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Millet response to microdose fertilization in south–western Niger: Effect of antecedent fertility management and environmental factors

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ABSTRACT

Soil fertility is a major constraint to agricultural development in most of the Sahel, with P being the most limiting nutrient for millet production on acid sandy soils. To address this issue, microdose applications of P fertilizer have been widely advocated in recent years. However, little is known regarding the effect of farmer management practices and environmental factors on millet's yield response to this technique. For this purpose, 276 farmer demonstrations were setup across a 3-year period in the Fakara region, western Niger. Five strata were considered based on antecedent organic manure management (corralling or transported manure). At each demo site, conventional management was compared to basal microdose fertilizer application of DAP (2 g hill^{-1}), NPK (6 g hill^{-1}), or DAP (2 g hill^{-1}) with urea (1 g hill^{-1}) applied at tillering. Millet grain yields on control plots were low (84% < 400 kg ha^{-1}), reflecting the unfavorable environmental conditions of the area. On average, the application of DAP, NPK and DAP + urea increased grain yields by 43, 46 and 69 kg ha^{-1} (2001–2002). A positive response to microdose fertilization was observed for 92% of the sites where yields on control plots were <100 kg ha^{-1} but only for 32% of the sites where yields on control plots were >500 kg ha^{-1}. In particular, the positive response to microdosing increased with later sowing given that late sowing tended to reduce yields on control plots. Higher rainfall during the early growing season favored a positive response to microdosing. On average over DAP and DAP + urea, 36% of the demonstrations had value-cost ratios (VCR) < 1. However, for low yielding control plots (<200 kg grain ha^{-1}), 26% of the demonstrations had VCR < 1, whereas for high yielding plots (>400 kg grain ha^{-1}), 55% had a VCR < 1. Not accounting for labor, DAP and DAP + urea had similar economic returns. The use of NPK could not be recommended as the cost per unit P is 3 times higher than DAP. It appears that, for the Fakara study area, microdosing may best be targeted to areas with low expected yields. In particular, it may serve as a famine mitigation strategy in case of late sowing. Nevertheless, for poorly endowed areas such as the Fakara, the economic risk associated with microdosing (2 g DAP hill^{-1}) appears higher than has hitherto been reported and widespread adoption may not be warranted without institutional support.

1. Introduction

Due to a high population growth rate (approx. 3.7% per annum for the 2000–2012 period), agricultural land in many areas of Niger has become a limiting factor to sustain the rapidly increasing food demand. Agricultural systems are now in transition (Cour, 2001; Raynaut, 2001), leaving to rural populations the option to either intensify and increase the productivity of the land, or to complement their needs through contracted farm labor, off-farm activities and seasonal migration.

Agricultural production in Niger is predominantly rainfed. Subsistence farming, which is still practiced by the vast majority of farmers, is often confronted with low and declining soil fertility (Bationo and Mokwunye, 1991; Sanchez et al., 1997). Traditional soil fertility restoration practices are no longer sufficient to maintain soil fertility. Fallow periods and fallow/cropland ratios have been drastically reduced. Animal manure, which constitutes a major source of nutrients for staple crops such as sorghum and millet in these mixed crop-livestock systems, is not available in quantities large enough to fertilize all fields at appropriate levels, such that only a small fraction of the cropped area benefits from it (Powell et al., 1996). Other sources of organic amendments

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(e.g., crop residue) are in short supply and suffer from competing uses such as cattle feed, fuel or construction material (Achard and Banoin, 2003; Baidu-Forson, 1995; Valbuena et al., 2012).

Given this situation, the recourse to external nutrient inputs to complement the traditional soil fertility management practices appears inevitable in order to increase or simply to maintain system productivity. Whereas more densely populated areas in south-central Niger with access to the large Nigerian market have to some extent already intensified their cereal production through the use of mineral fertilizer (Mortimore et al., 2001), a majority of rural households do not rely on mineral fertilizers to increase cereal yields (World Bank, 2014). Broadcast application of fertilizer in combination with organic amendments has shown its effectiveness at increasing yields in controlled experiments as well as on-farm demonstrations (Bationo and Mokwunye, 1991; Bationo et al., 1993), but this technique has not been widely adopted by farmers. Reasons for this include low fertilizer availability, high cost of fertilizers relative to millet price, limited market access for the produce, limited cash availability for buying inputs and high risk of low or even negative returns on investment (Abdoulaye and Lowenberg-DeBoer, 2000; Abdoulaye and Sanders, 2005). Consequently, researchers have investigated alternative fertilization techniques which rely on smaller quantities of placed mineral fertilizers targetting in priority the most limiting element, i.e., phosphorus (Buerkert et al., 2001; Payne et al., 1991).

Also referred to as 'microdosing', 'microfertilisation' or 'point placement', hill-placed application of small quantities of mineral fertilizer at sowing, typically 0.3 to 6 g $hill^{-1}$ of NPK or 0.3 to 2 g $hill^{-1}$ of DAP, has shown promising results in both on-station and on-farm trials conducted in Niger (Aune et al., 2007; Bationo et al., 1998; Buerkert and Hiernaux, 1998; Buerkert et al., 2001; Muehlig-Versen et al., 2003; Rebafka et al., 1993). Besides reducing the quantity of fertilizer to be applied and hence the financial investment, the microdose technique inherently adjusts application rates to sowing densities, as opposed to broadcast fertilization. This is important in the Nigerien context as sowing densities in farmer's fields can be highly variable (1300 to 12,500 hills ha^{-1}; Bationo et al., 1992). Compared to broadcast fertilizer applications, P use efficiency is greatly increased with microdosing. Because various trials demonstrated strong positive effects on yields and high returns on investments (Pender et al., 2008), the microdose technique has been referred to as the second of a 4-step agricultural intensification pathway for Sub-Saharan Africa (Aune and Bationo, 2008; Twomlow et al., 2008), and has been promoted accordingly.

The first results of large scale on-farm fertilizer microdose trials in the Sahel were reported by Buerkert et al. (2001). Hill-placed applications of 0.4 g P $hill^{-1}$ in the form of NPK (15–15–15; 6 g $hill^{-1}$) or DAP (18–46–0; 2 g $hill^{-1}$) were tested over a 2-year period on a total of 199 field demonstrations in the Maradi, Dosso and Say regions (south west Niger). The average yield increase was 120% over the unfertilized control for both DAP and NPK. In subsequent studies, millet grain yield increases ranging from an average of 4% (Camara et al., 2013) to an average of 144% (Aune et al., 2007) have been reported as a result of microdose fertilization demonstration trials in Mali, Niger and Burkina Faso. In Niger, mean yield increases of up to 320 kg ha^{-1} have been reported from demonstration trials (Bationo et al., 2005).

Although most existing studies reported substantial increases in mean millet grain yields, few studies actually reported on the variability of crop response to microdose fertilizer applications within a given region. This is surprising as such information is crucial with respect to evaluating risk, a central criterion in famers' decision making in rainfed subsistence farming in the Sahel. Mean responses, however good, do not convey this information. Buerkert et al. (2001) analyzed the distribution of millet responses to microdosing. Yields in microdose fertilized plots were almost always higher than in control plots. Yield increases ranged from 0 to 2000 kg ha^{-1} depending on the demonstration plot. Buerkert et al. (2001) reported that the probability of achieving lower net returns on microdose plots than on control plots decreased as the yield on the control plots increased. On low productivity plots, there was a >50% probability to achieve lower net returns on the microdose plots than on the control plot. Tabo et al. (2011) also plotted yield distributions, with responses varying from slightly negative to yield increases of the order of 900 kg ha^{-1}. Bationo et al. (2005) reported an even larger variability in millet responses to microdosing, from 0 to 1500 kg grain ha^{-1} in excess of yield on control plots. However, neither Tabo et al. (2011) nor Bationo et al. (2005) analyzed the economic risk of microdosing per se.

It is apparent from the above-mentioned studies that even for control plots with very similar productivity levels (e.g., Fig. 9 in Buerkert et al., 2001), the response to P microdose fertilization can be highly variable. This variability may stem from different combinations of environmental (such as soil type, rainfall distribution, pest and disease) and management factors (such as antecedent fertility management, sowing density, plant variety, sowing date, and weeding dates), yet this has hitherto not been investigated. Understanding the sources of variability would be highly desirable when defining the recommendation domain of the technology within a given agro-ecological zone. Questions such as "Should the technology be applied preferentially to low/high fertility plots within a farm?", "How does the technology respond to differences in climatic conditions within the same agro-ecological zone?", "How does the technology interact with farmer management practices?" remain largely unanswered. The interaction between microdosing and manure management is of particular importance. Indeed, manure application has become the principal means for soil fertility restoration applied by farmers in western Niger (Powell et al., 1996). This is achieved through transportation of manure to the fields, or through direct corralling of livestock in the fields with residual effects extending over several years (Gandah et al., 2003; Powell et al., 1996).

The objectives of the present study were therefore (1) to investigate whether the performance of microdose fertilization is affected by the farmer's organic manure management in previous years; (2) to determine to what extent locally variable environmental and management factors affect the response to microdose fertilization; and (3) to evaluate the economic risk associated with P fertilizer microdosing based on the distribution of value-cost ratios. For this purpose, on-farm demonstration trials of microdose fertilization were monitored across a 3-year period in the Fakara region of Niger. Besides millet grain yield, information was collected regarding soil, daily rainfall and farmer management practices.

2. Materials and methods

During three consecutive rainy seasons (2000–2002), a series of simple demonstrations were established in collaboration with voluntary farmers spread across an area of approx. 500 km^2 in the Fakara region of south–western Niger, 80 km east of the capital Niamey (Fig. 1). The region was selected because of the abundance of bio-physical and socio-economic data available in various spatial databases (Hiernaux et al., 2009; La Rovere et al., 2005; Schlecht et al., 2004).

The climate is tropical semi-arid with a single rainy season occurring between mid-May and early-October. The mean annual rainfall for the zone is 470 mm with high inter-annual variability and possible dry spells of a few weeks during the season. The soils are sandy, with low water holding capacity and low inherent soil fertility (Table 1).