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RESEARCH ARTICLE

Evaluation of application timing in fertilizer micro-dosing technology on millet production in Niger, West Africa

K. Hayashi · T. Abdoulaye · B. Gerard ·
A. Bationo

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Abstract Micro-dosing technology has been developed by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) and its partners to help subsistence farmers in the Sahel improve inorganic fertilizer application. However, the ICRISAT's recommendations regarding fertilizer application through this technology are only applicable at sowing and do not allow any flexibility in terms of labor and/or capital management. In rural areas, fertilizer cannot always be applied at sowing due to financial and labor constraints. The purpose of this study was to evaluate the effect of the timing of fertilizer application on millet production. A 2-year on-station experiment and a 1-year on-farm field experiment were conducted in the western region of Niger, West Africa. Even under the heterogeneous climatic conditions of the region during our experimental period, the results showed that the trend was the same as observed in previous studies: millet production improved through fertilizer application compared to the control (without fertilizer). The harvest index was also higher compared to that of the control. This increased production was consistently the same for all application timings. The marginal value–cost ratio on the investment calculated using a budgeting analysis for the on-farm experiment showed that – regardless of application timing – millet farmers who fertilized their fields with inorganic fertilizer made more profit than those who did not (control). This was also true for farmers who were unable to fertilize at sowing – delayed application was still the more profitable option relative to the no fertilizer control. Our results indicate that small subsistence farmers can be offered more options for inorganic fertilizer application timing using the micro-dosing technology. Delayed inorganic fertilizer application can help small farmers who are often labor constrained at the sowing period improve their yields as well as their economic returns.

Keywords Application timing · Fertilizer micro-dosing technology · Marginal value-cost ratio (MVCR) · Millet production · Niger · Sahel · West Africa

K. Hayashi · B. Gerard
ICRISAT-Niger, Niamey 12404, Niger

Present Address:
K. Hayashi (✉)
Crops production and Environment Division, Japan International Research Center for Agricultural Sciences, 1-1 Ohwashi, Tsukuba, Ibaraki 305-8686, Japan
e-mail: khayash@jircas.affrc.go.jp

T. Abdoulaye
INRAN, Niamey 429, Niger

A. Bationo
TSBF-CIAT, P.O. Box 30677-00100, Nairobi, Kenya

Introduction

In Niger, increasing millet production has been the result of increased cropped area, but grain yields have remained the same or even decreased slightly over the years due to the inability of the farmers to improve yield (FAO 2004a). Although millet is a crop that is well adapted to heat and drought (Pandey 2001), its productivity is reduced if the nutrient levels in the soil are low (Bindraban et al. 2000). In Niger, most of the millet production area is dominated by highly weathered sandy soils that have a low nutrient holding capacity due to the dominance of clay:mineral (1:1) soils, such as kalinite (Pieri 1989; Kyuma et al. 2001). Food deficits are frequent in the region as a result of a combination of poor fertility and high occurrence of droughts. Low levels of phosphorous (P) and nitrogen (N) in the soil are the major constraints to crop growth on these nutrient-depleted sandy soils, with the many studies carried out in the region concluding that the P deficiency is one of the most limiting factors of millet production (Payne et al. 1992; Buerkert et al. 2001a). Consequently, the application of inorganic fertilizer is necessary for an increased production in this region (Christianson and Vlek 1991; Payne et al. 1992; Shapiro and Sanders 1997).

The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) has been working on the improvement of fertilizer application in millet production systems (Klaij et al. 1994; ICRISAT 2002). In the case of Niger, one dose of fertilizer application is considered to be 200 kg ha^{-1} of a NPK fertilizer combination (15:15:15) (Buerkert et al. 2001b; Bationo and Buerkert 2001). Nevertheless, this quantity of fertilizer comes at too high a price for most local subsistence farmers (Abdoulaye and Lowenberg-DeBoer 2000). Micro-dosing technology was then developed in an attempt to increase the affordability of mineral fertilizer while giving plants enough nutrients for optimal growth. This micro-dosing technology consists of applying relatively small quantities of fertilizer (2–6 g $hill^{-1}$) at sowing time, thus decreasing substantially the recommended amount of fertilizer[1] that subsistence farmers need to apply per hectare [i.e., from 200 to 20 kg ha^{-1} in the case of di-ammonium phosphate (DAP)]. The implementation of this technology has resulted in enhanced improvements in nutrient use efficiency (ICRISAT 2002; Tabo et al. 2005).

However, some farmers are facing another problem with this technology. The recommended time frame for the application (planting or sowing time) is a period of high labor demand. Given the erratic nature of rainfall patterns in the Sahel, the planting opportunity window is small, and farmers often have to plant as wide an area as possible very quickly before losing the residual humidity. Micro-dosing (fertilizer application at planting) requires additional labor that farmers often do not have.[2] Delayed fertilizer application would allow farmers to push labor usage to later in the season, after planting, when the labor pool is not as limited. Therefore, a delayed fertilizer application strategy for micro-dosing would enable farmers to better manage available labor and also have some flexibility and an additional option in investing in inorganic fertilizer.

An additional factor is the lack of financial means confronting most farmers at the onset of the rainy season, when farmers must pay cash for food, leaving little over for purchasing inorganic fertilizer. Delayed fertilizer application is one option that would give small-holder farmers an opportunity to raise the cash need to purchase fertilizers. Given time, small-holder farmers can earn money after planting their own fields by working in other farmers' fields or they can borrow.[3]

Finally, by delaying application until the crops are established, farmers would apply fertilizer only to those plants that already have a good standing, thus increasing their chance of producing more grain. Delayed application allows the farmers not only to push the need for cash to later in the season but also to reduce the chance of bad results by applying fertilizer after crops have emerged.

However, the effect of delayed application on millet production within the context of micro-dosing technology is not well-understood. The purpose of this study was, therefore, to evaluate the effect of delayed application of inorganic fertilizer on millet production within this context.

[1] Final recommendation upon micro-dosing may take into account differences in crop land history

[2] It is often hard to find hired labor during planting because most farmers are eager to get their own crops into the ground before the moisture is gone.

[3] Compared to the dry season, it is much easier for small farmers to get a loan after planting because they have their crop as collateral. Also, most lenders in the villages (often traders) lend money with the assurance that the borrower will work in their fields as compensation.

Table 1 Chemical characteristics of Psamentic Pareustalf at the ICRISAT research station

Depth (cm)	pH		Total acidity ($cmol_c\ kg^{-1}$)	C Organic (%)	Bray1 P ($mg\ kg^{-1}$)	Total-N ($mg\ kg^{-1}$)
	(H_2O)	(KCl)				
0–15	5.3 ± 0.2	4.5 ± 0.2	0.19 ± 0.06	0.19 ± 0.02	5.46 ± 1.87	181.95 ± 22.65
15–30	5.0 ± 0.2	4.2 ± 0.1	0.58 ± 0.10	0.13 ± 0.01	2.97 ± 0.53	139.28 ± 27.22
90–105	5.0 ± 0.2	4.2 ± 0.1	0.36 ± 0.08	0.07 ± 0.01	3.11 ± 2.03	101.88 ± 9.16

Average ± s.d. 95%

Material and methods

Design of field experiments

Three years of field experiments were conducted in western Niger, West Africa from 1999 to 2002.[4] The experiment was conducted on the ICRISAT research station (ISC) during the first 2 years, and the field experiment was carried out on farmers' fields located close to the ISC during the third year. This region of Niger is a zone classified in the Sudano-Sahelian agro-ecological zone as having a mono-modal rainfall pattern with an annual rainfall of around 550 mm (FAO 2004b). Soils in the study area are similar to that of the ICRISAT research station: sandy, siliceous isohyperthermic Psammentic Paleustalf (West et al. 1984; Sivakumar 1999). The soil characteristics are shown in Table 1. Long-term average rainfall from 1983 to 2004 at Sadore station was 541 mm. The agricultural system in this area is rainfed millet-based crop–livestock.

(1) The on-station field experiments were sown in a completely randomized block design (CRBD) with four replications. Individual plot size was 5 × 5 m, and plant density was 10,000 hills ha^{-1}. There were five treatments based on the date of fertilizer application, with 0.9 g of P_2O_5 (6 g of NPK, 15:15:15) per millet hill applied to all four fertilized treatments – application at sowing and delayed application at 7, 21, and 45 days after sowing (DAS) – and a fifth treatment consisting of no fertilizer application (control plot). The millet cultivar CIVT, which has a 110-day cycle, was planted in all treatments in a 1 × 1 m spacing after the first rain that allowed millet sowing (10 mm or more). In the delayed application treatments, inorganic fertilizer was applied regardless of the rainfall event for both the 1999 and 2001 trials.

(2) The on-farm field experiment was farmer managed and sown in CRBD with four replications. Individual plot size was 6 × 26 m, and plant density was 3,620 hills ha^{-1} on average. The farmers themselves managed their fields. Fertilizer application was carried out after a rainfall event so as to follow as close as possible standard farming practices. There were six application dates: sowing and 10, 25, 29, 46, and 57 DAS. Three additional dates were added at 15, 22, and 60 DAS according to the phenological stages. The no fertilizer control treatment was also included in the on-farm experiment. Inorganic fertilizer[5] was applied at a rate of 0.9 g P_2O_5 per hill (2 g of DAP $hill^{-1}$; 18:46:0). The local millet landrace, Haïni tchirey, which has a 120-day cycle was planted using local farmers' practices in terms of geometry and spacing.

During the experiments, the meteorological data were recorded at the meteorological station in ISC by the Campbell Scientific Weather Station.

On-farm trial data for 2002 were used for the economic analysis. The effect of the delayed application of inorganic fertilizer was evaluated on both crop yields and economic returns to farmers (Abdoulaye 2002). Based on average yields for each treatment, a budget analysis was used to calculate a net return; the marginal value–cost ratio (MVCR) was then estimated based on the control treatment. The MVCR is defined using the following formula:

[4] Data for 2000 were not available for the analysis

[5] DAP was used as nutrient source for this on-farm experiment because it has the same P level and a higher N content which turn out to be important in this environment.

Table 2 Rainfall distribution during the cropping season of each experiment year

Year	Sowing date	Last rain	Total rainfall (mm)	Total days of rainfall	Period of rainfall after sowing (days)	Days of rainfall ≥10 mm (%)	Rainfall distribution during different terms (% of total rainfall)		
							First 30 days	Second 30 days	Third 30 days and later
1999	July 1	October 15	500	54	44	34	19	36	34
2001	June 21	October 11	458	41	32	41	36	28	30
2002	June 5	October 16	572	53	47	36	19	20	61

$$\text{MVCR} = \frac{NR_t - NR_c}{TC_t - TC_c}$$

where NR_t is the net revenue of treatment t; NR_c is the net revenue of the control treatment; TC_t is the total cost of treatment t; TC_c is the total cost of control treatment. Revenue was calculated by multiplying grain yield by the average market price of millet, and total cost was an aggregate of seed cost, labor cost and fertilizer cost for each treatment.

To determine statistical significance, we compared yield differences between treatments using a two-way ANOVA method. ANOVA was conducted in SigmaStat ver. 3.1 (SPSS, Chicago, IL) and a least significant difference (LSD) at 0.05% was used to test significance.

Survey on inorganic fertilizer use on millet in the region

A survey was conducted in the Fakara region in order to understand the strategy employed by local millet farmers in terms of inorganic fertilizer application. A questionnaire was administered to farmers in two villages (Ko Dey and Tchigo Tegui) in the Dantiandou district. A total of 20 households in Ko Dey and 27 households in Tchigo Tegui, representing 20% of the total households in each village, were interviewed. Both villages are located in an area where micro-dosing technology demonstrations have been conducted by FAO and ICRISAT from 2000 to 2002 (Amadou 2002).

Results

The results focus on the effects of delayed fertilizer application on millet yields, total biomass production, and harvest index (HI). An economic evaluation of the different treatments is then presented, followed by the results of the survey/questionnaire on farmers' fertilizer application practices.

Rainfall distribution during the experiments

The number of rainfall events and amount of rainfall during the 3 years of the study were variable (Table 2). In 1999, total rainfall was 500 mm (11% less than average annual rainfall), and rainfall events occurred on 54 days, 44 of which were DAS. About 34% of the total rainfall events in 1999 had rainfall amounts of ≥10 mm. During the experiment, 19% of the total rainfall occurred during the first 30 DAS, 36% occurred during the second 30 DAS and 34% occurred in the third 30 DAS or later.

In 2001, there was a total of 41 rainy days and total rainfall received was 458 mm, which is 18% less than the annual average rainfall. About 41% of the total rainfall events had rainfall amounts ≥10 mm and there were 32 rainy DAS. During the experiment, 36% of the total rainfall occurred during the first 30 DAS, 28% occurred during the second 30 DAS and 30% occurred during the third 30 DAS and later.

In 2002, total rainfall was 2% above the annual average rainfall, with a total of 572 mm falling in 53 days, 47 of which were DAS. About 36% of the total rainfall events were ≥10 mm. During the experiment, 19% of total rainfall occurred during the first 30 DAS, 20% occurred during the second 30 DAS and 61% occurred during the third 30 DAS and later.

Effects of delayed fertilizer application

As stated above, micro-dosing technology recommends that fertilizer be applied at planting time. Delayed application of fertilizer for a number of days after planting may affect millet grain yield, total biomass production and HI, among other parameters. The results of our analysis are shown in Table 3.

Table 3 Effect of delayed fertilizer application on crop yield for the on-station experiment in 1999 and 2001 and for the on-farm experiment in 2002

Year	Treatment	Yield (kg/ha)	Biomass (kg/ha)	HI (%)
1999	Control	683*	3000*	23
	Sowing	1142	4122	28
	7 DAS	838*	3347*	25
	21 DAS	907 ns	3600 ns	25
	45 DAS	840*	3433*	24
	P	0.031	0.031	
2001	Control	264	2035*	13
	Sowing	602	4144	15
	7 DAS	468	3801 ns	12
	21 DAS	374	2606*	14
	45 DAS	421	3496 ns	12
	P	0.129	0.001	
2002	Control	362	2521	14
	Sowing	746	4077	18
	10 DAS	731	4234	17
	15 DAS	621	4628	13
	22 DAS	608	3570	17
	25 DAS	623	3297	19
	29 DAS	795	4462	18
	46 DAS	712	4422	16
	57 DAS	798	4717	17
	60 DAS	635	3858	16
	P	0.487	0.625	

*Least significant difference = 0.05, ns; no significance

HI, Harvest index; DAS, days after sowing

Effects on millet yield

The yield results from the experiments for the two years are summarized in Table 3. The control plot in 1999 had a better yield than the control plot in the other years because the experiment was started just after a fallow, when soil nutrient had been restored. On average, the observed millet yield increased by 67% when fertilizer was applied at sowing compared to the control. For the delayed application treatments, yield increased by 23, 33, and 23% for applications on DAS 7, 21, and 45, respectively. Only, the 21 DAS treatment was not statistically different from the application at sowing. All of the delayed application treatments showed a trend to higher yields relative to the control treatment. Despite the lack of significant statistical difference, this trend is clearly expressed in the results (Table 3).

In 2001, the differences among treatments were more visible due to the rapid nutrient depletion in this poor sandy soil environment. Overall yields were also much lower for all treatments because of the depletion of soil nutrients in the second year after fallow as well as a lower and poorly distributed rainfall. Compared to the control, the estimated yield advantage in 2001 was 128% when the fertilizer was applied at sowing and 77, 42, and 59% for applications on DAS 7, 21, and 45, respectively. The statistical analysis showed low probability ($P = 0.129$), which may have been due to the poor rainfall during the three years of the study, but fertilizer application was shown to have a clear effect at both sowing and other application dates.

In the on-farm field experiment, yield differences were slightly larger when sowing occurred after a rainfall event than when it occurred at random, irregardless of the rainfall. There was a 106% increase in millet yield relative to the control when the fertilizer was applied at sowing, and increases of 102, 72, 120, 97, and 120% when applied at DAS 10, 25, 29, 46, and 57, respectively; the increase was 75, 72, and 68% for DAS 15, 22, and 60 DAS, respectively. It was not possible to draw any conclusion regarding statistical differences between the control and the treatment plots in this on-farm experiment. However, there was a clear positive trend between fertilizer application and increased millet production, and farmers often appreciated these small increases in yields.

Biomass production

Compared to the control plot in 1999, biomass production increased by 37% when the fertilizer was applied at sowing and by 12, 20, and 14% when applied on DAS 7, 21, and 45, respectively. The fertilizer application at 21 DAS was not significantly different from the application at sowing; however, all treatments showed a definite increase compared to the control.

The biomass production in 2001 also increased with fertilizer application irregardless of the timing of the fertilizer application. These increases amounted to 104, 87, 28, and 72% at sowing and DAS 7, 21, and 45, respectively, and are much higher than those of 1999 although total rainfall in 2001 was lower. The main factor explaining this difference is the late planting of millet in 1999, which did not allow good biomass production. The statistical analysis revealed no significant difference in biomass production for the 7 and 45 DAS treatments compared to the application at sowing. Biomass production in 2002 showed increases of 62, 68, 31, 77, 75, and 87% when the fertilizer application was applied after a rainfall event (at sowing, 10, 25, 29, 46, and 57 DAS, respectively), while the increase was 84, 42, and 53% when the fertilizer application without taking rainfall events into consideration (15, 22, and 60 DAS, respectively).

Harvest index

The HI in 1999 increased by 22, 10, 11, and 7% when the fertilizer was applied at sowing and on DAS 7, 21, and 45, respectively. Although the increase was also observed in 2001, the ratios were a bit lower in that year than in 1999 or they were negative values on DAS 7 and 45. In 2002, the increase in the HI compared to the control treatment was 27, 20, 31, 24, 12, and 18% when the fertilizer was applied after the rainfall event. The increased ratio for the treatments irregardless of the rainfall event was lower than that for the treatments after the rainfall events, and the HI for the 15 DAS treatment was lower than that of control. The harvest indices varied greatly among years, indicating another aspect of Sahelian agriculture – high between-year variations.

Table 4 Evaluation of the efficiency of delayed fertilizer application through a budgeting analysis of the on-farm experiment

	Grain yield (kg ha^{-1})	Total cost (FCFA ha^{-1})	Revenue (FCFA ha^{-1})	MVCR (%)
Control	362	23,552	30,421	–
Sowing	746	25,520	62,649	4.48
10 DAS	731	25,444	61,401	3.87
15 DAS	621	24,881	52,183	3.63
22 DAS	608	24,812	51,061	3.59
25 DAS	623	24,888	52,301	3.37
29 DAS	795	25,773	66,798	4.23
46 DAS	712	25,348	59,830	4.22
57 DAS	798	25,789	67,060	5.40
60 DAS	635	24,950	53,320	3.74

MVCR, Marginal Value–cost ratio; FCFA, free cash flow, annual

Economic evaluation

A budget analysis was performed for the 2002 on-farm experiment. The total cost, the gross revenue, and the result of Marginal Value–Cost Ratio (MVCR) are reported for each treatment in Table 4. The MVCR for each treatment measures the increase in revenue relative to the increased costs compared to the control treatment. A MVCR of 2 and higher is often required for a treatment to be profitable for farmers (CIMMYT 1988). Our results indicate that all MVCR values are above 3 (Table 4). The micro-dosing technology is thus more profitable than the control (no fertilizer treatment) regardless of the application timing. The profitability of micro-dosing technology has also been shown in previous studies in the region (Pender et al. 2006).

Fertilizer application at sowing had a MVCR of 4.48, indicating its high profitability; it started declining as the application was delayed for 10, 15, and 22 days. However, profitability started increasing again with the 29-day delayed application until it peaked with the 57-day delay in applying fertilizer. Thereafter, the MVCR started declining again, indicating a decrease in the return on investment. However, it is important to note that DAP was applied following a rainfall for all treatments except those on DAS 15, 22, and 60, and this might have affected the yields of those treatments and, consequently, their profitability.

Table 5 Summary of the survey on inorganic fertilizer application practices by farmers in Fakara

Results summary	Tchigo Tegui	Ko Dey
Number of sample (household)	27	20
Size of sample (% of total households)	20	20
Application of fertilizer (% of total households)	100	100
Mixed fertilizer with seeds (% of total households)	100	100
Think that it is double the labor to apply fertilizer after sowing (% of total households)	30	25
Have difficulty financing fertilizer purchase before sowing period (% of total households)	89	90
Would adopt an after-sowing fertilizer application technology (% of total households)	22	40
Area of fertilizer application (ha)	2.3	1.3
Applied seed quantity (kg)	11.4	13.1
Applied fertilizer quantity (kg)	2.1	2.3
Mixing rate of fertilizer and seed (fertilizer/seed)	0.2	0.2
Applied quantity of fertilizer in farmland (kg/ha)	0.9	1.8

Inorganic fertilizer use by farmers

Table 5 shows the result of the interviews with local farmers on their use/application of inorganic fertilizer for millet production in the Fakara region. Due mainly to financial constraints, the predominant inorganic fertilizer application method in the Fakara region consisted of mixing the fertilizer with the seeds at a rate of 0.2 (fertilizer/seed). The applied quantity was 1.0 kg ha^{-1} in Tchigo Tegui and 2.1 kg ha^{-1} in Ko Dey, which is far below the 60 kg ha^{-1} of NPK or 20 kg ha^{-1} of DAP recommended for micro-dosing. The results of the survey the purchase of inorganic fertilizer before the season was a financial problem for most farmers due to other pressing cash needs, such as food for the family, among others[6]. The farmers therefore mixed what little fertilizer they could afford with the seeds in order to plant as large an area as possible and still provide fertilizer treatment. The delayed application enabled them to apply higher quantities of inorganic fertilizers compared to mixing the fertilizer with seeds.

In Ko Dey village, 100% of the farmers surveyed used inorganic fertilizer for their millet production. However, 90% indicated that ready cash for purchasing the inorganic fertilizer before the cropping season was a problem, while 40% expressed interest in a technology that would allow delayed fertilizer application. About 25% of the farmers thought delayed fertilizer application would entail additional work (by doubling the labor), while 75% thought that funds for inorganic fertilizer purchase was a constraint.

In Tchigo Tegui village, all of the farmers surveyed used inorganic fertilizer for millet production; this was applied by mixing seeds and fertilizer. About 89% of these farmers felt that it was difficult to find money for buying inorganic fertilizer before the cropping season, while 22% of them thought that delayed fertilizer application could be a good option. However, 30% of the farmers thought delayed fertilizer application would require additional work, while 70% thought that financial requirements were a constraint.

Discussion

Micro-dosing is clearly an improvement from the conventional fertilizer application method as far as quantities applied are concerned. However, with micro-dosing, inorganic fertilizer has to be applied at planting. Abdoulaye and Lowenberg-DeBoer (2000) pointed out that local farmers cannot afford to invest in the purchase of inorganic fertilizer prior to the cropping season due to an insufficient food supply for the household and the need to use cash to purchase family food. Our survey in the Fakara region also indicated the same situation. Farmers are well aware of inorganic fertilizers but are unable to purchase these in adequate amounts at planting due to financial constraints. The beginning of the cropping season is the period when food stocks bottom out in most of rural households. Thus, local farmers have to look for cash to buy their food in the market. Some households try to get cash through borrowing from relatives or selling something to buy food and others have to go to work as day laborers, which often requires reducing the time to work on their own farmland.

[6] The warrantage or inventory credit system was later introduced in this region to help farmers with the cash constraint.

According to the recommendation for micro-dosing technology, 9 kg P_2O_5 ha^{-1} is necessary to obtain the optimal improvement in millet production (Tabo et al. 2005). However, local farmers generally mixed a small quantity of inorganic fertilizer with a large quantity of millet seeds before sowing the seeds over as large an area as possible; they generally did not take the recommended application rate or total amounts into account. Although some residual effect could be expected on the P level in the soil after such practices, it is quite small compared that which would have occurred at the original rate of 20 kg DAP (or 60 kg of NPK) ha^{-1} with an average quantity of 10 kg ha^{-1} millet seed (Abdoulaye 2002). In actual practice, local farmers applied a much lower quantity of fertilizer than recommended, as shown in Table 5; consequently, at the farmers' level, the single option of fertilizer application is not suitable for the adoption of the introduced technology.

It is interesting to note that one of the main concerns of farmers responses to the delayed fertilizer application was financial. They were particularly anxious that, with the delayed application of hill-placed fertilizer, a larger quantity of fertilizer per hill would be required. They also believed that delayed application would be more costly compared to the usually practiced wide area application. The quantity of fertilizer applied per hill by the farmers is actually insufficient due to the fact that the precise quantity of fertilizer and seeds cannot be evenly sown all the time. As a consequence, the application of fertilizer in the field is uneven, and production as well as income gains are often lower than expected. The results of the field experiments showed that MVCR probably improved through the application of the recommended quantity of inorganic fertilizer, not only at sowing but also at other dates after sowing. Therefore, in order to utilize their limited resources efficiently for millet production, the appropriate quantity of fertilizer application per hill is imperative. During the sowing period, delayed application could allow farmers more time for acquiring inorganic fertilizers after food and other pressing expenses have been taken care of.

Local varieties of millet are still predominantly used in the rural areas of Niger, and improved varieties have only been minimally adopted due to improved seed multiplication of the local varieties and distribution system problems, among others (Abdoulaye 2002). Some studies have recommended that inorganic fertilizers not be used on local varieties in Sahelian regions due to their response to fertilizer application wherein a marked increase in straw production was observed (Blondel 1971; Gigou 1986).This would appear to indicate that the application of inorganic fertilizer through micro-dosing technology is contradictory to what the results of conventional studies recommend. However, many researchers in the same region have demonstrated increased millet yields following the application of inorganic fertilizers (Bacci et al. 1999; Buerkert et al. 2001b; Oosterom et al. 2006). Bacci et al. (1999) showed that the application of inorganic fertilizer significantly improved not only the grain yield but also the HI of improved local millet varieties, and this result is consistent with those of this study. More importantly, inorganic fertilizer application to millet agricultural systems has also been shown to be profitable enough for farmers to invest in. Although the statistical significance of our study was low due to the heterogeneous climatic conditions during our experiments, our results show the same tendency as those of an earlier study on the application of inorganic fertilizer. Compared to the control, inorganic fertilizer application, regardless of timing, resulted in better yields, biomass production, HI, and economic returns. This information supports the importance of disseminating micro-dosing technology as well as the possibility of applying this technology at different times after sowing.

Conclusion

The results from this study confirm observations by others that micro-dosing with fertilizer increases millet yields regardless of the timing of the application. This result is important to small subsistence farmers because access to inorganic fertilizer at sowing and high labor demand during the same period often lead them to apply only very small quantities of fertilizer. Delayed fertilizer application can lessen the financial burden of the local farmers during the sowing period and give them another option to increase productivity and economic returns. Small subsistence farmers can then have a greater flexibility in managing their labor and cash resources in the purchase and application of inorganic fertilizers in micro-dosing form.

The economic returns for the delayed fertilizer application option were high enough to make this option attractive to small farmers. Fertilizer application after a rainfall was more effective in eliciting a better response and hence higher MVCR. Therefore, farmers can obtain higher economic returns from their inorganic fertilizer micro-dosing applications by delaying application until after crop emergence and rainfall to maximize their output.

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