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Review

Fertilizer micro-dosing in West African low-input cereals cropping: Benefits, challenges and improvement strategies

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Soil amendments are often unavailable in adequate quantities for increased crop production in smallholder cereal-based cropping systems in Africa. In order to increase crop yields and encourage farmers to apply inorganic fertilizers, fertilizer micro-dosing technology was developed. Fertilizer micro-dosing or "micro-fertilization" consists of the application of a small quantity of mineral fertilizer together with seeds of the target crop in the planting hole at sowing or 2-4 weeks after sowing. The objective of this paper is to review literature concerning crops responses to fertilizer micro-dosing in West Africa. The review also evaluates the benefits and challenges associated with nutrient management under fertilizer micro-dosing and supportive strategies for further improvement in the efficient use of limited nutrient sources of smallholder farmers were suggested. Recent scientific developments on fertilizer micro-dosing revealed that this technology has given promising results in respect of crop yields improvement, fertilizer use efficiency and economic returns. Other studies have, however, indicated that fertilizer micro-dosing increases the risk of soil nutrient imbalances due to low-input. For this reason, we suggest that fertilizer micro-dosing should be used in concert with organic amendments to optimize productivity of smallholder farmers in West Africa.

Key words: Fertilizer micro-dosing, smallholder farmer, crop yield, farmer's income.

INTRODUCTION

During the past three decades, the paradigms underlying the use of fertilizers and soil fertility management research and development efforts have undergone substantial change due to experiences gained with specific approaches and changes in the overall social, economic, and political environment (Sanchez, 1994). Contrary to conventional knowledge, it is vital to acknowledge that the farmers' decision making process is not merely driven by the soil and climate, but by a whole set of factors cutting across the biophysical, socioeconomic, and political domain (Izac, 2000). In the light of this consideration, food production for the expanding world population has required the development and application of new technologies, and an intensification management to produce more food per unit of land (Stewart et al., 2005). Currently, a holistic approach in soil fertility research and strategy focus on the new paradigm of Integrated Soil Fertility Management (ISFM) which embraces the driving factors and consequences of soil degradation – biological, chemical, physical, social, economic, health, nutrition and political (Bationo et al., 2006). The ISFM defined as the application of soil fertility management practices and the knowledge to adapt these to local conditions, which maximize fertilizer and organic resource use efficiency and crop productivity (Sanginga and Woomer, 2009) has been promoted and advocated to preserve soil quality while promoting its productivity. Earlier, this soil fertility management practice had been considered as a prerequisite for the achievement of productive and sustainable agricultural production systems (Akponikpe, 2008).

Mineral fertilizer has been recognized as an entry point for sustainable agriculture production systems. However, the use of mineral fertilizer is still very low in most smallholder cropping systems in West Africa. According to the African Fertilizer Summit (2006), the fertilizer consumption in 55% of SSA countries is less than 5 kg ha^{-1}. In order to encourage farmers to use mineral fertilizer, the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) and partners have developed fertilizer micro-dosing technology. This technology has been found as an appropriate precision agriculture for smallholder farmers in the sahelian region of Africa.

This paper, focusing on recently published data, gives emphasis on (1) what has been done at research level on fertilizer micro-dosing technology (2) what can be learnt from the adoption of this technology and (3) what can be suggested for the effective use of this technology to enhance the productivity of smallholder cropping systems in the Africa.

FERTILIZER MICRO-DOSING

Fertilizer micro-dosing technology consists of the application of a small quantity of mineral fertilizer together with seeds of the target crop in the planting hole at sowing or few weeks (3 to 4) after planting (Hayashi et al., 2008; ICRISAT, 2009). In the Sahelian countries, fertilizer micro-dosing relies on smaller quantities (2 to 6 g $hill^{-1}$) of placed mineral fertilizers targeting in priority the most limiting element, phosphorus (Buerkert et al., 2001; Tabo et al., 2007). Micro-dosing decreases substantially the recommended amount of fertilizer that smallholder farmers need to apply per hectare, that is, from 200 to 20 kg ha^{-1} in the case of di-ammonium phosphate (Hayashi et al., 2008).

The techniques of applying fertilizer vary depending on soil and climatic conditions. For instance, in southern Africa, farmers use fertilizer measured out in an empty soft drink or beer bottle cap, while in western Africa, the farmers measure fertilizer with a three-finger pinch (ICRISAT, 2009). A three-finger pinch is equivalent to 6-g doses in the case of NPK 15:15:15 fertilizer which is about a full soft drink bottle cap. With ammonium nitrate fertilizer for instance, a beer bottle cap is equal to 4.5 g which is equivalent to 17 kg N ha^{-1} (Twomlow et al., 2010). Farmers in the Sahel use a soda bottle cap to allocate fertilizer, hence fertilizer micro-dosing is popularly known as the Coca-Cola technique (Tabo et al., 2006). Applying fertilizer in micro-doses permits more precise and better timed fertilizer placement and hence appropriate management of fertilizer (Sanginga and Woomer, 2009). This technology has also been strategically combined with other practices such as seed priming (Aune and Ousman, 2011), water harvesting, or application of manure, crop residues, and compost prepared from household and garden wastes (Sanginga and Woomer, 2009).

ORIGIN OF FERTILIZER MICRO-DOSING TECHNOLOGY

Fertilizer micro-dosing or hill placement of mineral fertilizer is a technology originally developed by the International Crops Research Institute for the Semi-Arid Tropics, Sahelian Center (ICRISAT-SC) with partners in Germany (Rebafka et al., 1993). In 1999, ICRISAT began a series of modeling workshops in conjunction with the International Maize and Wheat Improvement Center (CIMMYT) and the Agricultural Production Systems Research Unit (APSRU) in which research and extension officers used a simulation model (APSIM - Agricultural Production Systems Simulator Model) (Keatinge et al., 2003) to evaluate the type of resource allocation questions faced by resource-poor farmers in the semi-arid regions of southern Africa. A common theme started from the proposition that farmers may, at best, initiate investments in small quantities of fertilizer (Rohrbach, 1999). The robustness of the simulated responses to small quantities of N fertilizer was surprising, and contrary to much of the documented soil fertility research

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results in the region which started with at least 25 kg N ha^{-1} (Mushayi et al., 1999; Mafongoya et al., 2006). Simulation results for 1951 to 1999 rainfall period in southern Zimbabwe, suggested that farmers could increase their average yields by 50 to 100% by applying as little as 9 kg N ha^{-1}. These results indicated that farmers were better off applying lower rates of N on more fields, than concentrating a limited supply of fertilizer on one field at the recommended rates (Carberry et al., 2004).

On-farm experimentation was then initiated with farmers on micro-dosing alone or in combination with available animal manures (Ncube et al., 2007). The on-farm trial results confirmed that farmers could increase their yields by 30 to 100 % by applying approximately 10 kg N ha^{-1} (Rusike et al., 2006). Scaling out of micro-dosing was initiated in 2003/2004 with support from the Department for International Development (DFID) and the European Commission Humanitarian Aid Office (ECHO) which encouraged the application of the micro-dosing of ammonium nitrate fertilizer by more than 160,000 farmers (Rohrbach et al., 2005; Twomlow et al., 2007). Currently, fertilizer micro-dosing technology has reintroduced fertilizer use by smallholder farmers in Zimbabwe, Mali, Burkina Faso, Niger, and Mozambique and in the southern part of the African continent (ICRISAT, 2009; INERA, 2010; Twomlow et al., 2010). This technology establishes a pattern for future productivity as farmers become accustomed to increasing their investments in inputs in order to generate increased returns. It is therefore an entry point for increased use of fertilizers in farmers' fields, which can lead to more sustainable development (Tabo et al., 2008). In fact, micro-dosing has been identified as a climate smart technology (The Montpellier Panel, 2013), and a pathway for the intensification of agricultural systems in Sub-Saharan Africa (Murendo and Wollni, 2015).

BENEFITS OF FERTILIZER MICRO-DOSING

Fertilizer affordability

Fertilizer micro-dosing was developed in an attempt to increase the affordability of mineral fertilizer while giving plants enough nutrients for optimal growth (Hayashi et al., 2008). High rates of fertilizer input have been recommended to farmers for a long time to increase yields, but smallholder farmers could not afford to apply such fertilizer quantities. Small amounts are more affordable for farmers (Bationo and Buerkert, 2001) because of reduced investment cost (Tabo et al., 2006, 2007). For example, the application of 20 kg ha^{-1} of diammonium phosphate instead of 200 kg ha^{-1} recommended to smallholder farmers reduces input cost and investments risk while increasing crop yields (Bielders and Gérard, 2015).

Increase in crop yield

Several studies have examined the immediate millet or sorghum response to fertilizer micro-dozing in the Sahel. Muehlig-Versen et al. (2003) showed that hill application of 5 kg P ha^{-1} led to 65% of the yield increase obtained with 13 kg P ha^{-1} broadcast, resulting therefore, in a significant increase in fertilizer-use efficiency. Abdou et al. (2012) reported consistently significant increase in pearl millet yield following strategic placement of 4 kg P per hectare as NPK 15-15-15 or DAP (di-ammonium phosphate) at planting. Similar effects have been previously reported from the application of 4 kg P ha^{-1} as compound NPK fertilizer (Bationo et al., 1998). Other studies in Niger have shown that application of 6 g NPK fertilizer per hill can more than double millet yields (Bationo and Buerkert, 2001) and there is a positive economic return to the use of fertilizer (Hayashi et al., 2008; Tabo et al., 2011).

Having tested this technology in three Sahelian countries (Niger, Mali and Burkina Faso), Tabo et al. (2007) showed that the average grain yields of millet and sorghum were greater by 44 to 120% while the farmers' income increased by 52 to 134% when using hill application of fertilizer compared to the earlier recommended fertilizer broadcasting methods and farmers' practice. However, the application of these rates of fertilizer needs one additional person at the time of sowing for fertilizer application. The labour demand at sowing period is high which can lead to delayed sowing thereby resulting in yield decrease. Recent on-farm research in Niger has shown that farmers can delay the application of fertilizer under micro-dosing technology from 10 to 60 days after sowing without significantly reducing the yield and the economic returns (Hayashi et al., 2008).

Recently, Okebalama et al. (2016) reported optimal maize grain yield with $N_{20}P_{40}K_{20}$ and $N_0P_{40}K_{20}$ fertilizer micro-doses. Also, Ibrahim et al. (2014) showed that increasing the depth of fertilizer micro-dosing application from 5 to 10 cm results in a marked increase in millet yields. Crops under micro-dosing have been observed to perform better under drought conditions because the crops' larger root systems are more efficient at exploiting moisture at greater depth later in the season when soil moisture at the surface of the soil is low (ICRISAT, 2009). The positive effect of fertilizer micro-dosing in increasing millet yield has been attributed to the better exploitation of soil nutrients due to early lateral roots proliferation within the topsoil (Ibrahim et al., 2015). In the early development, it was postulated that the positive effect of fertilizer micro-dozing can probably be attributed to a root-growth stimulating effect of phosphorus fertilization as previously reported by Aune and Bationo (2008) and Buerkert and Schlecht (2013).

Questions on whether these results could be replicated across different soil types, agro-ecological zones and climates have been raised by many researchers. Tabo et al. (2008) confirmed that fertilizer micro-dosing has the potential to greatly increase yields across a range of agro-ecological zones and rainfall situations in West Africa, from the drier Sahelian zone to the wet Sudano-Guinean environment. In Ghana, NPK fertilizer micro-dosing increased maize yields by 99% in the humid forest zone (Okebalama et al., 2016). In Zimbabwe, wide-scale testing of the micro-dosing (17 kg N ha^{-1}) consistently showed increased grain yields by 30 to 50% across a broad spectrum of soil, farmer management and seasonal climatic conditions (Twomlow et al., 2010). Also, the findings of Hayashi et al. (2008) showed that fertilizer micro-dosing improved the harvest index of millet crop.

Farmers' income increases due to fertilizer micro-dosing application

More important than yield increases are the financial returns and risk associated with the adoption of a technology. Generally, the application of reduced dose of mineral fertilizer increases the economic return of applied technology. Profitability of maize to low rates of N fertilizer has been reported (Twomlow et al., 2010). Millet under micro-dosing gave net monetary gains which were 68 % higher than the net returns from the traditional practice and 33% higher than the net gain from the conventional recommended practice (Tabo et al., 2008). Okebalama et al. (2016) showed that $N_{20}P_{40}K_{20}$ micro-dose under continuous sole maize cropping was more profitable than the recommended fertilizer rate by about GH¢1,000.00 (about $350.00) net return difference per ha. In Mali, Burkina Faso, and Niger, ICRISAT (2009) reported an increase in sorghum and millet smallholders' family incomes by 50 to 130%.

Recently, Bielders and Gérard (2015) reported a value-cost ratios (VCR) of less than 1 from 36% of 276 fertilizer micro-dosing demonstrations setup across a 3-year period in the Fakara region, western Niger. However, the economic risk associated with micro-dosing (2 g DAP $hill^{-1}$ for instance) appears higher than has hitherto been reported and widespread adoption may not be warranted without institutional support. In practice, one generally considers that the VCR should be at least 2 for adoption in developing countries, but VCR values of 3–4 may be required in risky environments (CIMMYT Economics Program, 1988). This means that yield increases following micro-dose application should be at least twice, but ideally 3 to 4 times. Better economic returns of micro-dosing have been obtained in Mali (Aune et al., 2007) and Sudan (Aune and Ousman, 2011) with 0.3 g fertilizer per hill, which was achieved by mixing seeds and fertilizer in a 1:1 ratio before sowing. In addition, the latter practice saves on labor costs at sowing, since seed and fertilizer can be applied simultaneously, something that is not feasible with the rate of 2 g fertilizer per hill. Aune et al*.* (2007) observed higher yield increases with the application of 6 g than 0.3 g per pocket with a VCR of 0.43 to 1.17 and 3.4 to 11.9, respectively. Accordingly, the application of 0.3 g of fertilizer appealed to farmers because of the good return on investment, low financial risk, low cash outlay and low workload required.

Increase in nutrient use efficiency (NUE)

Tabo et al. (2006) noted that micro-dosing optimizes NUE, while Zougmoré et al*.* (2004) found that the combination of water harvesting technologies and fertilizer improved water and NUE by crops. Okebalama et al. (2006) observed that micro-dosing increased N, P and K use efficiency of maize in rotation with cowpea than in sole cropping. Reports from ICRISAT (2009) showed that implementation of micro-dosing technology enhanced NUE and improved productivity relative to spreading fertilizer over the field. Small amounts of applied fertilizer give an economically optimum (though not biologically maximum) response, and if placed in the root zone of widely-spaced crops rather than uniformly distributed, result in more efficient uptake (Bationo and Buerkert, 2001). The efficient use of fertilizer by plants depends on mode of application, with the most efficient method being hill placement (Bationo and Waswa, 2011).

Technology adoptability

By using much lower rates of fertilizer than the recommended rate, in more efficient ways that deliver economically optimum returns, farmers are much more able and inclined to adopt the practice. Surprisingly, the adoption rate of micro-dosing, like many other intensification techniques in sub Saharan Africa (SSA) is generally considered to be low (Liverpool-Tasie et al., 2015). In northwest Benin, Natcher et al. (2016) found that both adoption and project awareness of micro-dosing were low following two years of field trials. However, recent survey on 415 smallholder farmers in eight semi-arid districts of Zimbabwe reported 47%micro-dosing adopters and 53% non-adopters (Murendo and Wollni, 2015). Among the adopters, the adoption of micro-dosing increased the likelihood of being food secure by 47 percentage points compared to the counterfactual case. Fertilizer micro-dosing adoption is also gender specific. Winter-Nelson (2014) reported that female-headed households were significantly less likely to adopt micro-dosing than others, possibly due to labour shortages or difficulties in accessing fertilizer. Across four countries in West Africa, a baseline study has shown that women are 25% more likely to adopt a combination of micro-dosing and rainwater harvesting compared to men (Abdoulaye et al., 2014).

To increase fertilizer micro-dosing adoption rate, it is very important to understand the constraints that farmers face and ascertain the technique adaptability to the farmers' existing farming practices. This is very important because insufficient adaptation of technologies to farmers' condition among others had been recognized as a major constraint to adoption (Sanginga and Woomer, 2009). Other identified major constraints to the widespread adoption of micro-dose technology include access to fertilizer, access to credit, insufficient flows of information and training of farmers, and inappropriate policies (ICRISAT, 2009). Winter-Nelson (2014) reported that training in micro-dosing raised the probability of adoption by 30 to 35% points in the semi-arid areas of Zimbabwe. Experiences from both western and southern Africa have shown that adoption of micro-dose technology requires supportive and complementary institutional innovation as well as input and output market linkages (Bationo et al., 2006).

Increased food security

Micro-dosing has the potential for improving food security. The over 100% yield increases of cereal crops produce of smallholder farmers (Tabo et al., 2006, 2007) suggests increased food security and less need for food aid. The findings of Twomlow et al. (2010) provided strong evidence that N micro-dosing has the potential for broad-scale impact on food security for a large section of the rural poor across dry regions of southern Zimbabwe. Rohrbach et al. (2005) reported that the estimated DFID's support for the distribution of 25 kg of ammonium nitrate fertilizer to each of 160,000 farm households contributed 40,000 additional tons of maize production, valued by the World Food Programme at 5 to 7 million USD. Murendo and Wollni (2015) found that micro-dosing improved household food security of smallholder farmers in the semi-arid areas. That notwithstanding, with the predicted significant reduction in productivity of the major crops because of future warming and shift in precipitation patterns in West Africa (Ahmed et al., 2015), the resilience of soils under fertilizer micro-dosing to climate change for improving food security becomes questionable.

With the projected decrease in the productivity of certain crops due to climate change (IFPRI, 2007) one wonders if fertilizer micro-dosing technology could be considered a climate change adaptation strategy that would replace nutrient losses via leaching and erosion resulting from high rainfall. This is important because without technology adaptation, the long-term mean of crop yield has been projected to decrease in most West African countries (despite some projected increase of precipitation) by the middle of the century, while the inter-annual variability of yield increased significantly (Ahmed et al., 2015).

FERTILIZER MICRO-DOSING CHALLENGES AND POSSIBLE SOLUTIONS

Labour intensive

Farmers have reported that micro-dosing is labourious, time consuming and difficult to ensure each plant gets the right dose of fertilizer (ICRISAT, 2009). In an attempt to address these issues, ICRISAT collaborates with private fertilizer companies in eastern and southern Africa, to identify appropriate fertilizer types and promote the sale of small packs suited to the resource constraints and risk preferences of small-scale farmers. ICRISAT is also exploring the use of seed coating (with fertilizer) as another option of further reducing the quantity of fertilizer to be used as well as the labour constraint. In addition, researchers are looking at packaging the correct dose of fertilizer as a tablet that aids in application (ICRISAT, 2009). Alternatively, with the development of labour-reducing equipment, precise plant hill fertilizer micro-dosing would complement farmers' efforts (Tabo et al., 2007).

On the other hand, Liverpool-Tasie et al. (2015) found no empirical evidence that micro-dosing is more labor intensive than traditional methods of fertilizer application as is conventionally thought. Hayashi et al. (2008) opined that delayed fertilizer application strategy for micro-dosing would enable farmers to better manage available labour and also have some flexibility and an additional option in investing in inorganic fertilizer. Accordingly, delayed application allows farmers to push labour usage to later in the season, after planting, when the labour pool is not as limited, thereby reducing the chance of bad results by applying fertilizer after crops have emerged. On the contrary, delayed application may attract additional labour cost thereby increasing the overall production cost and hence, becomes a constraint. Even though delayed fertilizer application to emerged crops may be cost effective, matching fertilizer nutrient requirement of crops during growth phase is dynamic. This is vital because the mismatching of nutrient availability with crop needs may probably contribute to nutrient losses or reduced nutrient use efficiency by crops. Plant responsiveness to micro-dose fertilizer nutrients availability depends partly on the fertilizer placement method and time. The fertilizer placement method reduces nutrient losses, while on time placement helps the plant to have early established roots that can explore for more nutrients deeper down the soil (Ibrahim et al., 2014). Be that as it may, delaying application in order to save the amount of fertilizer applied to the crops could be beneficial if the fertilizer is strategically applied to synchronized nutrient availability and crop demand, particularly when applications are timed to moisture availability. Therefore, obtaining maximum profitability lies not only in reducing the amount of fertilizer use per unit area but also in reducing costs per unit crop produce through higher nutrient use efficiency and yields.

Financial constraints

Most farmers are faced with lack of financial means at the onset of the rainy season. 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. Nevertheless, delayed fertilizer application can lessen the financial burden of the local farmers during the sowing period. Delayed fertilizer application offers smallholder farmers opportunity to raise the cash needed to purchase and apply fertilizers only to established plants, thus increasing their chance of producing more grain and economic returns (Hayashi et al., 2008). Also, farmers' supportive groups (co-operative) or warrantage/inventory credit strategy as practiced in West Africa aims to resolve the farmers' capital constraint. Organized farmer groups provide access to post-harvest credit provided on the basis of storage of grain as collateral (warrantage), enabling farmers to sell crops later in the season for higher prices and higher profits (Bationo et al., 2006).

Nutrient mining

The possibility of soil nutrient mining arising from fertilizer micro-dosing technology has raised much concern. Researchers have questioned the logic of micro-dosing, claiming that the use of such a small quantity of fertilizer is not sustainable (Twomlow et al., 2010). Singh and Ajeigbe (2007) noted that the average use of 10 kg/ha/yr of fertilizers in West Africa leads to a negative balance of nutrients in the soil and continuous decline in crop yields, which perpetuates malnutrition, hunger and poverty through the vicious circle of 'low input-low production-low income' and food insecurity. No doubt, as grain yields increase per unit area and very little organic matter, including crop residues, are put back into the soil, there is the risk that nutrient imbalances will inevitably develop with time (Tabo et al., 2007). As such practising fertilizer micro-dosing alone may lead to soil degradation on the long term. Accordingly, it is important to ensure that organic matter is added and incorporated into these soils to improve their structure and enhance their capacity to store adequate moisture and nutrients even after crops are harvested (Tabo et al., 2007). Soil organic matter plays a central role in maintaining tropical soil fertility and its conservation and maintenance in tropical cultivation systems is imperative if soil degradation is to be halted and cropping made sustainable (Ross, 1993). The quantity of soil organic matter in the soil has been found to depend on the quantity of organic material which can be introduced into the soil either by natural returns through roots, stubble, slough off roots nodules and root exudates or by artificial application in the form of organic manures (Adebola et al., 2012).

As opinioned by Gambo et al. (2008), the most satisfactory method of increasing crop yields are by judicious use of organic manures in combination with little portions of inorganic sources for nutrient use efficiency. This is factual because unlike organic fertilizer, mineral fertilizer does not improve aggregation of soil particles; neither does it activating soil microbial activities. The use of organic manures has been recommended for long term cropping in the tropics as slow mineralization of these manures promote crop yield for a long period of time (Gambo et al., 2008). Organic fertilizers are known to improve soil organic matter, and macro- and micro-nutrients qualities of the soil. Organic manures sustain cropping systems through better nutrient recycling and improvement in soil physical, chemical and biological properties (Ojeniyi, 2000). Hence, the principle that makes organic manure useful and important in soil fertility maintenance is their impact on soil fertility supplies, moisture holding capacity and structural characteristic (Udoh et al., 2005).

Finally, it appears that most micro-dose fertilization studies were mainly based on sole cropping of cereals such as maize, wheat, millet and sorghum. However, the effect of inter-cropping, strip-cropping, or mixed cropping of these crops and micro-dosing of fertilizer are yet unknown. In most African countries, most food crop farms are intercropped because of the predominance of smallholder farm holdings of less than 2 ha and the need to achieve household food security. As such, while monocropping is uncharacteristic of smallholder farming, intercropping/mixed cropping is typical to most smallholder farmers even though traditionally practiced with little or no application of fertilizers. Intercropping of cereals will encourage growing of traditional crops (millet, sorghum etc) in order not to be completely replaced by introduced high value crops such as maize (Bandyopadhyay et al., 2007). Also, little is known about the impact of fertilizer micro-dosing on performance of other crops such as cowpea, garden eggs, cucumber and amaranth. Research on these crops should be considered as the findings could benefit smallholder farmers, considering their nutritional advantage.

CONCLUSION

Fertilizer micro-dosing technique is useful in the management of fertilizer for cereal crop production, particularly under smallholder farming in most West and Southern African countries. The technology has led to high reduction in the recommended rate of fertilizer application to crops. Small quantities of fertilizer (about 9g per plant) placed with seed at sowing or at the base of each plant 3-4 weeks after sowing increases crop yield by 30 to 100%. Increase in nutrient use efficiency of crops and farmers income are added benefits associated to fertilizer micro-dosing. Despite its potential for broad-scale impact on food security, the technology adoption is low, in addition, soil nutrient mining and labour intensive challenges have raised concerns of some researchers and farmers, respectively. Nonetheless, fertilizer micro-dosing can contribute usefully to sustainable agricultural development, especially when integrated with organic fertilizer application.

Conflict of Interests

The authors have not declared any conflict of interest.

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