 = SOSAT, M2 = Millet 2 = IKMP5, C1 = Cowpea 1 = KVX 396-4-5-2D, C2 = Cowpea 2 = KVX 61-1, M1C1 = Intercropped Millet 1 and Cowpea 1, M1C2 = Intercropped Millet 1 and Cowpea 2, M2C1 = Intercropped Millet 2 and Cowpea 1, M2C2 = Intercropped Millet 2 and Cowpea 2

was calculated for each year and each crops association according to the four fertilization treatments (manure, NPK, manure + NPK and control). Then LER values of crops associations were compared for cropping years and fertilization treatments.

As part of the evaluation, the views of farmers about the acceptability of the tested options were assessed by asking which ones of the options they were ready to choose and try in their own fields. Beyond the classic way of choosing treatments without a commitment to take a risk, the approach in the current experience was to have farmers not only selecting the potential best options but showing the level of risk they were ready to take in trying these options in their own fields. At the beginning of the cropping season 2015, a survey was conducted to assess the acceptability of the chosen options by 36 farmers in the three villages. This survey was supplemented by direct observation in farmers' fields.

Data analyses

Data were analyzed using library Agricolae (1.2–1) of R software (3.2.1). Two-way repeated-measures analyses of variances were applied to crop data taking into account the effect of cropping year, village, fertilizer application, crop combination and their interactions. Significant differences between treatments means were tested using LSD test.

Results

Rainfall pattern of the two cropping seasons in the study area

As shown in Fig. 4, the two cropping seasons (2013 and 2014) of the study had similar rainfalls (518.5 and 523.5 mm, respectively). However, when considering the time between sowing and harvest of our experiment, there was a difference in rainfalls between the 2 years (378 and 476 mm, respectively, 2013 and 2014).

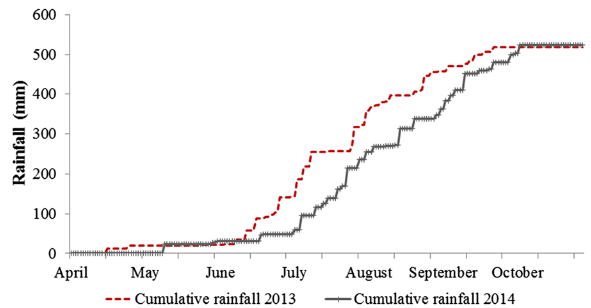

Fig. 4 Cumulative rainfall of the growing season 2013 and 2014 in the study site (northern region of Burkina Faso)

Referring to definition of drought even in Yatenga area [23], a maximum of seven (7) days without rain after an useful rain (8–10 mm), the 2 years rainfalls differed in drought events during plant growth periods (July to September). As shown in Fig. 5, a drought event occurred on the second decade of July 2013 after sowing. Indeed, only 2.5 mm was recorded during 16 consecutive days from the second decade to the third decade of July. In addition, the last rain event was on the third decade of September in 2013 while it was on the first decade of October in 2014. Therefore, crops have experienced a water stress at their maturing period in 2013.

Crop yields

The total biomass production was statistically different according to villages ($P = 0.000$), years ($P = 0.000$) and fertilizer application ($P = 0.003$). Total biomass produced in 2014 season (1460 ± 102 kg ha^{-1}) was higher compared to that of 2013 (600 ± 43 kg ha^{-1}). The increase in biomass production in 2014 occurred even on the control plot where no fertilizer was applied (Table 1). On both years, higher total biomass was observed when manure and NPK were applied together (1349 ± 139 kg ha^{-1}) compared to applying manure alone (1022 ± 109 kg ha^{-1}), NPK alone (1023 ± 141 kg ha^{-1}) and the control (728 ± 104 kg ha^{-1}). The total biomass production was higher in Ramdolla (1457 ± 40 kg ha^{-1}) and Tibtenga (1058 ± 144 kg ha^{-1}) and lower in Lemnogo (576 ± 89 kg ha^{-1}). The crop combinations did not differ significantly with respect to total biomass production. None of the interactions was significant (All $P > 0.05$). Cowpea and millet yields statistically varied according to villages ($P = 0.000$, both), cropping years ($P = 0.05$ and $P < 0.000$, respectively), fertilization application ($P = 0.006$ and $P = 0.003$, respectively) and crop combinations ($P = 0.000$, both). Both crop yields were higher in 2014 (218 ± 21 and 246 ± 23 kg ha^{-1}, cowpea and millet, respectively) compared to 2013 (160 ± 19 and 44 ± 6 kg ha^{-1}, cowpea and millet, respectively). This difference between yields of the 2 years was also observed in the control plot where no fertilizer was applied (Table 1). The increase in crop yield between years was higher for millet (463 %) compared to cowpea (37 %). Manure plus NPK application increased crop yield for cowpea by 75 % and millet by 112 % compared to the control. Applying manure alone also resulted in 36 and 56 % yield increase for cowpea and millet, respectively, while only millet yield was increased when applying NPK alone (88 %). Intercropping millet and cowpea resulted in both crop yield reduction, but cowpea displayed more decrease in yield (−35 %, on average) compared to millet (−16 %, on average).

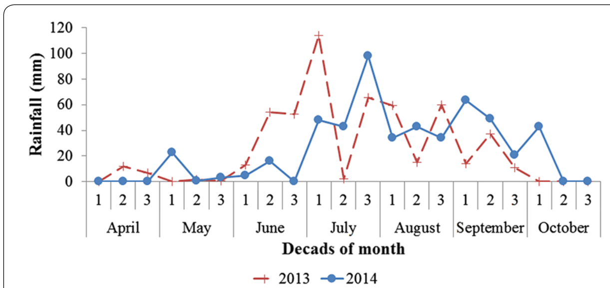

Fig. 5 Decadal rainfall variations in 2013 and 2014 in the study site (northern region of Burkina Faso)

There was a very highly significant interaction between cropping years and crop combinations for millet yield ($P = 0.0001$). Indeed, in 2013 the sole cropping of millet variety M1 yielded (55 ± 7 kg ha^{-1}) similarly as its intercropping with both cowpea varieties (50 ± 7, 44 ± 7 kg ha^{-1} for M1C1 and M1C2, respectively) but in 2014 its sole cropping yielded more (350 ± 27 kg ha^{-1}) compared to its intercropping with both cowpea varieties (318 ± 18, 297 ± 16 kg ha^{-1} for M1C1 and M1C2, respectively). There was no significant interaction for crop yields between villages and other factors and between cropping years and fertilizer applications. In addition, millet yield was similar in 2013 for manure and NPK applications while in 2014 NPK yielded more grains compared to manure application (Table 1). In intercropping involving the cowpea variety C1 and millet M1, the yield reduction was more pronounced for both crops when NPK fertilization was used (Fig. 6a, b). The intercropping of cowpea C2 with millet M1 resulted in a higher cowpea yield when applying manure compared to the combined application of manure and NPK (Fig. 6a). In the same intercropping, millet yield was higher when NPK was applied compared to applying both manure and NPK (Fig. 6b).

Table 1 Variation of millet and cowpea performances (kg ha^{-1}) at Lemnogo, Ramdolla and Tibtenga according to soil fertilization and cropping years in the north of Burkina Faso (2013, 2014)

Village	Fertilization	Total biomass (millet + cowpea)		Millet grains yield		Cowpea grains yield	
		2013	2014	2013	2014	2013	2014
Lemnogo	Control	271 ± 37	495 ± 64	10 ± 5	100 ± 29	50 ± 12	130 ± 30
	Manure	483 ± 77	690 ± 136	20 ± 14	120 ± 25	70 ± 17	185 ± 69
	Manure + NPK	613 ± 78	1060 ± 111	26 ± 16	230 ± 54	91 ± 23	255 ± 74
	NPK	440 ± 49	555 ± 49	41 ± 11	100 ± 23	68 ± 14	130 ± 36
Ramdolla	Control	501 ± 62	2115 ± 237	51 ± 12	305 ± 66	188 ± 50	328 ± 78
	Manure	803 ± 126	2288 ± 227	101 ± 22	360 ± 77	220 ± 73	295 ± 69
	Manure + NPK	1554 ± 179	2553 ± 289	154 ± 34	388 ± 96	503 ± 121	325 ± 91
	NPK	618 ± 91	2775 ± 335	88 ± 20	460 ± 117	140 ± 34	370 ± 96
Tibtenga	Control	503 ± 109	483 ± 84	0 ± 0	65 ± 20	90 ± 39	53 ± 13
	Manure	595 ± 140	1275 ± 132	9 ± 2	218 ± 49	127 ± 34	210 ± 48
	Manure + NPK	346 ± 84	1968 ± 316	22 ± 6	308 ± 81	209 ± 61	268 ± 62
	NPK	479 ± 69	1270 ± 235	4 ± 2	305 ± 88	163 ± 48	73 ± 19
Average		600 ± 43	1460 ± 102	44 ± 6	246 ± 23	160 ± 19	218 ± 21

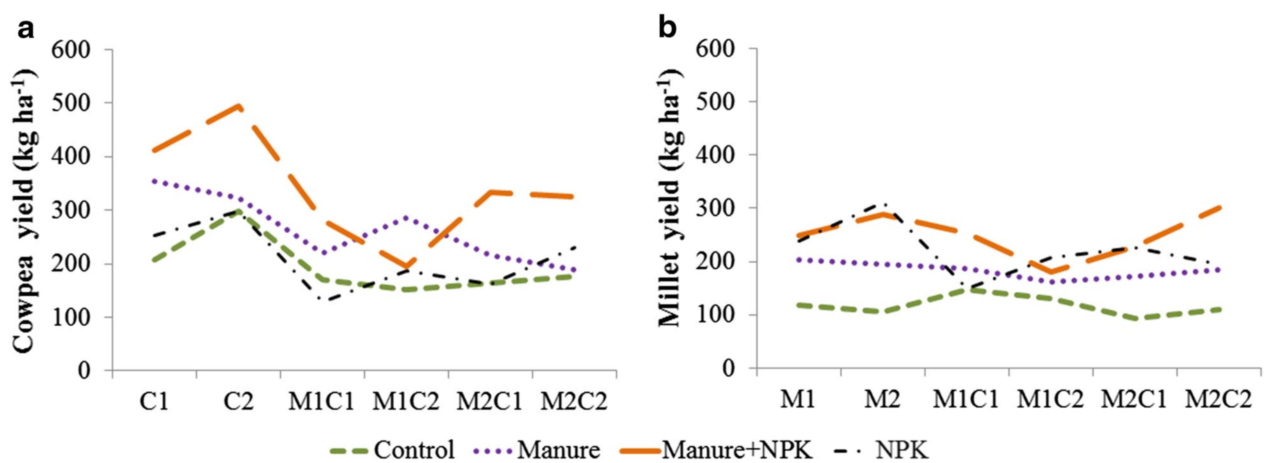

Fig. 6 Interactions between fertilizers applications and crop combinations for grain yield of cowpea (**a**), and grain yield of millet (**b**) in the northern region of Burkina Faso

Rain use efficiency (RUE)

RUE of cowpea was not significantly different between the two cropping years (0.42 ± 0.05 and 0.46 ± 0.04, 2013 and 2014, respectively), while its value in millet was very significantly lower ($P = 0.000$) in 2013 (0.12 ± 0.02) compared to 2014 (0.52 ± 0.05). Fertilizer effect was significant for RUE of cowpea ($P = 0.011$) and highly significant for RUE of millet ($P = 0.003$). Higher RUE value was obtained with manure plus NPK application for both crops (0.60 ± 0.09 and 0.41 ± 0.07, cowpea and millet, respectively). Manure application also increased RUE value of both crops (0.46 ± 0.06 and 0.30 ± 0.05, cowpea and millet, respectively), but only RUE of millet was increased by NPK single application (0.36 ± 0.07). Intercropping millet and cowpea resulted in a reduction of RUE of both crops, but cowpea displayed more decrease (−36 %, on average) compared to millet (−17 %, on average). As for RUE of millet, a highly significant interaction was noted between cropping years and crop combinations: Millet variety M1 had better RUE in 2014 compared to its intercropping with both cowpea varieties, while in 2013 similar RUE values were recorded.

Land equivalent ratio (LER)

There was a very highly significant difference between the two cropping years and crop combinations for LER

(P = 0.0005 and P = 0.0001, respectively). LER values of fertilization treatments did not differ significantly, whereas the interaction between cropping years and crop combinations was significant (P = 0.033). LER values were higher than 1 in all intercropping systems during both years. The values of LER were higher in 2014 compared to its values in 2013 (Table 2). Millet M2 intercropped with cowpea C2 had the highest LER value in 2013 (1.45 ± 0.12) compared to other crop combinations, while in 2014 the highest LER (1.88 ± 0.14) value was displayed by millet M1 intercropped with cowpea C1 (Table 2).

Evaluation and acceptance of tested technologies by farmers

Evaluation of fertilizer application

Most farmers (96 %) stated that manure application increases the density of weeds due to the increase of nutrients availability (66 %). Manure improves soil structure and as a consequence enhances soil moisture conservation capacity for 57 % of the interviewees. Better nutrients and water availability due to manure lead to an increase in crop yields. Similarly, most farmers recognized that NPK fertilizer application results in crop yield increase. However, they underlined that the efficiency of NPK is linked to good rainfall because in case of drought event after its application the mineral fertilizer kills the plants (80 %). In addition, some farmers (6 %) argued that in the long run, NPK application degrades the soil leading to the need for higher doses.

Evaluation of crop varieties

Cowpea C1 was described by farmers as a high productive (60 %) and early variety (46 %) with a good taste (60 %), tolerant to drought and with low attack of insects in storage (54 %). Farmers found C1 to display low soil coverage leading low to forage production (49 %). In addition, it has a spread maturity resulting in many harvests (more labor). Cowpea C2 is qualified as the most early maturing variety with grouped maturity, good productivity (33 %) and more fodder production but is less resistant to sustained moisture and is subject to high grain attacks by insects in storage (89 %). Farmers also highlighted that, because of its fast maturity, this variety is well suited for lean period.

Millet M1 was considered to be an early variety by 66 % of the interviewees and tolerant to drought (34 %) but less tolerant compared to their local variety (11 %). Millet M2 was also described as an early maturing and productive variety, but it loses some grains before harvest (97 %).

The intercropping of millet and cowpea in interspersed rows requires more labor according to most farmers (88 %) as they traditionally mix these crops in the same sowing hole. The majority prefers sole cropping because intercropping reduces cowpea yield and makes hard the weeding of the field (96 %).

Acceptance

After 2 years of the on-farm trial, most of the farmers were interested in the application of manure (67 %) and the application of both manure and NPK (33 %). The main raison of the acceptance of manure application by farmers was mostly its effect on soil fertility and water content. The application of NPK fertilizer alone is not accepted by most farmers because it kills the plants when drought occurs after its application (80 %) and it is costly (96 %).

Millet variety M1 and cowpea variety C1 are the most preferred by farmers (72 and 77 %, respectively). Some farmers have chosen to keep using their local varieties (11 and 9 % for millet and cowpea, respectively). The second improved varieties of millet (M2) and cowpea (C2) are accepted by 17 and 14 % of respondents, respectively.

Farmers who have accepted the millet M1 justified their choice by its precocity (66 %), its tolerance to drought (34 %) and its market value (46 %). The main reason that some farmers keep using their local variety is its better tolerance to drought compared to the introduced

Table 2 Variation of land equivalent ratio (LER) of cowpea and millet varieties intercropping between cropping years in the north of Burkina Faso (2013, 2014)

Crop combination	M1C1		M1C2		M2C1		M2C2	
Fertilizer	2013	2014	2013	2014	2013	2014	2013	2014
Control	1.22 ± 0.07	1.82 ± 0.17	1.12 ± 0.09	1.69 ± 0.20	1.13 ± 0.08	1.65 ± 0.06	1.33 ± 0.17	1.65 ± 0.06
Manure	1.16 ± 0.11	1.95 ± 0.16	1.13 ± 0.17	1.48 ± 0.18	0.91 ± 0.08	1.53 ± 0.04	1.53 ± 0.22	1.56 ± 0.06
Manure + NPK	1.09 ± 0.08	1.94 ± 0.05	1.15 ± 0.08	1.41 ± 0.15	1.24 ± 0.02	1.53 ± 0.20	1.52 ± 0.12	1.46 ± 0.15
NPK	1.14 ± 0.08	1.83 ± 0.19	1.11 ± 0.06	1.58 ± 0.12	1.16 ± 0.03	1.47 ± 0.19	1.42 ± 0.06	1.54 ± 0.06
Average	1.15 ± 0.08	1.88 ± 0.14	1.13 ± 0.10	1.54 ± 0.14	1.11 ± 0.05	1.55 ± 0.12	1.45 ± 0.12	1.55 ± 0.08

M1 = Millet 1 = SOSAT, M2 = Millet 2 = IKMP5, C1 = Cowpea 1 = KVX 396-4-5-2D, C2 = Cowpea 2 = KVX 61-1, M1C1 = Intercropped Millet 1 and Cowpea 1, M1C2 = Intercropped Millet 1 and Cowpea 2, M2C1 = Intercropped Millet 2 and Cowpea 1, M2C2 = Intercropped Millet 2 and Cowpea 2 ones. The majority of farmers (97 %) rejected the variety M2 because of the loss in grains of its panicles before harvest. The main arguments for the variety C1 of cowpea acceptance by farmers is its productivity (60 %), good taste (60 %), low insect attacks in storage (54 %), high forage production (49 %), precocity (46 %) and market value (46 %). The second cowpea variety (KVX 61-1) is accepted only for its good taste but rejected for its high grain attacks by insects in storage (89 %).

Discussion

Effect of rainfall distribution of the two cropping seasons on crops performances

Millet and cowpea have performed better in 2014 compared to 2013 in the on-farm trial. This increase in yields in 2014 was effective even on plots where no fertilizer was applied during the 2 years. Therefore, the increase could not be due to the residual fertilizer of the previous year but might be due to differences in rainfall distribution patterns. Indeed, even though cumulative rainfall amounts were similar during the 2 years, rainfall distribution was more erratic in 2013. A drought occurred in July causing high mortality of young plants of millet. That resulted in a low plant density at harvest and consequently in low yield. In addition, rain stopped at the end of September in 2013 when crops were at grain filling stage. This last drought event caused yield reduction mainly for millet as most cowpea fields were at maturity. That explains the higher increase of millet yield (463 %) from 2013 to 2014 compared to cowpea (37 %) and also the close values of RUE for cowpea during the 2 years as opposed its values in millet (0.12 ± 0.02 and 0.52 ± 0.05, 2013 and 2014, respectively). The erratic rainfall of 2013 reduced intercropped crop performances. Indeed, the average value of LER increased from 1.19 ± 0.06 in 2013 to 1.54 ± 0.09 in 2014. Drought events in 2013 increased competition for water between millet and cowpea that resulted in yield reductions compared to 2014 when rainfall was better distributed. This corroborates the findings of Yamoah et al. [24] on millet and cowpea intercropping in Niger.

Effect of fertilization and intercropping types on crop performances

Fertilizer applications had positive effect on crop performances (yield and RUE) but not on LER, suggesting that the main competition between the two crops in intercropping was for water as nutrient supply did not increase their LER. The effect of applying NPK alone on yields was more noticeable for both crops during 2014 with well-distributed rainfall. In contrast, the effect of applying manure on millet yield was of similar magnitude to applying NPK in 2013 while manure application yielded more cowpea grains compared to that of NPK during the 2 years. Indeed, applying manure could have increased water-holding capacity of soil as stated by Bationo and Mokwunye [25], therefore reducing water stress of plants during short drought events. Therefore, in erratic rainfall year, applying NPK alone increases the risk of crop failure for farmers. It should then be associated with manure or avoided if manure is not available. This highlights the necessity of the use of weather forecast by farmers for the planning of their cropping activities.

In addition, NPK application had negative effect on crop yields when cowpea C1 was intercropped with millet M1. However, combining NPK and manure resulted in the highest yields of both crop varieties in intercropping. Similarly, the effect of NPK was weak in cowpea C2 with millet M1 while applying manure resulted in better yield of cowpea in this intercropping. This suggests a high water competition in the intercropping of millet M1 with the two cowpea varieties. Indeed, these two intercropping systems have had the lowest RUE and LER in 2013 when drought spells occurred while in well-distributed rainfall year (2014) they have performed better. In contrast, millet M2 intercropped with cowpea C2 had higher LER and RUE during the erratic rainfall year (2013) compared to other crop combinations. In sum, intercropping millet M1 and cowpea C1 is suitable in well-distributed rainfall years while in years with drought spells the more indicated intercropping appears be the mixed of millet M2 with cowpea C2.

The values of LER were higher than one for all intercropping practices during the cropping years meaning that intercropping millet and cowpea was more productive compared to their sole cropping. Such result was found in a previous study in Burkina Faso [12] where LER of millet and cowpea intercropped ranged from 1.22 to 1.89. This advantage to intercropping system is explained by the fact that mixed crops might be using environmental resources in ways that are not competitive [12]. In a review of cereal and legume crop intercropping, the biological fixation of nitrogen has been pointed out as one of the advantages [26]. Such nitrogen supply benefits millet when intercropped with cowpea and is important in lower inputs agricultural systems [26].

The intercropping of cowpea and millet with the application of both manure and NPK generated the highest production of biomass. This is very important in the region for the forage requirements as livestock is the main income generating activity. Thus even in a year of low rainfall, forage availability guarantees a livelihood to the producers. In addition, this biomass converted into manure will be returned to the soil to increase its productivity.

Evaluation and acceptance of soil fertilization and crop varieties by farmers

Applying both manure and NPK was the best soil fertilization practice for millet and cowpea production in the on-farm trial. However, manure application was the most preferred practice of farmers. This choice of farmers is mostly based on climatic risk. Indeed, they justified it by the fact that soil humidity is better conserved with manure application. In contrast, they showed more reluctance in using NPK because of the risk of high mortality of plants when its application coincides with a period of drought spells. Indeed, our results confirmed that in year with drought spells, NPK application did not increase significantly crop yields. This risk related to the application of NPK can be avoided if weather forecasts are available to farmers and effectively used to plan the mineral fertilization application as suggested by Aune et al. [27]. In addition, the cost of the mineral fertilizer increases financial risks for farmers because of erratic rainfall. From our personal observation, the average rate of NPK applied is about 1 g per hole for farmers who apply it in millet fields. Therefore, the micro-dose of NPK (3 g per hole) used in our on-farm trial appears too costly for farmers. Aune et al. [27] reported 6 g of NPK per hole to give the highest yield of millet while 0.3 g per hole was the dose farmers could financially afford in Mali.

Minimizing climate risks was an important argument for the choice of crop varieties by farmers but not the determinant factor for their acceptance. Indeed, cowpea C1 was the most accepted by farmers because of its tolerance to drought, precocity, high productivity, good taste and low attack of insects in storage. Similarly, the acceptance of millet M1 by most farmers was justified by the precocity, tolerance to drought and market value of the variety. The acceptance of this last variety seems to be ruled by its precocity and market value as the performances of the two millet varieties in the on-farm trial showed that M2 was more drought tolerant than M1. In addition, most farmers argued that the panicles of M2 lose grains before harvest, reducing the yield. The reason of drought tolerance was also stated by some farmers to keep using their local varieties but some of these local varieties seem to be improved ones, introduced from other villages. In sum, the precocity and tolerance to drought of a variety are the key elements for climate risk reduction according to farmers' appreciation. The intercropping of millet and cowpea in interspersed rows was not accepted by most farmers because it requires more labor compared to their traditional practice: mixing these crops in the same sowing hole. They also prefer crops sole cropping because intercropping makes hard the weeding of the field.

Farmers of the northern region of Burkina Faso are practicing subsistence agriculture in a context of high climatic hazards. Many of their practices, as shown above, take into account minimizing risk of reduced rainfall, drought spells and early end of rainy season. The use of climate and weather information can improve their practices to assure better crop production [7, 28, 29]. The Participatory Integrated Climate Services for Agriculture (PICSA) which is a decision-making tool for farmers assisted by extension services and national meteorological services can help in this respect [28, 29]. Such tools have been designed to guide farmers to choose relevant crops or varieties for the cropping season and to plan their fields' activities during the season (weeding, applying fertilizers, fighting against pests, etc.) with regard to the predicted rainfall amount, the length and start date of the rainfall season and the timing of dry spells [7, 28].

Conclusions

The northern region of Burkina is facing high risk in crop production due to low soil fertility and erratic rainfall. The present study was an on-farm trial on soil fertilization practices and improved varieties of millet and cowpea for better production in a changing climate context. The results showed that the application of manure, NPK and the association of millet with cowpea significantly increased crop production but the best combination of crops varieties varied depending on rainfall distribution. Indeed, millet and cowpea intercropping yields better when using millet variety M2 and cowpea C2 in year of erratic rainfall. Unfortunately, these varieties are not well accepted by most farmers mainly because of their losses in grains before harvest for millet and in storage for cowpea. Further researches are needed to solve these two issues: Grain loss of M2 should be fixed by plant breeders, and entomologists should find better storage conditions for the cowpea variety C2. Farmers rejecting these varieties could use M1 and C1 in intercropping system and apply manure instead of NPK. In this region with high climate variability, farmers' choice of soil fertilization practices and crop varieties is determined by the ability of the option to reduce climate risk. In our endeavor toward climate-smart agriculture, it is necessary and urgent to make weather forecasts and related agronomic advices available to farmers to allow them plan their activities such as mineral fertilizer application, crop combination.

Abbreviations

ANACIM: National Civil Aviation and Meteorology Agency; INERA: Institut de l'Environnement et de Recherches Agricoles; CCAFS: Climate Change Agriculture and Food Security; CGIAR: Consultative Group on International Agricultural Research; ICRAF: World Agroforestry Centre; ICRISAT: International Crops Research Institute for the Semi-Arid Tropics; RUE: rainfall use efficiency; LER: land equivalent ratio; NPK: nitrogen, phosphorus and potassium fertilizer; PICSA: Participatory Integrated Climate Services for Agriculture; M1: Millet

1 = SOSAT-C88; M2: Millet 2 = IKMP5; C1: Cowpea 1 = KVX 396-4-5-2D; C2: Cowpea 2 = KVX 61-1; M1C1: Intercropped Millet 1 and Cowpea 1; M1C2: Intercropped Millet 1 and Cowpea 2; M2C1: Intercropped Millet 2 and Cowpea 1; M2C2: Intercropped Millet 2 and Cowpea 2.

Authors' contributions

JS, BAB, SB and LDN designed the experiments, the data collection instruments and gathered the data, and helped in analysis and write up. JB and RZ supervised the design, the entire data collection process and provided guide, corrections and supervision to the entire research and critically read and amended the manuscript. All authors read and approved the final manuscript.

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Competing interests

The authors declare that they have no competing interests.

Availability of data and material

The datasets analyzed during the current study are available from the corresponding author on request.

Ethics approval and consent to participate

The present study was validated as part of research programs by the scientific committee of "Institut de l'Environnement et de la Recherche Agricole (INERA)" to which belongs the first author. INERA has mandate and missions to generate scientific knowledge, technological innovations and decision support tools for improving agricultural sector in Burkina Faso (http://www.inera.bf/index.php/inera/missions). All procedures followed were in accordance with the Helsinki Declaration of 1975, as revised in 2000. Informed consent was obtained from all participants included in the study.

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