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Original Research Article

Microferilizing assessment using ^{15}N: Dose and placement of Nitrogen fertilizer and N uptake by pearl millet in the semi-arid region of Niger

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Abstract: Next to drought, poor soil fertility is the single biggest cause of hunger in Africa. The micro-dosing is a fertilizer use technologies tailored to smallholders' climatic and socioeconomic conditions that is being promoted by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) in low potential areas of the Sahel and southern Africa. This method showed real interest for the poor producers of West Africa. But the long-term application of this practice is yet unknown. In this work, as post-evaluation, we use labeled fertilizer ^{15}N (5.25% atom excess), to determine the fate of nitrogen fertilizer applied with these small doses in semi-arid conditions in Niger. The total amount of labeled fertilizer was split in two periods of application: (1) at sowing, mixed with seeds or deposit under it, with three levels (0.12; 0.24 and 0.48 g Nm^{-2}) and (2) in one of three stages of development (tillering, Steam elongation and earing) with the same dose of 0.8 g Nm^{-2}. The experimental was conducted in completed randomized bloc design with 4 replications. Each bloc has 20 elementary plots of 27 m^{2} wide, composed of 3 rows of 9 plants. Only 6 of the central plants were considered for the observation and for the labeled nitrogen application. Results demonstrated that mixing the seed with fertilizer before planting leads to lack of 30 to 40% of plant lifting and the nitrogen fertilizer applied by micro-dosing technique to pearl millet crop, is found in very small quantities in the plant and the soil is almost exclusive source (96%) for plant nutrition. Long term application of the micro-dosing technique can have negative effect on soil fertility and should be monitored.
Keywords: Labeled Fertilizer, Micro-dosing Semi-Arid, Pearl Millet (Pennisetum glaucum (L.) R.Br.), Niger

INTRODUCTION

Millet is the basis of the daily diet of 50 million inhabitants in the Sahel. It has a potential to adapt to difficult conditions, especially aridity and low soil fertility. Millet occupies more than 65% of cultivated areas in some countries of the Sahel and its production is in some cases, nearly three quarters of cereal production [1]. Agricultural systems are dominated by small farms with low inputs and, yields rarely exceed 400 kg ha-1 [2]. In Niger, millet occupies sandy soils, characterized with low intrinsic fertility. This combined with erratic rainfall led to very low yields [3]. Despite the huge area planted (over 7 million ha in 2014), the production is still insufficient in Niger [4]. The use of mineral fertilizers by farmers is very low or non-existent because of the poverty of the farmer [5]. The fertilizer micro dosing technology developed by ICRISAT [6] and its partners has shown promising first results in improving millet yields, at smallholder farmer's level in the Sahel [7, 8, 9] and in southern Africa [10, 11]. Since then, "Micro fertilizing technique" is widely popularized in Niger, as well as in all sahelo-sahelian zones, because it is well adapted to low income African farmers [12, 13].

The micro fertilizing method consist in applying small amount of fertilizer, directly mixed with the seeds or just placed under it, when sowing in the planting hole (pocket). This method has the advantage of saving fertilizer, but when used for a long time, it can affect negatively the fertility status of the soil.

The method was evaluated on one or two successive years and the result was positive on crop yields. However, the long-term impact of its implementation on soil status has not been examined. The main reason cited by farmers for low use of fertilizers in semi-arid areas is the high risk of crop failure as a result of droughts and dry spells. But the result of the low use of fertilizer is depletion of soil fertility. To reverse the trend of nutrient depletion, there is a need to develop soil nutrient budget, according to harvest uptake, fertilization input and different losses.

Fertilization input must compensate what has been exported by harvest and losses.

The isotopic labeling technique is used to separate, nutrients from different sources (soil and fertilizer). This work was initiated to use this technique to assess the "micro-dosing" technique in long term application. By another way, placing nitrogen fertilizer directly in seed bed, or mixed with seeds, must undoubtedly increase soil temperature and risk of abortion of germination and emergence. This work is a contribution to a better understanding and elucidation of these phenomena, using ^{15}N labeled fertilizer.

MATERIALS AND METHODS

General conditions of the study

The experimentation took place, in the University Abdou Moumouni of Niamey, Republic of Niger from May to October 2009, at latitude 13°29 North and longitude 2°10 Est. The test was conducted in experimental field station, under strictly storm conditions without any irrigation. Climatic conditions were characterized by the alternation of two contrasted seasons: one cold and dry season, from November to March, and the other hot and wet from May to October. Total water falling by year varies between 400 to 700 mm, with wide heterogeneity inside the season. Period of 30 days and more without rain were frequent in a year. In 2009, a total of 487 mm of rainfall has been recorded. The repartition (as shown in the Figure 1 below) was heterogenic. July and August were the two humid months with more than 6 mm of rain a day, water amount required for pearl millet in growing period. The curve of water need for pearl millet was higher than total rainfall at the end of the season 2009. Water deficit has probably affected earing, a thesis and grain filling.

As indicated in Table 1, the soils of Niger cultivated in pearl millet are mostly deep sandy soil (more than 95% sand) originating from aeolian sand parent material. The typical pH-value (0.01 M CaCl2) of the soils is slightly acidic (5.5 in the up surface layer). Organic carbon content less than required (< 0.2%), and the fertility indicator are very bad (CEC less than 2 méq/100g de sol). The easily assimilated phosphorus is around 3 ppm (Bray I extraction Method), with a low buffer capacity (r/R>0.4). The water capacity holding is very low (0.1 cm^3 water by $cm^3$of soil).

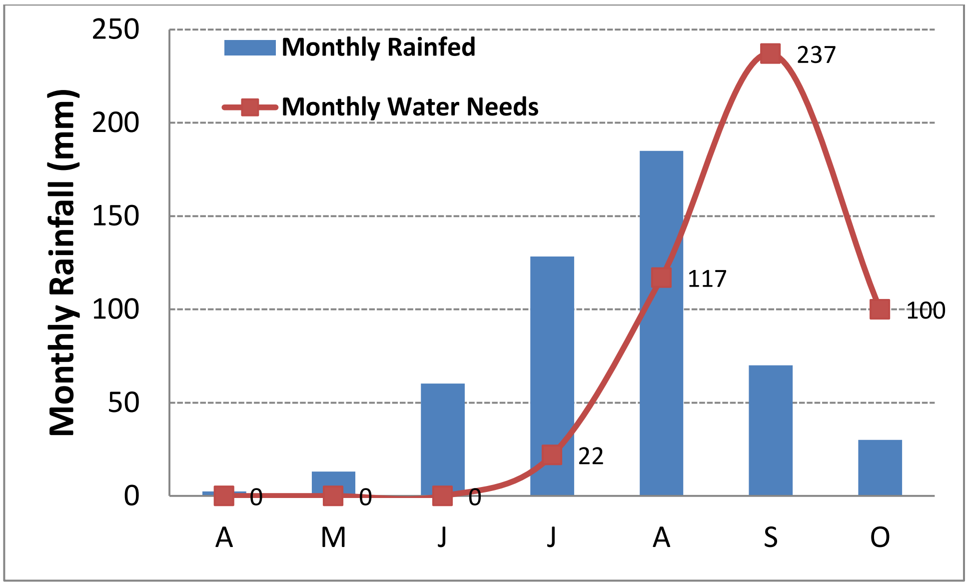

Fig 1: Rainfall observed at the experimental station, in 2009

The millet variety used for the experimentation is HKP [14], coming from recombination of early ecotypes of local pearl millet from the west Niger country. HKP is one of the best and most suitable cultivars, promoted by the main national agronomic institutions in Niger.

Table 1: Soil Physical and chemical properties at the experimental station

Depth (cm)	pH	Sand %	Silt %	Clay %	OM g/kg	N g/kg	P(E1) ppm	CEC meq/100g
0-50	6.0	96.3	1.0	1.7	1.6	0.09	3.0	1.3
50-150	5.9	93.0	1.1	4.8	0.8	0.08	6.1	1.9
150-250	6.1	90.8	1.5	6.9	0.9	0.08	4.4	2.6

Experimental Design

The experimentation was conducted in situ, on rainy season, without any complementary irrigation. A deep plowing (10-15 cm depth) was done manually a few weeks before planting. Seeds of millet were sown on July 15th, after 12.1 mm rain. The seeds are sown at a dose of ten per hill in a small hole of 5 to 7 cm depth and thinned to one plant after emergence.The planting density is 1m x 1m, giving a total density of 10,000 plants by hectare.

Treatments derived from 3 factors as indicated in the Table 2. The first factor was the fertilizer placement, with 2 levels: In the Mixed placement, slightly moistened seeds and nitrogen fertilizer were mixed before sawing; in the second placement, the fertilizer was buried 2 cm under the seeds in the hole. The fertilizer application was split in two periods: at sowing and after seedling emergence. So, the second factor was the dose of nitrogen fertilizer applied at sawing period, with 3 doses: 0.12; 0.24 and 0.48 g Urea by hole. The third factor was the date of the second application of nitrogen fertilizer, with three dates: at tillering, at steam elongation and at heading stages.

The classic formula, consisting to an application to 4.6 g Urea per hole was considered as control. It is amount of nitrogen fertilizer recommended for pearl millet in Niger. A second control without any fertilizer input was considered as absolute control.

The experimental design is a bloc randomized with 4 replications. Each bloc has 20 elementary plots of 27 m^2 wide, composed of 3 rows of 9 plants. Only 6 of the central plants were considered for the observation and for the labeled nitrogen application.

Biometric measurements were made from emergence to maturity at a rate of three times a week. The number of tillers was followed from seedling emergence to steam bolting and the number of ears was followed until harvest. Statistical analyzes focused mainly on total dry matter.

At harvest, 6 plants of ^{15}N-labeled microplots were harvested separately between stem leaves and ears. Then, they were dried and ground and samples were sent to the Laboratory of the IAEA Seiberdief for chemical and isotopic analyzes. Nitrogen Derive from Fertilizer (Ndff) and the effective rate of fertilizer use (CRU) are calculated according to the formulas:

$$Ndff\,\% = \frac{X}{Q_N}100 = \frac{E_{pl}}{E}100$$

$$CRU\% = \frac{Q_N E_{pl}}{FE}100 = \frac{Q_N}{F}\,Ndff\,\%$$

With:

Q_n: the amount of nitrogen in the plant, wherein a portion X derived from fertilizer

E_{pl}: isotopic excess of the plant

F: the amount of nitrogen of the fertilizer

E: isotopic excess of the fertilizer

Table 2: Different Treatments

Factor	Levels	Treatments
Fertiliser Placement	2	Mixed with Seeds at sowing
		Fertilizer position 2 cm under seeds at sowing
Dose of the first application of Fertilizer (g m^{-2})	3	0.12 g Urea
		0.24 g Urea
		0.48 g Urea
Date of the second application of fertilizer	3	0.8 g Urea At tillering stage
		0.8 g Urea At steam elongation stage
		0.8 g Urea At earing stage
The control is the classic application		

0.12; 0.24; 0.48 and 0.8 gm^{-2} Urea are equivalent to 0.3; 0.6; 1.2 and 2 gm^{-2} Di-Ammonic Phosphate (DAP)

RESULTS AND DISCUSSION

Dry matter production

Total dry matter at harvest varies widely between 98.3 and 408.3 gm^{-2}, equivalent to 0.98 to 4.08 tons per hectare. This ranks well with previous results obtained in similar conditions in Niger [15]. Despite these important differences, statistical analysis indicates no significant difference between treatments. This shows the great heterogeneity of infertile sandy soils left to millet crops in Niger. Our results did not confirm the positive trend of micro-dosing technique, showed by previous results [7, 11, 10, 8, 9]. Probably involved drought observed at the end of the crop cycles (see Figure 1), whose consequence is a reduction of nitrogen assimilation and the loss of fertilizer use efficiency [16, 17]. Pearl millet is surely a plant that responds well to nitrogen fertilization [18, 16, 19]. This result has been established mainly on higher doses beyond 10 to 20 kg N per hectare. Some authors [12] have obtained significant responses with small doses (3-6 kg per ha), but in relatively wetter conditions. Christianson *et al.;* [16] found no N response in drought years, whereas in years of good rainfall a response of 15 Kg grains for each Kg of nitrogen applied was recorded. In other hand, residual soil fertility is a very important factor for the response of pearl millet as showed many authors [20, 17]; perhaps the low fertility of our soil and the arid climate in 2009 may be decisive in the non-response of pearl millet to nitrogen fertilizer in this experiment.

Seedling Emergence (SE)

Percentage of seedling emergence was calculated as a ratio between seedlings emerged to whole sowed holes, for each treatment. 5 days after sowing, the seedling emergence varies from 40.6% to 87.5% for all treatments (table 3), lower than that observed for the classically recommended application. Application of moderates nitrogen doses under seed (treatments 10 to 15) were found to show better seedling emergence (fig 2). But it decrease when the dose of fertilizer increase from 0.12 to 0.48 g by pocket (Fig 3). In any case, mixing fertilizer with seed before sowing was found to decrease pearl millet germination and lifting up to 40% (treatments 1 to 9). The mixture of fertilizer to seeds before sowing should result in an increase of the temperature of the seedbed. In case of severe drought, it may abort germination by firing the young radicle. This unprecedented result indicates the necessary precaution before popularize the mirco-dosing technique, especially those who recommend to mix the fertilizer and seed before sowing. This is extremely hazardous in sub-arid zone where the occurrence of droughts has been well established in the beginning and end of the growing season for pearl millet.

Plant growth

The average number of tillers observed varied from 3.1 to 9 and the ears of 1.9 to 5.2. This is relatively low compared to the potential values in the millet that can reach 15-30 tillers and up to 15 spikes in favorable conditions [14]. The biometric data (number of tillers, number of ears) showed better growth conditions with fertilizer placed under seed (treatments 10 to 18).

The nitrogen content of the Dry Matter varies between 0.71 to 1.88%. The plant nitrogen derived from fertilizer (Ndff) varies from 0.83 to 3.91%. These values are comparable to those obtained in normal conditions of millet crop production, for the nitrogen content, but very low for Ndff [15, 21]. These indicate that, up to 96% of plant nitrogen comes from the soil source. The total amount of N withdrawn from the soil by pearl millet yield was evaluated to 40 kg N per hectare in Niger [19], Corresponding to 4 g N m^{-2} (8.9 g of urea m^{-2}). It can be concluded that a long term application of micro-dosing technique could reduce progressively the soil fertility, especially for the Sahel where the entire aerial dry matter produced is totally exported, seeds for human consumption and straw for livestock and / or as a source of energy or building material. The continued practice of this type of fertilization will result in depletion of soil fertility and as the result, a yield reduction if any correction is not applied.

Loss by volatilization is not neglected in sahelian semi-arid circumstances. This may partly explain the low dose of fertilizer use by millet in our experimental conditions. Working on different forms of nitrogen fertilizers, Bresh *et al.;* [22] showed that the loss of nitrogen from urea fertilizer by volatilization is very important in sandy soils under semi-arid tropical circumstances. They recommend the deep band placement as solution. This may also explain the result of classic application (treatment 19) which showed Ndff of 1.18%. Broadcasting fertilizer on all soil surfaces should be avoided in the semi-arid condition of Niger. Our results are consistent to those obtained by Christianson *et al.;* [16]. Despite having high values of Ndff of 20-30%, they found no significant differences in ^{15}N uptake through placement methods.

Table 3: Biometrics and minerals data of pearl millet as affected by the N fertilizer dose, placement and date of application

	Traitements	DM (gm^{-2})	SE (%)	Tillers	Ears	N%	Ndff%
1	Mixed With 0,12 at sawing +0,8 at tillering	139.8	65.6^{cdef}	6.9^{abcde}	2.2^{abc}	1.79	1.63
2	Mixed With 0.12 at sawing +0.8 at Steam development	159.6	75.0^{efgh}	4.0^{abcd}	2.7^{abcd}	1.08	3.91
3	Mixed With 0.12 at sawing +0.8 at panicle emission	187.1	71.9^{defg}	4.4^{abcd}	2.9^{abcd}	0.74	
4	Mixed With 0.24 at sawing +0.8 at tillering	168.4	65.6^{cdef}	3.3^{ab}	2.0^{ab}	1.62	
5	Mixed With 0.24 at sawing +0.8 at Steam development	379.3	59.4^{abcde}	5.9^{abcde}	3.9^{bcde}	1.37	2.08
6	Mixed With 0.24 at sawing +0.8 at panicle emission	98.3	65.6^{cdef}	3.1^{a}	3.1^{abcd}	1.65	1.36

7	Mixed With 0.48 at sawing +0.8 at tillering	217.9	43.8[ab]	5.6[abcde]	2.2[abc]	1.39	1.47
8	Mixed With 0.48 at sawing +0.8 at Steam development	213.4	50.0[abc]	3.9[abc]	1.9[a]	1.34	2.55
9	Mixed With 0.48 at sawing +0.8 at panicle emission	197.0	40.6[a]	4.4[abcd]	2.5[abcd]	0.98	1.70
10	Fertilizer under seeds 0.12 at sawing +0.8 at tillering	408.3	87.5[gh]	12.1[f]	6.2[f]	1.27	2.19
11	Fertilizer under seeds 0.12 at sawing +0.8 at steam development	136.5	93.8[h]	5.6[abcde]	2.5[abcd]	1.49	1.35
12	Fertilizer under seeds 0.12 at sawing +0.8 at panicle emission	227.5	84.4[fgh]	7.1[abcde]	3.9[bcde]	1.63	1.11
13	Fertilizer under seeds 0.24 at sawing +0.8 at tillering	235.5	71.9[defg]	7.4[bcde]	4.2[cde]	1.39	1.21
14	Fertilizer under seeds 0.24 at sawing +0.8 at steam development	192.6	75.0[efgh]	4.8[abcde]	3.1[abcd]	1.35	3.86
15	Fertilizer under seeds 0.24 at sawing +0.8 at panicle emission	239.9	62.5[bcde]	6.6[abcde]	3.3[abcde]	1.94	0.83
16	Fertilizer under seeds 0.48 at sawing +0.8 at tillering	185.8	53.1[abcd]	8.2[def]	3.8[abcde]	1.70	1.53
17	Fertilizer under seeds 0.48 at sawing +0.8 at steam development	197.8	59.4[abcde]	4.8[abcd]	2.3[abcd]	1.88	3.47
18	Fertilizer under seeds 0.48 at sawing +0.8 at panicle emission	160.1	71.9[defg]	6.3[abcde]	3.5[abcde]	0.71	1.56
19	Classic application Sawing :10-20-0 +Tillering 26-0-0 + Steam development 10-0-0	266.4	86.5[gh]	9.0[ef]	5.2[ef]	1.47	1.18
20	Témoins		90.6[gh]	7.8[cde]	4.3[def]		
	Lsd (5%)		20.3	4.2	2.0		
	P		< 0.001	0.012	0.004		

Means followed with same letter did not differ significantly at probability level of 5% according to Duncan's multiple range tests. DM Dry Matter; SE: Seedling Emergence;

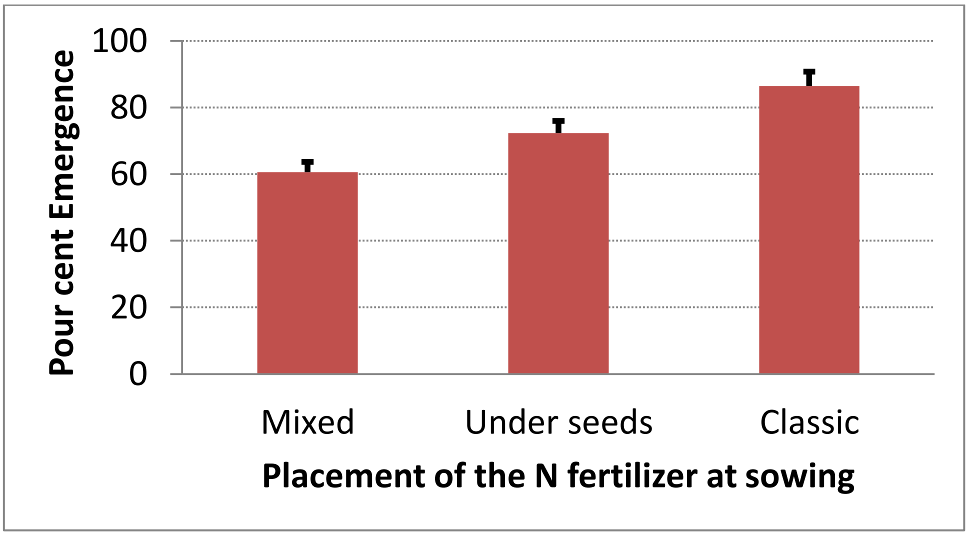

Fig 2: Pearl millet seedling emergence as affected by N fertilizer placement at sowing time

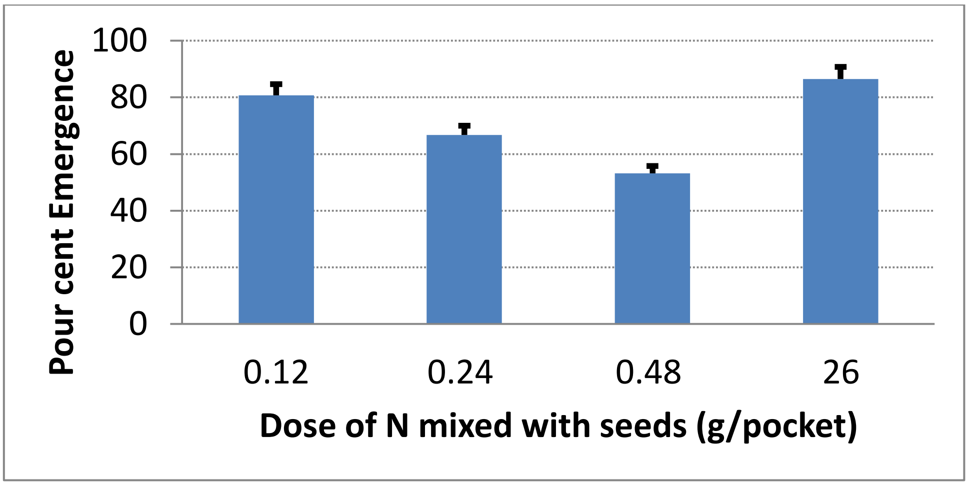

Fig 3: Pearl millet seedling emergence as affected by N fertilizer and seeds mixture before sowing

CONCLUSION

The principal agricultural interest of the isotopic technique in the management of fertilizers is paramount. It is the only one to help determine, in a plant, nutrients coming from the soil and those coming from fertilizer. It is the best method to fallow the fate of the applied fertilizer and to evaluate the real Use efficiency of a fertilizer. This work demonstrated that nitrogen fertilizer applied by micro-dosing technique to pearl millet crop, is found in very small quantities in the plant and the soil is almost exclusive source (96%) for plant nutrition. Long term application of the micro-dosing technique can have negative effect on soil fertility and should be monitored. Without saying that the extension of this technique is premature, a parallel study should be conducted to avoid irreversible destruction of the soil in the Sahel condition. Furthermore, mixing the seed with fertilizer before planting leads to lack the lifting of 30 to 40% in Sahelian conditions. This may have as much effect on the final grain yield.

REFERENCES

1. IRD. Le mil, aliment du futur au Sahel. Actualité scientifique. Fiche N° 325. Institut de Recherche pour le Développement. Marseille, France, 2009 ; 2p
2. Sivakumar MV, Salaam SA. Effect of year and fertilizer on water-use efficiency of pearl millet (Pennisetum glaucum) in Niger. The Journal of Agricultural Science. 1999 Mar 1; 132(02):139-48.
3. Schlecht E, Buerkert A, Tielkes E, Bationo A. A critical analysis of challenges and opportunities for soil fertility restoration in Sudano-Sahelian West Africa. Nutrient Cycling in Agroecosystems. 2006 Nov 1; 76(2-3):109-36.
4. Doumbia A, des Statistiques C, de la Planification MD, Afrique B. Perspectives de croissance des exportations de viande rouge et de betail malien.
5. Bationo A, Mokwunye U, Vlek PL, Koala S, Shapiro BI. Soil fertility management for sustainable land use in the West African Sudano-Sahelian zone.
6. ICRISAT (2009). Fertilizer micro dosing boosting production in unproductive lands. http://www.icrisat.org/impacts/impact-stories/icrisat-is-fertilizer-microdosing_ (accessed 14.02.14.).
7. Mashingaidze N, Belder P, Twomlow S, Hove L, Moyo M. Improving maize (Zea mays L.) performance in semi-arid Zimbabwe through micro-dosing with ammonium nitrate tablets. Experimental Agriculture. 2013 Apr 1; 49(02):179-96.
8. Aune JB, Bationo A. Agricultural intensification in the Sahel–the ladder approach. Agricultural Systems. 2008 Sep 30; 98(2):119-25.
9. Tabo R, Bationo A, Gerard B, Ndjeunga J, Marchal D, Amadou B, Annou MG, Sogodogo D, Taonda JB, Hassane O, Diallo MK. Improving cereal productivity and farmers' income using a strategic application of fertilizers in West Africa. In Advances in integrated soil fertility management in sub-Saharan Africa: Challenges and opportunities 2007 (pp. 201-208). Springer Netherlands.
10. Twomlow S, Rohrbach D, Dimes J, Rusike J, Mupangwa W, Ncube B, Hove L, Moyo M, Mashingaidze N, Mahposa P. Micro-dosing as a pathway to Africa's Green Revolution: evidence from broad-scale on-farm trials. Nutrient Cycling in Agroecosystems. 2010 Sep 1; 88(1):3-15.
11. Kamanga BC, Waddington SR, Whitbread AM, Almekinders CJ, Giller KE. Improving the efficiency of use of small amounts of nitrogen and phosphorus fertilizer on smallholder maize in central Malawi. Experimental Agriculture. 2014 Apr 1; 50(02):229-49.
12. Aune JB, Doumbia M, Berthe A. Micro fertilizing sorghum and pearl millet in Mali: Agronomic,

economic and social feasibility. Outlook on agriculture. 2007 Sep 1; 36(3):199-203.

13. Doumbia MD, Aune JB, Berthé A. Integrated plant nutrition management in Mali: summary report 1998-2004. DCG report. 2005.
14. INRAN. Catalogue des variétés recommandées de mil, sorgho, niébé et autres cultures au Niger. Institut National de Recherche Agronomique du Niger: 1987 ; 5-26.
15. Boukerrou PM, de la Réunion-France CH. Annales de l'Université Abdou Moumouni de Niamey, Tome XVII, 2014 Série A: Sciences exactes, naturelles, agronomiques et de la santé.
16. Christianson CB, Bationo A, Henao J, Vlek PL. Fate and efficiency of N fertilizers applied to pearl millet in Niger. Plant and soil. 1990 Jul 1; 125(2):221-31.
17. Fofana B, Wopereis MC, Bationo A, Breman H, Mando A. Millet nutrient use efficiency as affected by natural soil fertility, mineral fertilizer use and rainfall in the West African Sahel. Nutrient Cycling in Agroecosystems. 2008 May 1; 81(1):25-36.
18. Buresh RJ, Vlek PL, Stumpe JM. Labeled nitrogen fertilizer research with urea in the semi-arid tropics. Plant and Soil. 1984 Feb 1; 80(1):3-19.
19. Bationo A, Christianson CB, Klaij MC. The effect of crop residue and fertilizer use on pearl millet yields in Niger. Fertilizer research. 1993 Jan 1; 34(3):251-8.
20. Diouf O, Brou Y, Diouf M, Sarr B, Eyletters M, Roy-Macauley H, Delhaye J. Response of pearl millet to nitrogen as affected by water deficit. Agronomie. 2004; 24(2):77-84.
21. Sarr PS, Khouma M, Sene M, Guisse A, Badiane AN, Yamakawa T. Effect of pearl millet–cowpea cropping systems on nitrogen recovery, nitrogen use efficiency and biological fixation using the 15N tracer technique. Soil science and plant nutrition. 2008 Feb 1; 54(1):142-7.
22. Buresh RJ, Vlek PL, Stumpe JM. Labeled nitrogen fertilizer research with urea in the semi-arid tropics. Plant and Soil. 1984 Feb 1; 80(1):3-19.