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Effects of Fertilizer Micro-Dosing on Grain Yield of Cereals and Legumes in Western Niger, West Africa

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Abstract: In an unfavourable pedoclimatic condition, rapid population growing and rainfed agriculture predominance, it is imperial to improve crops yield by practising sustainable techniques, in order to achieve food security. Fertilizer intake becomes essential but must be done judiciously and seasonally to minimize its usage cost as well as its degradation effect on soils. In this view, an experiment has been conducted in the department of Kollo in the Niger Republic. The principal objective of the study was to determine the effects of different NPK (15-15-15) fertilizer micro-doses on some cereals and legumes crops grain yield. The Fisher's randomized complete block design (RCBD) was used to assess the fertilizer effect up taken with seven (7) treatments levels (0 g/hole; 0.25 g/hole; 0.5 g/hole; 1 g/hole; 2 g/hole; 4 g/hole; and 6 g/hole) for cereals and five treatments levels (0 g; 0.25 g; 0.5 g; 1 g, et 2 g) for legumes; and with four (4) repetitions for each treatment. Results showed a substantial increase of grain yield for pearl millet (87 and 149%) sorghum (117.69 to 164.32%), cowpea (106.40% to 149.08%) and, peanut (119.66% to 451.41%). The economic efficiency analysis showed that the optimal doses were 0.5g/hole; 0.25g/hole; 0.25g/hole and 1g/hole respectively for pearl millet, sorghum, cowpea and peanut. These results will serve as a reference for the fertilization of farmers' fields.

Keywords: NPK micro-doses, rainfed crops, pearl millet, sorghum, cowpea, peanut.

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1. Introduction

The rapid decline of natural resources, including nutrient resources is of serious concern for the sustainable future of agriculture (Schütz et al., 2018). Low organic matter content and cationic exchange capacity are the primary reasons for poor soil fertility in the west African Sahelian zone (Häring et al., 2017; Ussiri and Lal, 2019). Rainfed agriculture of Niger is very much volatile with spatiotemporal variations in precipitation. Despite these agroclimatological limitations, rainfed agriculture contributes about 43% of the gross domestic product of Niger (INS-Niger, 2018). These adverse conditions are further aggravated by changing climate and land degradation. Therefore have severe impacts on agricultural production in Niger (Habou et al., 2016). Increasing the yield gap of cereals and their price volatility, rising to 40% (CORAF/WECARD, 2011). However, to ensure national food security, it is crucial to increase crop yield mainly by increasing pressure on agricultural lands. Hence, it is necessary to develop management strategies and cropping practices that allow increasing crops yield, to reduce the production cost and to optimize resources.

The efficiency of fertilizer application significantly varies depending on soil and climatic conditions (Blessing et al., 2017; Yan et al., 2010).

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Appropriate nutrient management tools and method of application can reduce nutrient losses, increase the nutrient accessibility for plant use, enhance nutrient uptake (Bi et al., 2013; Sharma and Bali, 2018; Salim and Raza, 2020). Efficient use of mineral fertilizers not only increases crops yield and biomass by increasing availability of soil nutrients (Batiano et al., 2003; Somba et al., 2017; Sanoussi et al., 2020). However, the Sahelian farmers' accessibility to mineral fertilizer is minimal because of their low income during the hunger gap (Abdoulaye and Lowenberg-DeBoer, 2000; Blessing et al., 2017). In this context, the localized fertilizer application technique (inside the hole) called micro-dose is particularly promising in terms of the plant fertilizer use efficiency and the investment cost reduction (Aune et al., 2007; Hayashi et al., 2008).

Micro-dose fertilizer application promotes the input optimization by its application directly in the root zone leading to enhanced nutrient extraction by crop (Ibrahim et al., 2016a; Ibrahim et al., 2016b). This technique has advantages for Niger conditions, where the organic amendments needed to improve the crop yields. According to several studies, micro-dose fertilization has produced encouraging results. In West African zone (Burkina Faso, Mali and Niger), a variable improvement (44-120%) in pearl millet and sorghum production was achieved by applying 2g/hole of DAP or 6g/hole of NPK (Tabo et al., 2007). Likewise, similar results were proved and reported in Niger (Hayashi et al. 2008; Demisie 2018). CORAF/WECARD, (2011) has highlighted increases in crops yields due to fertilizer micro-dose for crops including sorghum (67%), pearl millet (57%), cowpea (97%), peanut (26%) and sesame (42%). Micro-doses fertilization of NPK and DAP resulted in increased millet yield of 39 and 72% (Ibrahim et al. 2016b). Besides, micro-doses of NPK (14-23-14) and urea increased grain yields by 143%, 134% and 155% respectively for sorghum, millet and cowpea (Saba et al., 2017). Yield increase using fertilizer micro-doses (3g and 6g per hole) varied among crops and crop types, e.g., millet (31.3% to 90.3%) and sorghum (40.9% and 83%) (Demise, 2018). Similarly, a millet yield of 989 kg ha^{-1} was obtained with the fertilizer micro-dose of 6 g per hole of NPK compared with 732 kg ha^{-1} without fertilization (Sanoussi et al., 2020).

This study was aimed to facilitate farmers with scarce resources to adapt the micro-dose technique, for better crops rainfed system. Thus, the objective was to assess the effect of different NPK (15-15-15) doses on pearl millet, sorghum, cowpea and peanut grain yield, under the farmer's usual agricultural practices conditions, to determine the optimal micro-doses for these crops.

2. Materials and Methods

This study was conducted in Kollo department in the Niger Republic according to the following geographical coordinates: 12°30' and 13°53' north latitude, and 1°30' and 2°55' East longitude. The climate is Sahelian, characterized by the average rainfall ranges from 300 mm to 600 mm.

To determine the optimal micro-doses for each crop experiment was conducted. Treatments consisted of NPK (15-15-15) micro-doses application, which varied between 0 and 6g/hole for cereals and between 0 and 2 g/hole for legumes (Table 1). The 0 g/hole treatment corresponded to the control for each crop. Trials were conducted at the experimental site of the National Institute of Agricultural Research (Kollo Center) in N'dounga. The Fisher's randomized complete block design (RCBD) has been used, including seven (7) treatments and four (4) repetitions, and five (5) treatments and four (4) repetitions; respectively for cereals and legumes (Table 1).

Varieties adapted to the study areas pedoclimatic conditions, usually used by farmers have been exploited. These are: "haini kirei Précoce" (HKP), mota-maradi (MM), IT90K 372-1-2 and Arachide RRB, respectively for pearl millet, sorghum, cowpea and peanut. Crops were grown following the local recommendations to avoid any stress other than the treatments described. Plants were sown by maintaining plant densities for pearl millet [(10000 holes/ha (either a gap of 1 m × 1 m)], sorghum [25000 holes/ha (either a gap of 0.8 m ×5 m)], cowpea [156250 holes/ha (either a gap of 0.8 m x 0.8 m)] and peanut [125000 holes/ha (either a gap of 0.4 m × 0.2 m)]. The fertilizer micro-doses were applied for cereals at the seeding time according to Hayashi et al. (2008) and Ibrahim et al. (2015) while it was carried out for legumes at the flower initiation.

Table 1. Different NPK (15-15-15 g/hole) micro-doses treatments for cereals (pearl millet and sorghum) and Legumes (cowpea and peanut)

Cereals		Legumes	
F0	0	**L0**	**0**
F1	0.25	**L1**	**0.25**
F2	0.5	**L2**	**0.5**
F3	1	**L3**	**1**
F4	2	**L4**	**2**
F5	4	-	-
F6	6	-	-

Table 2. Effect of different NPK micro-doses on the pearl millets economic efficiency indicator

Topics	Pearl millet treatments (NPK micro-doses in g/hole)						
	F0 (0)	F1 (0.25)	F2 (0.5)	F3 (1)	F4 (2)	F5 (4)	F6 (6)
Fertilizer amount (kg/ha)	0	2.5	5	10	20	40	60
Crop yield (kg/ha)	697.5ab	607.5a	1040.75d	919.13cd	841.5bcd	838.33bcd	730ab
CV (%)	20.17	20.96	5.09	2.74	9.8	4.39	15.75
Yield increment due to the fertilizer micro-dose (kg/ha)	0	-90	343.25	221.63	144	140.83	32.5
Fertilizer cost (FCFA/ha)	0	675	1350	2700	5400	10800	16200
Crop yield increment value at harvesting (FCFA/ha)	0	-18000	68500	44326	28800	28166	6500
VCR at the harvesting	0	-26.66	50.74	16.41	5.33	2.60	0.4

At maturity, crops were harvested (1 m^2) and data of grain yield and economic efficiency of micro-dose fertilizer application was calculated. The grain yields were extrapolated per hectare by multiplying the yield square per 10000, and validated by the normality test. The collected data were processed using the Xlstat statistical software version 2014.5.3, and the ANOVA test (Least Significant Difference, LSD) at 5% probability level allowed to compare different treatments grain yield by crops. Economic efficiency of micro-dose fertilizer application was assessed by value cost ratio (VCR) following the procedure described earlier (Aballa et al., 2015; Hayashi et al., 2008; Sime and Aune (2019). This indicator is defined as the ratio between the value of the grain yield increase due to the fertilizer usage and its cost. It is calculated as follows:

$$VCR = \frac{(X - X_0) * \text{Product price at harvesting}}{\text{Fertilizer dose} * \text{Fertilizer price}}$$

Where X = micro-dose treatment yield and X_0 = control yield

According to this indicator, the fertilizer micro-dosing is economically efficient if only its value is higher than two (VCR > 2). Micro application of fertilizer help to reduce production cost and increase profit. VCR calculation was based on information from Niger's agricultural market system (50 kg of NPK amounting to 135000 FCFA, and the price per kilogram of pearl millet, sorghum, cowpea and peanut at harvesting period were respectively equal to 200 FCFA, 250 FCFA, 450 FCFA and 300 FCFA.

3. Results and Discussion

3.1. Effect of the NPK dose level on the different crops grain yield

Grain yields of pearl millet, sorghum, cowpea and peanut, under different NPK (15-15-15) micro-doses levels treatments are presented in Tables 2, 3, 4 and 5. The average values followed by the same alphabetical letters are not statistically different at the 5% probability level. The trial showed that the treatments crops yield increased compared to the controls, except for pearl millet F1 and cowpea L2 and L3 treatments. Thus, it results an augmentation like follow: 87% to 149% for pearl millet, 117.69% to 164.32% for sorghum, 106.40% to 149.08% for cowpea and 119.66% to 451.41% for peanut. This crop yield increment can be attributed to improved soil nutrient status by localized fertilizer application, which favorized the crops roots proliferation, and consequently, absorption of nutrients and water is facilitated (Saba et al., 2017; Sanoussi et al., 2020).

Table 3. Effect of different NPK micro-doses on the sorghum economic efficiency indicator

Topics	Sorghum treatments (NPK micro-doses in g/hole)						
	F0 (0)	F1 (0.25)	F2 (0.5)	F3 (1)	F4 (2)	F5 (4)	F6 (6)
Fertilizer amount (kg/ha)	0	6.25	12.50	25	50	100	150
Crop yield (kg/ha)	58.59c	200bc	179.17bc	351.56bc	350.78bc	400b	1266.84a
CV (%)	20.00	30.74	20.79	6.66	14.22	20.46	14.61
Yield increment due to the fertilizer micro-dose (kg/ha)	0	141.41	120.58	292.97	292.19	341.41	1208.25
Fertilizer cost (FCFA/ha)	0	1687.5	3375	6750	13500	27000	40500
Crop yield increment value at harvesting (FCFA/ha)	0	35352.5	30145	73240	73050	85350	302060
VCR at the harvesting	0	20.94	8.93	10.85	5.41	3.16	7.45

Table 4. Effect of different NPK micro-doses on the cowpea economic efficiency indicator

Topics	Cowpea treatments (NPK micro-doses in g/hole)				
	L0 (0)	L1 (0.25)	L2 (0.5)	L3 (1)	L4 (2)
Fertilizer amount (kg/ha)	0	3.9	7.81	5.62	31.25
Crop yield (kg/ha)	318.45c	474.77d	270.31b	183.3a	338.85c
CV (%)	7.79	3.35	13.49	5.14	7.68
Yield increment due to the fertilizer micro-dose (kg/ha)	0	156.32	-48.14	-135.15	20.4
Fertilizer cost (FCFA/ha)	0	1053	2108	4217	8437.5
Crop yield increment value at harvesting (FCFA/ha)	0	70344	-21663	-60817.5	9180
VCR at the harvesting	0	66.8	-10.27	-14.42	1

Higher crop yields were recorded by F2 (0.5g/hole), F6 (6g/hole), L1 (0.25 g/hole) and L4 (2g/hole) treatments, and they corresponded to 1040.75 kg/ha (pearl millet), 1266.84 kg/ha (sorghum), 474.77 kg/ha (cowpea) and 564.12 kg/ha (peanut). However, the crop yield did not increase linearly with the micro-doses application for legumes. The highest fertilize micro-dose did not necessarily produce the highest yield for these crops; this result could be attributed to the influence of factors other than fertilization.

The comparison of yield of different crops showed that the NPK micro-doses had a highly significant effect on the F_2 grain yield compared to others treatments of pearl millet, F_6 compared to others treatments of sorghum, L_1 relative to others treatments of cowpea and L_3 and L_4 compared to others treatments of peanut. However, the F6 pearl millet treatment (NPK micro-dose of 6g/hole, either 60 kg/ha) produced similar results as described by earlier studies (Ibrahim et al., 2016a; Ibrahim et al., 2016b; Ibrahim et al., 2015), though, these values are lower than the results reported by Sanoussi et al. (2020). Nevertheless, with lower fertilizer micro-doses, Abdalla et al. (2015) obtained higher grain yield for sorghum and peanut. WECARD, (2011) also reported higher yield for pearl millet and cowpea with micro-dose of nutrients. Likewise, the NPK micro-doses equals to F_4 and L_2 treatments, respectively, for sorghum and peanut, produced the lowest grain yield values than (WECARD, 2011). Thus, indicating that a gap for these crops yield improvement depended on the micro-dose fertilizer application.

3.2. Economic efficiency of different treatments

Economic efficiency for various treatments, assessed through the VCR indicator, which allows economic efficiency evaluation of micro-dose fertilizer application. This resulted in higher yields leading to lower VCR values for sorghum and peanut. There is variability in the VCR values, and the following treatments were considered economically efficient (VCR > 2): F_2, F_3, F_4 and F_5 for pearl millet; L_1 for cowpea and all fertilizer treatments for sorghum and peanut. The negative VCR values (the F_1 pearl millet treatment, and L_2 and L_3 cowpea treatments) were due to the reason that treatment yields were lowered than the controls. According to VCR indicator, L_1 [cowpea, 0.25 g/hole either 3.9 kg/ha; VCR value of 66.80 (Table 4)], was the most efficient treatment, followed by F2 [pearl millet, 0.5 g/hole either 5 kg/ha) with VCR value of 50.74 (Table 2)], F_1 [sorghum, 0.25 g/hole either 6.25 kg/ha; VCR value of 20.94 (Table 3)] and L_3 [peanut, 1g/hole either 50 kg/ha) with VCR value of 7.56 (Table 5)].

Table 5. Effect of different NPK micro-doses on the sorghum economic efficiency indicator

Topics	Peanut treatments (NPK micro-doses in g/hole)				
	L0 (0)	L1 (0.25)	L2 (0.5)	L3 (1)	L4 (2)
Fertilizer amount (kg/ha)	0	12.5	25	50	100
Crop yield (kg/ha)	124.97a	149.54a	230.73a	465.52b	564.12b
CV (%)	14.91	17.22	20.45	11.84	24.62
Yield increment due to the fertilizer micro-dose (kg/ha)	0	24.57	105.76	340.55	439.15
Fertilizer cost (FCFA/ha)	0	3375	6750	13500	27000
Crop yield increment value at harvesting (FCFA/ha)	0	7371	31728	102165	131745
VCR at the harvesting	0	2.18	4.7	7.56	4.87

4. Conclusion

Low accessibility and reduced usage of mineral fertilizer due to their higher cost limit the agricultural production in the Sahel, particularly in the study area (at Kollo in the Niger Republic) where most of the soils are sandy and poor in organic matter. Micro-dose technique can be a potential alternative for effective mineral fertilization for smallholders leading to improved and sustainable crop productions. Despite the unfavourable pedoclimatic conditions, the NPK micro-doses had a significant effect on crops grain yield. Increasement between 87% and 149% for pearl millet, 117.69% and 164.32% for sorghum, 106.40% and 149.08% for cowpea and, 119.66% and 451.41% for peanut, was obtained. The highest economically efficient doses have been 0.5g/hole (5kg/ha); 0.25g/hole (6.5 kg/ha); 0.25g/hole (3.9 kg/ha) and 1g/hole (50kg/ha) respectively for pearl millet, sorghum, cowpea and peanut. Promising results of the micro-dose application of fertilizer can be helpful for crop yield sustainability in the studied area. Besides, the organic matter accumulation in the soil, potentially due to increased the aerial and root biomass potentially can lead to the reduced environmental losses of applied fertilizer.

List of Abbreviations: CORAF: "Conseil Ouest et Centre Africain pour la Recherche et le développement Africole"; DAP: Diammonium phosphate; FCFA: "Franc de la Communauté Financière en Afrique"; GDP: Gross Domestic Product; INRAN: "Institut Nationnal de Recherche Agronomique du Niger"; INS: "Institut Nationnal de la Statistique du Niger"; kg/ha: kilogram per ha; NPK: Nitrogen Phosphorus and Potassium; VCR: Value Cost Ratio; WECARD: West and Central African for Agriculture Research and Development.

Competing Interest Statement: All the authors declare that they have no competing interest.

Author's Contribution: (i) Authors 1, 2 and 3 implemented protocol design, set up and monitored the tests, collected and analyzed data, wrote and corrected the manuscript, (ii) Author 4 set up and monitored the tests, (iii) Authors 5 and 6 contributed to data analysis and the manuscript correction.

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