

Chapter 13

Improving Agronomic Efficiency of Mineral Fertilizers through Microdose on Sorghum in the Sub-arid Zone of Burkina Faso



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Abstract Maintaining and/or improving soil fertility under conditions of climatic deterioration remains one of the major challenges facing small-scale farmers of the sub-Saharan regions in ensuring their food production. To address this issue, trials combining mineral fertilizer microdosing, MD (2g NPK/seed hole), soil and water conservation (SWC) techniques (zaï associated or not with stone lines or grass strips) were conducted for three years with sorghum (local and improved varieties) on two sites in the north Sudanian zone of Burkina Faso. The main objective of the study was to analyze the effects of the different technology packages tested on sorghum yields and soil chemical characteristics. The results showed that the use of MD technique enabled to double sorghum grain yields. This effect was further enhanced when combined with SWC techniques (45%). The use of the improved sorghum variety increased grain yields by approximately 11%, 70% and 85% when combined with SWC, MD and SWC + MD techniques respectively. Regarding the impact of these technologies on soil fertility, plots developed with SWC techniques showed increases in total organic carbon, nitrogen and phosphorus contents as well as in available phosphorus between 30% and 80%.

Keywords North Sudanian zone • Organic fertilizer • Rainwater management • Soil fertility • Sorghum varieties

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13.1 Introduction

Sustainable management of agricultural soil fertility has always been a major challenge for farmers in the Sudanian savanna region and particularly in Burkina Faso (Piéri 1992; FAO 2009). Indeed, due to their pedogenetic origin, these soils have low inherent fertility (Lal 2000). The predominance of kaolinite in their clay fraction gives them very low restructuring capacity under natural conditions (Yang and Wei 2012; Phillips et al. 2015) and low water and nutrient retention capacity (Lahmar et al. 2012; Otalvaro et al. 2016). The depth of root soil is very often limited by the presence of a shallow hard pan. Sandy-silty-clayey of texture on the surface, these soils are very sensitive to slacking and runoff. Therefore, their low water holding capacity did not allow them to provide sufficient water to buffer the effects of drought spells often occurring during the growing cycle (Ouattara et al. 2006b; Sermé et al. 2015). Moreover, they showed widespread phosphorus deficiency and very low organic matter content, hardly reaching 1% (Elshout et al. 2001; Lompo 2009). Unfortunately, inappropriate cropping practices and insufficient levels of mineral fertilizers due to the low purchasing capacity of small-scale farmers have led to a drastic decline in soils fertility. As a consequence, soils set off a process of chemical degradation marked by organic matter depletion and increased deficiency in some basic mineral nutrients such as phosphorus. Lompo (2009) showed that the response curve of sorghum to phosphorus is nowadays highly related to agricultural land use intensity.

Given such a production environment on the verge of ecological rupture and the low capacity of farmers to invest in production factors (Bado 2002; Morris et al. 2007; Masse 2007; Tabo et al. 2007; Bagayoko et al. 2011), agricultural research efforts within the Sahelian area have focused on the development of simple and inexpensive packages of Integrated Soil Fertility Management (ISFM). This approach combines rainwater harvesting techniques, efficient use of organic matter and mineral fertilizers and the use of improved germplasm.

The use of mechanical and biological soil and water conservation techniques (stone lines; grass strips; agroforestry; etc.) allowed to disperse runoff and facilitate rainwater infiltration (Zougmore et al. 2000; Reij and Thiombiano 2003). Studies have shown that in years of rainfall deficit, increases in sorghum grain yield reached 109% against 20% to 50% in years of good rainfall. However; the induced effects of these techniques are even enhanced when they are associated with zaï and/or with organo-mineral fertilization (Zougmore et al. 2003, 2004a).

The need to improve small-scale farmers' access to mineral fertilizers led to the development of the microdose fertilization technique by some research institutes in the Sahelian area (Buerkert et al. 2001; Aune et al. 2007; Bagayoko et al. 2011). This low cost fertilization technique consists in applying small amounts of mineral fertilizers; from 2g for sorghum to 3g for maize in seed holes or to the feet of the plants after emergence (62.5 to 94 kg. ha⁻¹). It should be highlighted that the recommended fertilizers rates vary between 100 and 150 kg/ha for these two crops in the north-Sudanian zone. Indeed, several studies highlighted the positive agronomic effects of mineral fertilization microdosing technique.

These research works focused on the use of microdosing alone (Tabo et al. 2006; Aune et al. 2007; Bagayoko et al. 2011) or combined with improved germplasm (Palé et al. 2009). However; it is important that this technique which has been tested in some Sahelian countries; be integrated into the ISFM technology packages to be disseminated in similar agroecological zones in West Africa.

Therefore, the present study was conducted in four countries in West Africa (Benin; Burkina Faso; Mali and Niger) to test the effects of inorganic fertilizer microdosing technique combined with soil and water conservation (SWC) techniques and the use of improved seed varieties. In Burkina Faso; the study was conducted in two provinces at the central (Kourittenga) and northern (Zondoma Province) parts of the North-Sudanian zone. These are two zones with relatively contrasting socio-economic and pedoclimatic conditions; and where sorghum ranks first among the cereals grown.

The present article aims to evaluate the effects of inorganic fertilizer microdosing technique, associated or not with SWC techniques on sorghum production and soil physico-chemical characteristics.

13.2 Materials and Methods

13.2.1 Study Sites

The study was carried out on two sites located at the northern (Zondoma Province) and central (Kourittenga Province) parts of the north Sudanian zone of Burkina Faso. The province of Zondoma is situated between 12°38' and 14°18' north latitude and 1°33' and 2°55' west longitude. Annual rainfall is very variable (500-800 mm). The province of Kourittenga lies between 11°48' and 12°34' north latitude and 0°20' and 0°38' west longitude. The annual rainfall varies between 600 and 900 mm.

These two sites, characterized by open savannas to wooded parks, are experiencing a more or less advanced degradation of their physical environments. This phenomenon is under the dominant influence of climate (climate variability) and anthropic actions, combined with strong demographic pressure (density of 100 inhabitants/km²), rudimentary farming systems, extensive animal husbandry. (Ganou 2005; Ouédraogo et al. 2010).

Table 13.1 Technology packages implemented

Technology packages	Factors combined	Study sites	
		Zondoma	Kourittenga
P1	SWC + MO + MD + IV	X	X
P2	SWC + MO + Without MD + IV	X	X
P3	SWC + MO + MD + LV		X
P4	SWC + MO + Without MD + LV		X
P5	Without SWC + MO + MD + IV	X	X
P6	Without SWC + MO + Without MD + IV		X
P7	Without SWC + MO + MD + LV		X
P8	Without SWC + MO + Without MD + LV		X

SWC (Soil and Water conservation technique); OM (organic matter); MD (Fertilizer microdosing technique); IV (Improved seed variety); LV (local seed variety)

Most soils are tropical ferruginous soils (CPCS 1967) which are similar to Luvisols and Lixisols according to the classification of the World Reference Base (WRB) for soil resources (FAO 2006). They represent approximately 39% of the soils of Burkina Faso. Of sandy loamy to sandy silty texture, they are very sensitive to compaction and slacking. They are poor in phosphorus and nitrogen and have degraded structures (Ouattara et al. 2006a; Sermé et al. 2015).

13.2.2 Choice and Conduct of Trials

Demonstration trials were carried out from 2011 to 2013 in five villages in the provinces of Zondoma and Kourittenga. Each of thirty farmers (men and women) identified in each province, freely choose a pair of technology packages proposed by the research team. These packages combine SWC techniques; organic fertilization (OM); micro-dose mineral fertilization (MD); local variety (LV) and/or improved variety (IV) of sorghum (Table 13.1). The SWC technique was either stone lines or grass strips associated with zaï.

Zaï holes were dug during the dry season; with spacing of 0.80 m between sowing lines and 0.40 m between sowing holes on the sowing line; i.e. a density of 31,250 pockets per hectare. The zaï holes received uniformly a handful of organic matter (OM) at a rate of about 2.5 tons per hectare.

The amount of fertilizer applied in microdose per sowing hole was 2 g, i.e. 62.5 kg.ha⁻¹ of NPK (14-23-14) and 1 g of urea; i.e. 31.2 kg ha⁻¹ of urea. NPK and urea were supplied respectively 10 days and 45 days after sowing.

The target crop was either a local variety (Kansiagui; Belko; Kapelga) or the improved variety (Sariaso 11) of sorghum. Sorghum cropping cycle varied between 75 and 110 days for the local varieties against 90 and 100 days for the improved variety.

The size of the elementary test plot was 500 m². The experimental design was the Fisher-type with scattered blocks in which each farmer was considered as a replicate and was testing two technology packages.

13.2.3 Yields Evaluation

Sorghum panicles and straw were collected on the elementary plot, after removing the outer two lines and two sowing holes, each side. They were air dried until constant weight. The panicles were then threshed. The grains obtained were weighed.

13.2.4 Soil Analysis

Composite soil samples were collected during the dry season prior to the third year of the trial and on the 0-20 cm soil horizon. Soil chemical analyzes were conducted in the laboratory of the University of Saskatchewan (Canada). pH, cation exchange capacity (CEC), organic carbon, nitrogen and total phosphorus, as well as, available phosphorus were determined using analytical methods adapted to tropical soils.

The pH was determined by the electrometric method (Nelson & Sommers 1982). Determination of organic carbon was done through dry combustion using LECO-C632 (LECO © Corporation 1987); opting for standard references applicable to soils with very low organic matter content.

Soil total nitrogen and phosphorus levels were measured using the standard method of digestion with sulfuric acid and dilution with hydrogen peroxide (Thomas et al. 1967). The diluted total N and P extracts were dosed with an automatic analyzer.

Available phosphorus and CEC were simultaneously evaluated through the Mehlich III method (Mehlich 1984).

13.2.5 Statistical Analysis

Statistical analyzes were carried out using the Mix Model package of Genstat software and the means were compared according to the Chi 2 test. This tool allowed to carry out statistical analyzes on unbalanced experimental devices and in farmers' fields where variability is fairly high.

13.3 Results

13.3.1 Effects of Technologies on the Evolution of Soil Chemical Fertility

Table 13.2 presented the results of the measurement of various soil chemical characteristics. With the exception of pH and cation exchange capacity, soil chemical characteristics were significantly improved (at the 5% probability threshold), following the implementation of the technology packages. Plots developed with SWC techniques, with or without mineral fertilizers, showed increases of 30-40% in nitrogen and available phosphorus and 70-80% in soil organic matter and total phosphorus; compared to treatment without SWC and plots under farmers' practices. However, the latter had higher nutrient content than the demonstration plots that were not under SWC or MD techniques. On the other hand, the pH and CEC did not vary significantly with the treatments, even though the CEC experienced increases due to rainwater harvesting techniques, with or without microdose.

13.3.2 Effects of Technology Packages on Sorghum Production

Tables 13.3 and 13.4 showed the results of the trials carried out during the three years of experimentation in Zondoma and the two year average in Kourittenga.

Table 13.2 Effects of technology packages on soil chemical properties

Treatments	Avail. P (mg kg ⁻¹)	CEC (cmol kg ⁻¹)	Total N (mg kg ⁻¹)	OM (%)	Total P (mg kg ⁻¹)	pH
Farmer Practices	2.62b	6.13	317bc	0.70bc	127.8b	6.06
SWC+OM+MD +IV	3.04ab	6.41	405ab	0.89ab	161.4a	5.96
SWC +OM+ WMD+IV	4.33a	7.44	454a	1.02a	163.5a	6.16
WSWC +OM +MD+IV	2.34b	5.84	266c	0.54c	101.4b	6.25
WSWC +OM +WMD+IV	1.92b	4.88	249c	0.53c	91.0b	6.08
Fpr	0.03	-	0.001	0.001	0.001	-
Lsd	1.4	-	100	0.21	36	-

WSWC (without soil and water conservation techniques); SWC (Soil and water conservation technique); MD (Fertilizer microdosing technique); WMD (Without fertilizer microdosing technique); OM (organic matter); IV (improved seed variety); Avail P (Available phosphorus); CEC (Cation exchange capacity); N (Nitrogen); Lsd (Least significant difference). Numbers with the same letter are significantly different at the 5% threshold, according to the Chi2 test

Table 13.3 Effect of the different technologies on sorghum yields (kg ha^{-1}) on the experimental site of Zondoma during the three years of experimentation

Treatments	2011 (R = 554 mm)		2012 (R = 825 mm)		2013 (R = 649 mm)	
	Grain	Straw	Grain	Straw	Grain	Straw
SWC + MD	505.2a	2051a	1827a	3848a	1054.9a	3294a
SWC + WMD	246.3c	1700ab	927ab	2992b	986.2ab	2912b
WSWC + MD	357.4b	1498b	1275b	3592ab	859.3b	3033ab
Chi probability	0.02	0.031	0.001	0.002	0.002	0.011
SED	103	234	176	284	214	355

SWC (soil and water and soil conservation technique), WSWC (without soil and water conservation technique), MD (microdose), WMD (without microdose), SED (Standard error deviation), R (mean annual rainfall) Numbers with the same letter are significantly different at the 5% threshold, according to the Chi2 test

Table 13.4 Effects of different soil quality management techniques on sorghum yields (kg ha^{-1}) at Kourittenga

Treatments	Grain yield	Straw yield
SWC + MD + IV	1426.5a	4518a
SWC + SMD + IV	862.7b	3365a
SWC + MD + VL	772.8bc	3231ab
SWC + SMD + VL	447.2bc	2058b
WSWC + MD + IV	1022.5ab	3699a
WSWC + SMD + IV	334.3c	2091b
WSWC + MD + LV	598bc	3290ab
WSWC + WMD + LV	360c	3040ab
Chi probability	0.001	0.005
Sed	456	1267

MD (Fertilizer microdosing), WMD (without Fertilizer microdosing), SWC (Soil and Water Conservation), WSWC (without Soil and Water Conservation), IV (improved seed variety), LV (local seed variety). Values with the same letter are significantly different at the 5% threshold, according to the Chi2 test

In Zondoma; sorghum yields varied from year to year and in the same year between treatments. Relatively low in the first year of experimentation, sorghum grain yields increased more than tripled in the second year with all treatments. The average annual rainfalls recorded were 554 and 825 mm; respectively. Despite these inter-annual variations; differences in yields between treatments were significant for any given year. The MD technique associated with SWC techniques proved to be the most productive combination compared to other treatments. This treatment increased grain yields by 105%, 97% and 7% compared to SWC alone, during 2011, 2012 and 2013 respectively. Compared to the treatment using micro fertilization alone, the combination MD + SWC increased grain yields by 41%, 43% and 23% in 2011, 2012 and 2013 respectively. By contrast; without SWC techniques, MD technique induced substantial yield gains in sorghum grain during the first two years. These improvements in grain yields were in the order of 45% and 35.5% in 2011 and 2012 respectively.

Regarding straw production; the differences between the effects induced by the different technology packages were not as clear as those observed on grain production. However, SWC and MD association produced the highest yield.

In Kourittenga, on the other hand, the highest yields in sorghum grain and straw were achieved by combining MD, SWC techniques and the improved variety. However, without SWC techniques, grain yields fell by 39% and 28% respectively with improved and local sorghum varieties. Therefore, microdose combined or not with water harvesting technique, substantially improved sorghum production, irrespective of the variety considered. The lowest yields came from treatments that did not use SWC techniques or mineral fertilizers with any given variety. The use of the improved variety of sorghum increased grain yield by about 11%, 70% and 85% under SWC, MD and SWC + MD techniques respectively. However, the improved variety without any technology produced less than the local one.

Furthermore, just as in Zondoma, there were no significant differences between the induced effects of the technology packages on straw yields, although the values were higher.

13.3.3 Discussion

After three years of on-farm trials, the results of soil chemical analyzes highlighted the need to combine soil and water conservation techniques (SWC) with micro fertilization in order to improve soil fertility and crop productivity.

Soil organic matter contents were significantly improved in plots under rainwater harvesting technique. The improvement in organic status is largely due to the sedimentation of vegetation fragments upstream the stone lines (Zougmoré et al. 2000). It could also be linked to the organic fertilization on the trial plots (Yaméogo et al. 2013). Total nitrogen and phosphorus contents, as well as available phosphorus contents were particularly higher on the plots under SWC techniques. These increases highlighted the crucial role played by SWC techniques (stone lines; grass strips) in the process of Soil organic matter accumulation and mineralization (Zougmoré et al. 2000, 2004a). OM is, among others things, a source of plants nutrients such as nitrogen and phosphorus.

Generally, the gains in soil fertility induced by the combination of SWC and MD techniques, compared to farmer practices highlighted the importance of this technology package in improving soil productivity. Indeed, the implementation of SWC structures was considered as a prerequisite for organo-mineral fertilization (Zougmoré et al. 2003, 2004a).

The relatively high level of the nutrient content of farmers' plots compared to the demonstration trials that did not benefit from fertilizers or SWC techniques could be due to the great diversity characterizing the management of farmer plots' fertility. Surveys carried out among farmers (Traoré 2014) showed that some applied OM and/or mineral fertilizers to plants facing development deficits. This soil fertility management strategy is commonly observed among small-scale farmers in the use

of the mineral fertilizers acquired according to their limited financial capacity (Traoré 2014).

The effects of the different technology packages tested on sorghum grain production were determined by rainfall over the three years (Sawadogo et al. 2008). The first year of the trial was characterized by great intra-annual variability evidenced by (i) a late installation of the rainy season; (ii) early cessation of rains and (iii) drought spells during the wet season. The annual rainfalls recorded on the two study sites (554 mm in Zondoma and 641 mm in Kourittenga) were lower than the expected annual rainfall of 8 years out of 10 (686 mm) in the north-Sudanian zone (MED 2006). This resulted in a particularly harsh agricultural season for farmers in the area. The other two campaigns were wetter. This inter-annual and intra-annual variability of rainfall which is highly endemic in the sub-arid regions of West Africa (Stoorvogel and Smaling 1990; Ouédraogo et al. 2010) highlighted the “buffering” or depressing effects of the technology packages tested. Integrated soil fertility management (ISFM) is nowadays the recommended strategy for the sustainable improvement of agricultural production which is plagued by the perverse effects of climatic hazards (Cooper et al. 2008; Twomlow et al. 2010; Sawadogo et al. 2008). The results of this study clearly supported this assessment.

Soil and water conservation techniques combined with organo-mineral fertilization and the use of high-performance plant material led to maximum yields at each of the two study sites. These results were consistent with those of Zougmore et al. (2004a, b); Bagayoko et al. (2011) in the sub-arid zones of West Africa. Yield gains were all the greater as rainfall was not a limiting factor (Stoorvogel and Smaling 1990; Zougmore et al. 2003). When the rainfall conditions became severe like in Zondoma, yields have dramatically decreased. At this moment, the combined use of SWC techniques and mineral micro fertilization really expressed; their “buffering” effects against climatic vagaries (Palé et al. 2009). Therefore, fertilizer applications tripled sorghum production whereas the use of SWC techniques doubled it. These results showed, the importance of mineral fertilization in increasing crop production and soil fertility (Buerkert et al. 2001; Zougmore et al. 2004b; Twomlow et al. 2010; Bagayoko et al. 2011). Similarly, SWC techniques improved the water status of these soils (Botoni and Reij 2009; Zougmore et al. 2004a) which left alone, could not provide adequate water reserve to buffer the negative effects of the inherent rainfall deficits in the Sahelian area. This is particularly due to their degraded structures and the low depth of their rooting zone due to the presence of underlying hard pans (Ouattara et al. 2006b; Sermé et al. 2016).

The effects of the ISFM techniques were particularly marked during the phases of grain formation and filling as evidenced by the little or no significant difference between straw yields. The beneficial effect of ISFM techniques was supported by the fact that farmers who did not apply any of such techniques had no grain harvested in Zondoma in 2011.

The genetic potential of the plant material further contributed to improving the performance of SWC techniques and/or mineral fertilizers as shown in the results of the trials conducted in Kourittenga. The use of the improved sorghum variety increased grain yields by 11%, 70% and 85%; respectively; compared to the SWC; MD and the SWC+MD combination. This was consistent with the results

of previous studies which showed that crop genetic potential affected the effectiveness of SWC techniques (Zougmore et al. 2003, 2004b). On the other hand, it further enhanced the performance of mineral fertilizers (Palé et al. 2009). Then, an improved variety expressed its potential, when its water and nutrient requirements were met.

Yield reduction was found greater with local varieties (73%) than with the improved variety (65%), when no fertilizer was applied. This may indicate that the local varieties used more efficiently fertilizer in Kourittenga. This finding contrasted that of several research studies led on the subject (Zougmore et al. 2003). The investigations carried out showed that among the local varieties used by farmers as controls; there was an improved local variety such as Kapelga. This could explain this situation.

13.4 Conclusion

This study confirmed the agronomic efficiency of MD technique enabling to which enables to achieve remarkable yield levels on degraded soils. This technique was enhanced even more by the prior installation of mechanical and/or biological soil and water conservation techniques. Because of the erratic pedoclimatic conditions (soil degraded structure, rainfall deficiency, etc.) of sub arid areas of West Africa, like in Burkina Faso, it was necessary to install some SWC techniques to improve the MD technique. The use of high-performance plant material enhanced the efficiency of SWC techniques. This enhancement was even more pronounced with MD technique. MD technique intervened within an integrated soil fertility management system in which OM played a crucial role. The ex-ante characterization of soil fertility confirmed the agronomic efficiency of these technology packages. It is absolutely essential to show whether investment in these technologies is economically profitable and socially beneficial to the small-scale farmers for whom they were intended.

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