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Full Length Research Paper

Effect of optimizing organic fertilizer doses on Sorghum (*Sorghum bicolor*) production in Mali

Guindo Moumini[1], Coulibaly Alou[2], Traoré Bouba[1,3,] * and Birhanu Zemadim Birhanu[4]

[1]Institut d'Economie Rurale (IER), Centre Régional de la Recherche Agronomique de Sikasso, BP 16, Mali; moumini.guindo@yahoo.fr; moumini.guindo1@gmail.com, (M.G)
[2]Institut Polytechnique Rurale de Formation et de Recherche appliquée (IPR/IFRA) de Katibougou, BP 06, Koulikoro, Mali; coulibalynalou@gmail.com, (A.C)
[3]International Crops Research Institute for the Semi-Arid Tropics (ICRISAT); B.Traore@cgiar.org (B.T.), ORCID ID: 0000-0002-4458-6440
[4]International Water Management Institute (IWMI), PMB CT 112, Accra, Ghana; (Z.Birhanu@cgiar.org) (B.Z.B), ORCID ID: 0000-0002-3497-2364; Auteur correspondant: moumini.guindo@yahoo.fr; (+223)76084540 / 65886834.

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Abstract

The recommandation of 5 t ha^{-1} of organic manures (O.M.), whatever the type, is inadequate, given their diversity. The aim of the study is to identify the types of organic manure, the doses used by farmers, determine optimised doses according to their qualities and assess the effect of the different doses on sorghum. A survey of 45 farmers in Koutiala identified, farmyard manure, compost and cattle yard manure as the main manures used. The doses are low, 1.33 t ha^{-1}, 0.88 t ha^{-1} and 0.25 t ha^{-1} respectively for these fertilizers. After analyzing NPK in these fertilizers, the optimised doses calculated for the needs of sorghum producing 2 t ha^{-1} grain were 7.27 t ha^{-1}, 3.20 t ha^{-1} and 2.18 t ha^{-1} respectively for the types of organic manure identified. Experimentation with optimised doses of compost and cattle yard manure yielded 2361.5 kg ha^{-1} of sorghum grain and 9288 kg ha^{-1} above-ground biomass, similar to the yields obtained with the recommended dose of 5 t ha^{-1} for organic fertilizer. Farmers need to rethink their organic input practices by adopting optimised doses, while intensifying manure production.

Keywords: Organic manure, manure quality fertilizers, optimized doses, sorghum, yield, Mali.

1. INTRODUCTION

In Mali, food security and socio-economic development are major challenges. The agricultural sector employs nearly 90% of the working population and contributes nearly 40% of the country's income (Saba et al., 2017). As population growth and the extension of cultivated areas are no longer possible, producers are forced to invest in agricultural intensification to improve crop yields (Doumbia et al., 2020; Sissoko et al., 2020). However, 72% of farmers are small producers (Saba et al., 2017). They have limited financial capacity and resources to purchase mineral fertilizers (Bationo et al., 2015; Falconnier, 2016; Coulibaly et al., 2022). The work of Green climate fund (2018) have shown that in Mali, a decline in agricultural yields and an increase in food insecurity are observed, which has risen from 24% in 2014 to 25.6% in 2017.

Nowadays, one of the major challenges facing agriculture is the productivity and sustainability of production systems. They are particularly based on improving soil organic matter management (Bouajila et al., 2014), which requires adequate fertilization in order to cope with nutrient

Corresponding author E-mail : moumini.guindo@yahoo.fr

shortages in the soil.

Masse et al., (2015) had noted that the effect of organic matter inputs in general and the improvement of soil fertility are very often positive on agricultural production and system sustainability. According to them, it is important to adapt the quality of the organic product used as an amendment or fertilizer to the cropping system for which the product is used.

The diversity of organic sources and the variability of their effect on agricultural production mean that organic fertilizers need to be better valorized according to their sources and the nutrient requirements of crops.

In fact, Dieng, (2021) considers organic matter to be the fundamental parameter of short- and long-term soil fertility. In this context, maintaining soil fertility is essential (Berger et al., 1987; Ganry et Badiane, 1998). These authors mention that an application of 5 t $ha^{-1}$of good quality of organic fertilizer every two years, or 6 t ha^{-1}every 3 years, is necessary to maintain soil fertility.

Other authors point out that the dynamics of soil organic matter are strongly linked not only to its nutrient content, but also to the type of fertilization applied. The different sources of organic matter have different effects on the availability of nutrients to crops and on the physico-chemical and biological properties of soils (Blanchard et al., 2014; Coly et al., 2018; Tatiana, 2019).

In southern Mali (Koutiala zone), the production and use of organic manure is common practice, but despite the efforts of agricultural research and advisory services, the use of organic manure by farmers is not yet well adapted to sustainable land productivity.

According to Guindo et al (2024), on most farms (73%), organic manure stocks vary from 34 to 60 t per year, covering only 12% to 35% of cultivated areas. The organic manures used are sources of organic matter, containing nutrients necessary for crops (Bationo et al., 2015; Blanchard et al., 2014; Faucon et al., 2015). When calculating the use of organic fertilizers, the diversity of organic fertilizers has long been neglected, while the recommended dose of 5 t ha^{-1} for any type of organic fertilizer does not take this diversity into account. For this reason, the systematic application of the same dose without taking into account the quality of the fertilizer is a problematic and the specific needs of the crops.

The aim of this study is to establish optimized doses of the different types of organic fertilizers used by farmers and to assess their effect on sorghum production, compared with the recommended dose of 5 t ha^{-1}, which does not take into account the diversity of organic fertilizers. The basic questions are: Is it possible to differentiate organic fertilization doses on sorghum according to the type of manure used? Has a significant influence on sorghum production compared to using the recommended dose ?

2. MATERIAL AND METHODS

2.1. Material

2.1.1. Study sites

The study was carried out in the villages of N'golonianasso, Sirakélé and Zansoni, all within a 30 km radius of Koutiala (12°35'05'' nord, 5°36'40''ouest) with a population growth rate of 3.7% and a human density of 63 people/km^2. The soils are shallow ferruginous, sometimes with a light texture poor in organic matter. The production systems are strongly dominated by the interaction between agriculture and livestock farming. Cropping systems are characterized by a cotton-cereal rotation with insufficient inputs of organic manure, particularly for sorghum and millet.

2.1.2. Plant material and inputs used

The “Soubatimi” sorghum variety for dual use (human food and livestock fodder) was used as plant material. This variety, with a sowing-maturity cycle of 110 days, is very productive and has a potential grain yield of 3 t ha^{-1} at the controlled area (station) and 2 t ha^{-1} on the farm, with the yield average of 10 t ha^{-1} of dry biomass. The inputs used were organic manures (farmyard manure, compost, cattle yard manure) and mineral fertilizers (NPK : 17-17-17 and Urea : 46-0-0.

2.2. Methods

2.2.1. Farmers' perceptions of organic fertilizer application

In May 2020, a survey was carried out among 45 farmers in the villages of N'Golonianasso, Sirakélé and Zansoni to determine their perceptions of manure use practices. The aim of this survey was to identify the types of organic manures used in fertilization, the application rates, the way manures are distributed in the field and the constraints observed in manure production. For this purpose, individual meetings were held, using a survey form to collect data.

2.2.2. Sampling of organic manures used by farmers

To determine the organic fertilization dose for each type of organic fertilizer, we first sampled each type of fertilizer. In all, 24 samples of organic manure were collected in the villages of N'golonianasso, Sirakélé and Zansoni. They included 12 samples of farmyard manure, 6 of compost and 6 of cattle yard manure. The sampling was carried out on the stocks of manure produced by farmers, to obtain a representative sample of each type of manure taken at 3 depth levels (on top, middle, and bottom of the stock) after having discarded the surface layer exposed to climatic hazards. For each type of organic fertilizer, sub-samples were mixed to form composite samples. Then 5 kg of which were retained for laboratory analysis at Sotuba in Bamako.

2.2.3. Determination of the chemical composition of organic fertilizers for sorghum cultivation.

The organic manure samples were dried in an oven at a temperature of 105°C for 24 hours. (CRAAQ, 2003). Follow drying, they were carefully preserved before being sent to the laboratory. The analysis focused on the determination of nitrogen (N), phosphorus (P) and potassium (K). Total nitrogen was determined by the modified Kjeldahl method (Mellon, 1953). After digestion, the sample was subjected to hot etching with concentrated sulfuric acid. Then, with the

addition of a pinch of selenium catalyst and H_2O_2, the intermediate product was progressively heated until discoloration occurred. Dosing was carried out using automatic calorimetry.
According to the Novozamsky et al (1983), total phosphorus concentration was determined by automatic colorimetry. The ammonium molybdate and potassium antimony tartrate react in an acid medium with ascorbic acid to form a blue-colored complex in the presence of phosphorus, with absorbance measurement at 880 nm. The color intensity is proportional to the amount of phosphorus contained in the material.
As for total potassium, it was determined by an atomic adsorption spectrophotometer after mineralization of substrate samples with a hot concentrated sulfuric acid solution in the presence of a catalyst (Gomgnimbou et al., 2016).
The optimized doses of organic fertilizers were calculated using the balance method. These doses were based on the nutrient requirements for a desired yield of 2 t ha^{-1} of grain sorghum. The inputs consist of nutrients (N, P, K) from organic manure and mineral fertilization recommended for sorghum. (100 kg ha^{-1} NPK 17-17-17 + 50 kg ha^{-1} Urea), while the outputs consisted of nutrients stored in grain and biomass. Grain analysis (2.035 %N, 0.23 %P, 0.41 %K) and biomass (1.17 %N, 0.08 %P, 4.73 %K) determined the concentration of NPK in these products. So, in anticipation of these mineral exports, to cover sorghum's nutrient requirements, the quantities of organic fertilizers needed (optimization) as element supplements in addition to mineral fertilizers (NPK, urea), were calculated. The doses optimized for each type of organic manure (farmyard manure, compost, cattle yard manure) were compared with the recommended dose of 5 t ha^{-1} for the same types of organic manure.

2.2.4. Agronomic tests of organic fertilizer doses on sorghum

In 2020, tests were carried out on 6 farmers' plots, 2 per village. Each farmer's plot was considered as a replicate, i.e. 6 replicates. The experimental set-up was split-plot with two factors studied, namely the types of organic fertilizers at 3 levels of variation as the main factor and the doses of organic fertilizers at 3 levels of variation as the secondary factor in the subplots. A control was also assessed.
The levels of factor variation are :

Primary factor (types of organic fertilizers):

T1 = farmyard manure
T2 = compost
T3 = cattle yard manure

Secondary factor (fertilizer doses) :

D1 **=** dose optimized according to the quality of the organic Fertilizer (7.27 t ha^{-1} of farmyard manure, 3.20 t ha^{-1} of compost and 2.18 t ha^{-1} of cattle yard manure)
D2: uniform dose recommended for all types of organic manure (5 t ha^{-1})
D3: farmer's practice doses (survey data): 1.33 t ha^{-1} farmyard manure, 0.88 t ha^{-1} compost and 0.25 t ha^{-1} of cattle yard manure.
Treatments: The combination of organic manure types and doses (recommended, optimized, farmer's doses) results at 9 treatments. These treatments receive chemical fertilizers of 100 kg ha-1 NPK 17-17-17 and 50 kg ha^{-1} Urea. Three other treatments serving as controls for each type of organic fertilizer and receiving no mineral fertilization are also put into competition.
The treatment combinations are as follows
T1D1 : 7.27 t ha^{-1} of farmyard manure
T1D2 : 5 t ha^{-1} of farmyard manure
T1D3 : 1.33 t ha^{-1} of farmyard manure
T2D1 : 3.2 t ha^{-1} of compost
T2D2 : 5 t ha^{-1} of compost
T2D3 : 0.88 t ha^{-1} of compost
T3D1 : 2.18 t ha^{-1} of cattle yard manure
T3D2 : 5 t ha^{-1} of cattle yard manure
T3D3 : 0.25 t ha^{-1} of cattle yard manure
T4D1, T4D2, T4D3 : controls.

Observed parameters: plant height, rod diameter, grain yield and biomass have been mesured.

2.2.4.3. Statistical analysis

The results from chemical analyses of organic manure in the laboratory were subjected to a statistical analysis of variance (ANOVA) using Genstat 20th edition software to compare the variability of NPK content with the variability of organic manure.
The results of the agronomic tests were also subjected to analysis of variance to determine the variability between treatments. The Student-Newman and Keuls test at the 5% threshold was used to compare means. Descriptive analysis was used to process the survey data.

3. RESULTS

3.1. Farmers' organic fertilization practices and quality of manures used

The results showed that on all the farms surveyed, three main groups of organic manure were identified as organic matter used to fertilize cultivated soils. They include the farmyard manure, the compost and the cattle manure. The surveys showed that 96% and 78% of farmers respectively compost and farmyard manure close to their homes. Cattle yard manure is produced by 42% of farmers. In all farms, organic manure is transported by cart, so that 47% of farmers have an average of 2 carts, while 53% have just one cart for all transport work. The quantity measurements showed average cart weights of

300 kg for farmyard manure, 250 kg for compost and 120 kg for cattle yard manure. After the end of the dry season, the organic manures are transported to the fields by cart and deposited at 2 or 3 small piles arranged in rows 3 to 4 m apart and 3 to 5 m apart, i.e. 4 to 5 crop ridges.

The spreading is done manually with a shovel or by cross harrowing. The results of the surveys show that 73% of farms systematically produce and transport organic manure, and try to bring it to the fields where soil fertility is low, regardless of the distance between the house and the field. The fields targeted for organic fertilizer vary according to the crop to be planted. The cotton and maize fields have priority for receiving organic manure. For cotton plots, 69% of growers apply organic fertilizer to between 1% and 40% of the cultivated area, while 71% of growers apply fertilizer to between 2% and 33% of the maize area. For the millet and sorghum plots, only 4% of farmers provide organic manure, but can only fertilize a maximum of 20% of the cultivated area. The average doses of organic manure applied to millet and sorghum are around 1.33 t ha^{-1} with farmyard manure, 0.88 t ha^{-1} for compost and 0.250 t ha^{-1} of cattle yard manure.

Depending on cultural rotation and the disponibility of organic manure quantities, the manuring plan varies from 2 to 4 years. The survey shows that 49% of farmers consider the quality of farmyard manure poor in nutrients and 38% of those surveyed consider it to be poor in nutrients, while 7% of farmers consider it to be a good fertilizer for crops (Table 1). The compost that is usually made by farmers using various sources of organic residues piled up in a hole is described by 47% and 40% of farmers respectively as a product poor or at least low in fertilizing elements, while only 2% evaluate it as a good quality. About cattle yard manure, 78% of farmers considered a good organic fertilizer, moderately rich in fertilizing elements, while 4% considered it to be very rich in fertilizing elements for crops (Table 1).

Although the use of organic manure is recognized as a practice that helps maintain or improve soil fertility, 36% of farmers find that its production and transport require means that can be a major constraint, with the lack of carts and the availability of workers. However, 18% of farmers believe that transporting organic manure to the fields is not a problem (Table 2). With regard to workers, 49% of farm managers surveyed were faced with the problem of insufficient or sometimes insufficient workers for organic manure production. According to them, this is a major constraint for manure production, transport and spreading in the fields, while 13% of farmers think that there are no constraints for this work. With regard to the work calendar, 53% of farmers say that their work calendar takes account of manure production activities, and that this is even one of their priorities. While 4% say that they are very overworked, putting this manure transport operation behind the times.

3.2. Concentrated N, P, K content of organic manures

An analysis of variance of the total N, P, K content of the different organic manures shows a highly significant difference (Prob = 0.002) between the nitrogen content of the manures used. The cattle yard manure and compost are the richest in total nitrogen, with an average content of 1%, while farmyard manure contains less nitrogen than compost and cattle yard manure (Table 3), but all these organic manures have similar levels of phosphorus (0.2%) and potassium (0.8%).

3.3. Optimized doses based on the diversity of organic manure types

With the aim of producing 2 t ha^{-1} of grain sorghum with the "Soubatimi" variety, and taking into account the nutrient content analyzed in the grain and biomass, the nutrient requirements are of the order of 64 N-6 P_2O_5 - 103 K_2O per hectare (Table 4). To satisfy these needs, the recommended dose of mineral fertilizer is 100 kg ha^{-1} NPK 17-17-17 and 50 kg ha^{-1} urea (46-0-0), contributing 40 N-17P_2O_5 -17 K_2O resulting in a nutrient deficit of 24 kg ha^{-1} N and 86 kg ha^{-1} K_2O, which must be met by organic fertilizer. When the manure used is the farmyard manure, given that the recommended dose of 5 t ha^{-1} only satisfies 69% of sorghum's nutrient requirements, particularly the nitrogen. As a result, the dose of farmyard manure was increased to 7.27 t ha^{-1}, an increase of 45.4% on the recommended dose (5 t ha^{-1}).

However, for compost and cattle yard manure, the recommended dose far exceeds the nitrogen (N) requirement with more than 56% and 129%, respectively. The dose of 5 ha^{-1} for these two types of manure (compost and cattle yard manure) was reduced to 36% and 56.4%, i.e. 3.20 t ha^{-1} for compost and 2.18 t ha^{-1} for cattle yard manure (Table 4). These optimized doses meet the need for nitrogen (N) and phosphorus (P), but are still deficient to cover the enormous need for potassium (K).

3.4. Effect of doses on plant height, rot diameter, grain yield and sorghum biomass

The results of the analysis of variance of the effect of organic fertilizer doses on sorghum revealed no significant differences between growth parameters, notably plant height (Prob = 0.342) and rot diameter (Prob = 0.219). The mean plant height was 194.3 cm with a coefficient of variation of 3.5%, while the rot diameter was 19.69 mm with a coefficient of variation of 3% (Table 5).

The difference between grain and biomass yields was statistically highly significant (Prob < 0.001). The applications of the optimized dose of farmyard manure (7.27 t ha^{-1}) resulted in a grain yield of 2042 kg ha^{-1}, 21%

Table 1. Farmers' assessment of the quality of manures used as organic inputs.

Types of organic manure	Poor (%)	Weakly wealthy (%)	Moderately wealthy (%)	Very rich (%)
farmyard manure	49	38	7	7
compost	47	40	11	2
cattle yard manure	4	13	78	4

Table 21. Constraints on the production and use of organic manure.

Contraints (%)	Very restrictive	Moderately restrictive	Slightly restrictive	No constraints
workers availability	48.89	31.11	6.67	13.33
transport arrangement	35.6	35.56	11.11	17.78
occupation calendar	4.44	13.33	53.33	28.89

Table 3. N, P, K and organic matter content of organic manures (%).

Types of manure	N	P	K	M.O
farmyard manure	0.329b	0.231	0.87	16.4
compost	0.748a	0.139	0.58	33.7
cattle yard manure	1.1a	0.157	0.95	31.8
Mean	0.627	0.189	0.82	24.6
P. Value	0.002	0.434	0.6	0.069
S.E.D	0.1882	0.078	0.336	8.11
CV (%)	60	82.4	82.4	65.9
N'Golonianasso	0.48	0.106	0.66	15.1
Sirakélé	0.64	0.199	0.62	21.6
Zansoni	0.76	0.263	1.15	37
P. Value	0.527	0.149	0.21	0.061
S.E.D	0.249	0.0776	0.328	8.88
CV (%)	79.3	81.9	80.5	72.2
Interaction between types of manure and villages				
P. Value	0.943	0.764	0.462	0.509
S.E.D	0.3582	0.1436	0.585	14.25
CV (%)	66	87.6	82.8	66.9

higher than that obtained with the recommended dose of 5 t ha^{-1}, and more than 46% higher than the control.

Applying compost at the optimized rate of 3.20 t ha^{-1}gave the same grain yield of 2361.5 kg ha^{-1} as at the popularized rate of 5 t ha^{-1}. This trend is the same with the application of the optimized dose of 2.18 t ha^{-1} of cattle yard manure, which yielded 1548.5 kg ha^{-1}, identical to that obtained with the recommended dose of 5 t ha^{-1}.

Our results show that with the application of the recommended dose (5 t ha^{-1}), without distinction between types of organic manure, the yield of 2334 kg ha^{-1} of grain

Table 4. Nutrient requirements (kg of N, P, K) for sorghum and optimized fertilization rates for different types of manure.

Nutrient requirements and fertilization doses	N	P	K
Nutrient requirements for 2 t ha-1 of grain sorghum	64.10	6.20	102.80
100 kg ha^{-1} NPK 17-17-17	17,00	17.00	17.00
50 kg ha^{-1} urea 46-0-0	23.00	0.00	0.00
proportion of organic fertilizer (kg ha^{-1})	24.00		85.80
5 t ha^{-1} of farmyard manure	16.50	11.5	43.5
5 t ha^{-1} of compost	37.5	7	29
5 t ha^{-1} of cattle yard manure	55	8	47.5
Types of manure	Optimized minimum dose (t ha^{-1})		Optimized maximum dose (t ha^{-1})
farmyard manure	7.27		9.86
compost	3.20		14.79
cattle yard manure	2.18		53.63

Table 5: Effect of different doses on plant height, rot diameter, grain yield and biomass of sorghum according to types of fertilization.

Treatment	Height (cm)	Rod diameter (mm)	Grain Yield (kg ha^{-1})	Biomass Yield (kg ha^{-1})
optimized dose (farmyard manure: 7.27 t ha^{-1})	196	19.49	2042b	9722a
recommended dose (farmyard manure: 5 t ha^{-1})	194.69	19.8	1611c	9306abc
farmers' dose (farmyard manure: 1.33 t ha^{-1})	195.25	19.77	1646c	9097abc
optimized dose (compost : 3.20 t ha^{-1})	193.53	19.34	2389a	10139a
recommended dose (compost : 5 t ha^{-1})	195.11	19.54	2334a	8583abc
farmers' dose (compost : 0.8 t ha^{-1})	194.53	19.57	1958b	9514ab
optimized dose (cattle yard manure : 2.18 t ha^{-1})	196.83	19.92	1500c	8639abcd
recommended dose (cattle yard manure: 5 t ha^{-1})	198.44	19.41	1597c	9306abc
farmers' dose (cattle yard manure: 0.25 t ha^{-1})	195.72	20.29	1111d	7722bcd
control (no fertilization)	190.45	19.73	1104d	7310cd
Mean	194.29	19.692	1625	8560
P. Value	0.342	0.219	0.001	0.001
S.E.D	3.95	0.3415	136.2	627.1
CV (%)	3.5	3.00	14.50	12.7

sorghum obtained with the application of compost is 31% higher than that obtained with manure from cattle yards and farmyard manure, which are similar to each other.

On the basis of farmers' practice in applying organic fertilizers, the 0.88 t ha^{-1} dose of compost gave the highest grain yield of 1958 kg ha^{-1}, 16% and 43% higher than the yields obtained with the farmyard manure (1.33 t ha^{-1}) and the cattle yard manure (0.25 t ha^{-1}) (Table 5). The 2334 kg ha^{-1} grain yield obtained with the optimized dose of 3.20 t ha^{-1} of compost is 32% higher than that obtained with the optimized doses of farmyard manure and cattle yard manure (Table 5). Our results also showed that all treatments, whether fertilized with the recommended dose or with optimized doses, obtained a similar biomass yield of 9288 kg ha^{-1}, but 19% higher than that obtained by the control and the farmers' practice of spreading cattle manure (0,25 t ha^{-1}).

4. DISCUSSION

4.1. Organic manures used in fertilization and their qualities

The identification of three types of organic manure used by farmers shows the diversity of manures used to fertilize crops. The weight of a cart load depends on the type of manure, the distance from the field and the person driving the cart. The use of these various organic fertilizers is a widespread practice in Koutiala district. Despite efforts and constraints, organic manure production is insufficient to cover the fertilization needs of all cultivated plots. The quality of the types of organic manure available showed that compost and cattle yard manure are significantly richer in total nitrogen (1%), compared with farmyard manure with a much lower content of 0.33%. These variations in nitrogen content can be explained by the quality of their constituents and production methods. This study concurs with Abdallah (2012) assessment of the fertilizing value of different types of organic manures, indicating an average content of 0.93% total nitrogen for cattle manure. These results are also similar to those of Michel et Bazoumana (2021) who had shown compressed nitrogen contents between 1.05% and 1.9% for composts made by recycling sorghum (*Sorghum bicolor*), sesame (*Sesamum indicum*) and *Mucuna prurien* husk residues. Chabalier et al., (2006) obtained an average N content of 0.62%, much lower than that obtained in this study.

Using compost and manure from cattle pens could provide a lot of nitrogen that could be used by the plant. The application of farmyard manure (generally poorly decomposed), low in nitrogen, causes the immobilization of nitrogen by telluric microorganisms, which need it to feed. This result in a temporary reorganization making the nitrogen unavailable to the plant (Dhaouadi, 2014; Ganry & Thuries, 2017; Cisse, 2022)**.**

4.2. Optimized fertilization doses for different types of organic manure

The optimization of organic manure doses for sorghum fertilization makes it possible to better meet the nutritional needs of sorghum and to better manage the manure stocks available on farms. The high optimized dose of farmyard manure compared to the popularized one could be explained by its very low total nitrogen content (0.33%), unlike compost and cattle yard manure, which have a much higher nitrogen content (1%).

The studies conducted by Khedija et al., (2015) et Biekre et al., (2018) had shown that with farmyard manure and compost from green waste and sludge, nitrogen levels varied from 2 to 3%. The diversity in the quality of organic manures could also be explained by the way in which the residues used are processed, in particular domestic chores that allow the storage of farmyard manure, composting of residues and the keeping of animals with the use of crop straws either in the houses or close to the dwellings.

The new doses established (optimized doses) are therefore a function of the fraction of mineral elements (N, P, K) derived from each type of organic manure. Blanchard et al., (2014) had specified the great diversity of organic manure used by farmers has consequences on dose recommendations and necessary to apply according to soils and manure types. The authors have indicated that doses ranging from 2.4 t ha^{-1} per year to 5.1 t ha^{-1} every 2 years are very reasonable. Cisse (2022) had also noted that the dose of 2 to 3 t ha^{-1}/year seems to be within the reach of small farmers with little organic manure

The optimal doses for each type of organic manure, which help to meet sorghum's nutrient requirements, are also expected to have a significant carryover-effect, as well as their mineralization in the soil, as pointed out by Michau et al (2019) and Rucakumugufi et al (2021). To satisfy sorghum's potassium (K) requirements, very high levels of organic fertilizers must be applied, in quantities between 10 and 54 t ha^{-1}. This enormous need for potassium in sorghum is explained by the much greater export of this element in grain and biomass (Kante, 2001; Gnoumou et al., 2017; Traore et al., 2021). These high doses of K, despite the need to contribute satisfying sorghum's nutrient requirements, are beyond the farmers' capacity. It is therefore essential that, in addition to the use of mineral fertilizers, organic fertilizers are optimized according to their qualities, so that they provide the quantities of nutrients needed for crop growth and yield. This not only improves water retention capacity by increasing the soil's organic matter content, but also makes efficient use of nutrients (Akanza et al., 2016). Futa et al., (2020) found that soil nutrient content increased when the quantity of organic fertilizer applied was high.

The optimization of organic manure doses according to their quality, showed a reduction in the popularized dose of 36% (from 5 t ha^{-1} to 3.2 t ha^{-1}) for compost and 56.4% (5 t ha^{-1} to 2.18 t ha^{-1}) for cattle yard manure, representing an opportunity to meet the nutritional needs of sorghum and to improve the management of manure stocks available on the farm. For this reason, crop residues are an important source of organic manure, and recycling them is seen as a way of maintaining soil fertility and improving crop productivity (Bationo et al., 2015; Bacye et al., 2021). The practice of burying crop residues is a strategy that could make a major contribution to improving soil nutrient levels, particularly for potassium (Koulibaly et al., 2010; Naitormbaide, 2012).

4.3. Effect of dose application on sorghum agronomic parameters

The effect of applying optimized doses of organic fertilizers according to their types resulted in similar grain sorghum and biomass yields, compared to the recommended dose (5 t ha^{-1}). This advantage of applying optimized doses is linked to the fertilizing value of the quantities of manure used. This performance of optimized doses confirms the results of work by Bagayoko et al., (2017) which specifies that when manure is better decomposed and of good quality, its effect, even at low doses, can be perceptible on agricultural production.
The results of work carried out by Blanchard et al., (2014) on the diversity of the quality of organic manures produced by West African farmers, showed that with the diversity of organic manures, it would be necessary to apply doses taking into account the quality of the manures to obtain the best yield. Several researchs have shown that appropriate use of different organic sources provides a satisfactory supply of fertilizing elements, from which it is possible to build a fertilization plan to improve crop productivity (Albrecht, 2007; Camara et al., 2013; Laaboudi & Mouhouche, 2021; Lompo et al., 2021; Grossrieder et al, 2022).
This corroborates the work of Ibrahim et al., (2015), Coulibaly et al., (2019) according to which the application of a very nutrient-rich fertilizer even at a low dose, maximizes the effects on the growth and production of millet and sorghum.
Other authors have also noted that an annual input of 2.5 t ha^{-1} of good quality organic manure results in a satisfactory grain yield (Blanchard et al., 2014; Ganry et Thuries, 2017; PALE et al., 2021). Our results show that applying the recommended dose of 5 t ha-1 without distinguishing between types of organic manure, induces a variable and less significant effect for certain organic manures such as farmyard manure in influencing grain yield improvement.
This result shows that the importance of the effect of organic manure on grain yield would be linked to its quality, hence (Somda et al., 2017; Dhaouadi, 2014; Coly et al., 2018) indicated that organic manure is an important source of organic matter and nutrients and its supply helps improve the availability of nutrients in the soil.
To do this, a consistent supply of organic manure, in quantity and quality, provides the essential nutrients required for growth and yield.

5. CONCLUSION

The study showed that the diversity of organic fertilizers used to fertilize fields varies widely in terms of N, P, K. The farmyard manure, is less rich in fertilizing elements, particularly nitrogen (N), requires a high dose of fertilization to satisfy the nutritional needs of sorghum. Whereas compost and manure from cattle yards, are much richer in nitrogen, require lower doses. However, these optimized doses tested on sorghum resulted in good development of the sorghum's agronomic parameters. The application of the recommended dose and the optimized dose of compost resulted in the same sorghum grain yield. The recommended dose of 5 t ha^{-1} is much more favorable for obtaining higher sorghum grain yields when the fertilizer used is compost. The alternative of optimizing organic inputs based on the quality of organic manures is of great importance from an agronomic point of view, improving sorghum growth and yield parameters. Compost and cattle yard manure, used as organic fertilizers, are still the best way to solve fertility problems, given their good quality.

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REFERENCES

Abdallah, S., 2012. Appréciation de la valeur fertilisante de différents types de fumier. Mémoire de fin d'études, Université Kasdi Merbah - Ouargla, Faculté des sciences de la nature et de la vie et sciences de la terre et de l'univers, 57p.

Akanza, K.., Sanogo, S., N'DA, H.., 2016. Influence combinée des fumures organique et minérale sur la nutrition et le rendement du maïs : impact sur le diagnostic des carences du sol. Tropicultura 34 (2), 208-220.

Albrecht, R., 2007. Co-compostage de boues de station d'épuration et de déchets verts : Nouvelle méthodologie du suivi des transformations de la matière organique. Sciences de la Terre. Université de droit, d'économie et des sciences - Aix-Marseille III, 189p.

Bacye, B., Kambire, H.S., Sawadogo, M.O., Zonga, A.M., 2021. Effets des modes de gestion des résidus du bananier et d'options de fumure minérale sur le rendement du maïs et les caractéristiques chimiques du sol dans un système de rotation bananier /maïs à l'Ouest du Burkina Faso. International Journal of Biological and Chemical Sciences 15, 1208-1221. https://doi.org/10.4314/ijbcs.v15i3.26

Bagayoko, M., Traore, G., Samake, O., 2017. Variabilité spatiale des rendements du riz en système de riziculture intensive (SRI) en zone Office du Niger au Mali. Agronomie Africaine 29, 137-147

Bationo, A., Fairhurst, T., Giller, K., Kelly, V., Lunduka, R., Mando, A., Mapfumo, P., Oduor, G., Romney, D., Vanlauwe, B., Wairegi, L., Zingore, S., 2015. Manuel de gestion intégrée de la fertilité des sols. Consortium Africain pour la Santé des Sols, Nairobi, Edité par Thomas Fairhurst (CTA), 179p.

Berger, M., Belem, P.C., Dakouo, D., Hien, V., 1987. Le maintien de la fertilité des sols dans l'ouest du Burkina Faso et la nécessité de l'association agriculture-élevage. Coton Fibre Tropical 42 (3), 1–10.

Biekre, A.H.., Tie, B.., Dogbo, D.., 2018. Caractéristiques physico-chimiques des composts à base de sous-produits de ferme de Songon en Côte d ' Ivoire Physico-chemical characteristics of composts based on by-products of Songon farms in Côte d ' Ivoire. International Journal of Biological and Chemical Sciences 12 (1), 596-609. https://doi.org/https://dx.doi.org/10.4314/ijbcs.v12i1.45

Blanchard, M., Coulibaly, K., Bognini, S., Dugué, P., Vall, É., 2014. Diversité de la qualité des engrais organiques produits par les paysans d'afrique de l'ouest : Quelles conséquences sur les recommandations de fumure ? Biotechnology, Agronomy and Society and Environment 18 (4), 512-523. https://doi.org/https://popups.uliege.be/1780-4507/index.php

Bouajila, K., Jeddi, F. Ben, Taamallah, H., Jedidi, N., Sanaa, M., 2014. Effets de la composition chimique et biochimique des résidus de cultures sur leur décomposition dans un sol Limono-Argileux du semi-aride (Chemical and biochemical composition's Effect of crop residues on their decomposition in semi-arid). J Mater Environ Sci 5, 159–166.

Camara, A., Dieng, A., Mergeai, G., 2018. Analyses prospectives des possibilités d'amélioration durable des performances des exploitations agricoles de l'Ouest du Bassin Arachidier du Sénégal : cas des producteurs de Jatropha (Jatropha curcas L.). Tropicultura 36 (4), 658-672. https://doi.org/https://hdl.handle.net/2268/262953

Camara, B.S., Camara, F., Bergthe, A., Oswald, A., 2013. Micro-dosing of fertilizer a technology for farmers' needs and resources. International Journal of AgriScience 3 (5), 387-399. https://doi.org/20133204035

Chabalier, P., Van de Kerchove, V., Saint Macary, H., 2006. Guide de la fertilisation organique à la Réunion. Montpellier : CIRAD, 302 p. ISBN 2-87614-629-0 https://www.mvad-reunion.org/focus/guide-de-la-fertilisation-organique-a-la-reunion/, CIRAD

Cisse, D., 2022. Effets des amendements à base de biochar sur les paramètres agro-pédologiques dans une rotation coton-maïs à l'ouest du Burkina Faso, 2020. Université de Liège Gembloux, Agro-Bio Tech, 126p.

Coly, I., Diop, B., Goudiaby, A.O.K., 2018. Effet du fumier sur le bilan des éléments nutritifs des champs dans le terroir de la Néma au Saloum (Sénégal), URL:http://dx.doi.org/10.19044/esj. 2018.v14n27p126. European Scientific Journal 14, 126. https://doi.org/10.19044/esj.2018.v14n27p126

Coulibaly, A., Woumou, K., Aune, J.B., 2019. Sustainable intensification of sorghum and pearl millet production by seed priming, seed treatment and fertilizer microdosing under different rainfall regimes in Mali. Agronomy (MDPI) 9 (10), 664. https://doi.org/10.3390/agronomy9100664

Coulibaly, M., Samake, S., N'diaye, B., Malle, M., Timbely, D., Coulibaly, M., Atta, S., 2022. Strategies d'adaptation des agropasteurs aux changements climatiques dans la commune rurale de Diema (Mali). European Scientific Journal, ESJ 18, 21. https://doi.org/10.19044/esj.2022.v18n8p21

CRAAQ, 2003. Guide de référence en fertilisation. 1ère édition. 294 p.

Dhaouadi, A.K., 2014. Insertion des Produits Résiduaires Organiques dans les systèmes de culture : Cas des systèmes céréaliers de la Plaine de Versailles et du Plateau des Alluets, 216p https://pastel.archives-ouvertes.fr/pastel-01067665.

Dieng, M., 2021. Effets de différentes doses de fertilisation organo-minérale sur les propriétés chimiques du sol, sur la croissance et le rendement du riz (Oryza sativa L.) à Balmadou (Casamance-Sénégal). Mémoire de Master, Université Assane Seck de Ziguinchor, UFR Sciences et Technologies, 52p.

Doumbia, S., Dembele, S.G., Sissoko, F., Samake, O., Sousa, F., Cicek, H., Adamtey, N., Fliessbach, A., 2020. Evaluation de la fertilité des sols et les rendements de cotonnier, maïs et sorgho à Gliricidia sepium (Jacq.) Kunth ex. Walp. International Journal of Biological and Chemical Sciences 14, 2583–2598. https://doi.org/10.4314/ijbcs.v14i7.17

Falconnier, G.N., 2016. Trajectories of agricultural change in southern Mali. Thesis, Wageningen University, 209p.

Faucon, M.P., Houben, D., Reynoird, J.P., Mercadal-Dulaurent, A.M., Armand, R., Lambers, H., 2015. Advances and Perspectives to Improve the Phosphorus Availability in Cropping Systems for Agroecological Phosphorus Management, Advances in Agronomy. Elsevier Ltd. https://doi.org/10.1016/bs.agron.2015.06.003

Futa, B., Oleszczuk, P., Andruszczak, S., Kwiecinska-Poppe, E., Kraska, P., 2020. Effect of Natural Aging of Biochar on Soil Enzymatic Activity and Physicochemical

Properties in Long-Term Field Experiment. Agronomy (MDPI) 10 (449), 1-11. https://doi.org/10.3390/agronomy10030449

Ganry, F., Badiane, A., 1998. La valorisation agricole des fumiers et des composts en Afrique Soudano-sahélienne. Diagnostic et perspectives. Article de revue à comité de lecture, Cirad - Agritrop (https://agritrop.cirad.fr/390389/). Agriculture et Développement n°18, 73-80.

Ganry, F., Thuries, L., 2017. Intérêt des fumiers pour restaurer la fertilité des sols en zone semi-aride d'Afrique. In : Eric Roose. Montpelier. Restauration de la productivité des sols tropicaux et méditerranéens, Contribution à l'agroécologie. ird, chapitre13, Lutte antiérosive, IRD, p. 179-195. https://doi.org/10.4000/books.irdeditions

Gnoumou, X.N., Yameogo, J.T., Traore, M., Bazongo, G., Bazongo, P., 2017. Adaptation aux changements climatiques en Afrique sub-saharienne : impact du zaï et des semences améliorées sur le rendement du sorgho dans les villages de Loaga et Sika (province du Bam), Burkina Faso. International Journal of Innovation and Applied Studies 19 (1), 166-174. https://doi.org/https://www.researchgate.net/publication/315615098

Gomgnimbou, A.P.K., Coulibaly, K., Sanon, A., Nacro, H.B., Sedogo, M.P., 2016. Caractérisation chimique de quelques fertilisants d'origine animale dans la zone de Bobo-dioulasso au Burkina Faso. Sciences et technique, Sciences naturelles et agronomie Spécial ho, 339-346.

Green climate fund, 2018. Enhancing climate change adaptation of the vulnerable agriculture communities in Segou region in Mali. Concept Note, GCF documentations projects. 13p.

Grossrieder, J., Ringger, C., Argento, F., Grandgirard, R., Anken, T., Liebisch, F., 2022. Fertilisation azotée spécifique au site : méthodes actuelles et expériences. Recherche Agronomique Suisse 13, 103–113. https://doi.org/https://doi.org/10.34776/afs13-103f

Guindo, M., Traoré, B., Birhanu, Z.B., 2024. Biomass and Nutrient Flow Dynamics from Households to Farm Fields : Sustainability Practices to de-Risk Environmental Challenges in the Farming System of Southern Mali. Under review. Farms System 42p.

Ibrahim, A., Pasternak, D., Fatondji, D., 2015. Impact of depth of placement of mineral fertilizer micro-dosing on growth, yield and partial nutrient balance in pearl millet cropping system in the Sahel. Journal of Agricultural Science 153 (8), 1412-1421. https://doi.org/10.1017/S0021859614001075

Kanté, S., 2001. Gestion de la fertilite des sols par classe d'exploitation au Mali-Sud. Tropical resource Manegement Papers, No. 38 (2001), ISSN 0926-9495, thesis, Wageningen University and Reseaarch Centre, Departement of plant Science, 225p.

Khedija, B., Faysa, B.E.N.J., Houcine, T., Naceur, J., Mustapha, S., 2015. Rôle de la composition chimique et biochimique des résidus des cultures et de fumier de ferme dans la décomposition des sols dégradés sous climat aride Tunisien. Algerian Journal of Arid Environment "AJAE" 5(2), 50–70.

Koulibaly, B., Traoré, O., Dakuo, D., Zombré, P.N., Bondé, D., 2010. Effets de la gestion des résidus de récolte sur les rendements et les bilans culturaux d'une rotation cotonnier-maïs-sorgho au Burkina Faso. Tropicultura 28, 184–189.

Laaboudi, A., Mouhouche, B., 2021. Amélioration de l'efficience d'utilisation du phosphore et de potasse par la culture du blé dans les régions sahariennes. Recherche Agronomique 19 (1), 77-95. https://doi.org/https://www.asjp.cerist.dz/en/downArticle/214/19/1/148752

Lompo, D.J.., Yé, L., Balboné, A., Sori, S.., 2021. Effets combinés du biocharbon et du fumier sur les propriétés physico- chimiques d ' un sol ferrugineux tropical sous culture de mil en zone semi-aride du Burkina Faso. Journal of Applied Biosciences 157, 16172–16181. https://doi.org/https://doi.org/10.35759/JABs.157.3

Masse, D., Ndiénor, M., Hien, E., Rafolisy, T., Ndour, Y., Bilgo, A., Houot, S., Aubry, C., 2015. Valorisation agricole des déchets domestiques et industriels dans les agrosystèmes en Afrique de l'Ouest et à Madagascar. Restauration de la productivité des sols tropicaux et méditerranéens 209-221. https://doi.org/10.4000/books.irdeditions.24282

Mellon, M.G., 1953. Applied inorganic Analysis : With Special Reference to the Analysis of Metals, Minerals, and Rocks (Hillebrand and Lundell.) Revised by GEF Lundell, HA Bright, and JI Hoffman. New York : Wiley ; London : Chapman and Hall, 1953. 1034 pp. Illus. $15.00. Science 118, 334. https://doi.org/10.1126/science.118.3064.33

Michau, J., Laurent, Q., Jordan-Meille, L., Salducci, X., Morel, C., Nesme, T., Plat, B., 2019. Meth@+.com - Modéliser le développement d'un système innovant de méthanisation collective et à hautes performances environnementales à l'échelle d'un micro-territoire. Innovations Agronomiques 71, 275–293. https://doi.org/0.15454/GF5DVN

Michel, N., Bazoumana, K., 2021. Amélioration de la composition chimique des composts par le recyclage des résidus de sorgho (Sorghum bicolor), de sésame (Sesamum indicum) et des cosses de Mucuna pruriens au Tchad. Journal of Applied Biosciences 165, 17092–17098.

Naitormbaide, M., 2012. Incidence des modes de gestion des fumures et des résidus de récolte sur la productivité des sols dans les savanes du Tchad. Thèse de Doctorat Unique en Développement Rural, Science du sol, Université Polytechnique de Bobo-Dioulasso (UPB), 171 p.

Novozamsky, I., Houba, V.J.G., Van Eck, R., Van Vark, W., 1983. A novel digestion technique for multi-element plant analysis. Communications in soil science and plant analysis 14(3), 239-248.

Pale, S., Barro, A., Koumbem, M., Sere, A., Traore, H., 2021. Effets du travail du sol et de la fertilisation organo-minérale sur les rendements du mil en zone soudano-sahélienne du Burkina Faso. International Journal of Biological and Chemical Sciences 15, 497–510. https://doi.org/10.4314/ijbcs.v15i2.10

Rucakumugufi, D., Dieng, M., Ntakarutimana, V., Sambe, F.M., 2021. Co-compostage des déchets solides ménagers avec les déjections d'élevage : optimisation du rapport C/N des substrats de départ. ISSN 1813-548X. Afrique Science 18 (2), 94-107. http://www.afriquescience.net

Saba, F., Jean, S., Taonda, B., Serme, I., Bandaogo, A.A., Sourwema, A.P., Kabre, A., 2017. Effets de la microdose sur la production du niébé, du mil et du sorgho en fonction la toposéquence Effects of fertilizer microdosing on cowpea, millet and sorghum production as a function of the toposequence. International Journal of Biological Chemical Science 11, 2082–2092. https://doi.org/https://dx.doi.org/10.4314/ijbcs.v11i5.12

Sissoko, F., Diarra, S., Traore, M., 2020. Le semis direct sous couverture végétale : une opportunité de mise en place rapide du cotonnier en culture pluviale au Mali. International Journal of Biological and Chemical Sciences 14, 722–738. https://doi.org/10.4314/ijbcs.v14i3.7

Somda, B.B., Ouattara, B., Serme, I., Pouya, M.B., Lompo, F., Taonda, S.J.B., Sedogo, P.M., 2017. Détermination des doses optimales de fumures organo-minérales en microdose dans la zone soudano-sahélienne du Burkina Faso. International Journal of Biological and Chemical Sciences 11, 670–683. https://doi.org/10.4314/ijbcs.v11i2.11

Tatiana, R.L., 2019. Etude des bases génétiques de l'efficience de l'utilisation de l'azote du riz pluvial (Oryza sativa L.) à Madagascar. Thèse de Doctorat, Université d'Antananarivo, Sciences et Technologies, 138p.

Traore, B., Serme, I., Ouattara, B., Bougma, A., Ouedraogo, J., Pouya, B.M., 2021. Effet de micronutriments et de nutriments secondaires sur la production du mil et du sorgho en Zone nord soudanienne du Burkina. International Journal of Biological and Chemical Sciences 15, 1902–1913. https://doi.org/10.4314/ijbcs.v15i5.17