**Literature review**

Maize is an essential crop for tackling hunger, food insecurity and nutrition-relation challenges, globally. Across Africa including Ghana, maize serves as a major staple crop in many households, particularly in poor and vulnerable farming communities constituting the largest population on the continent (Makate et al., 2017; Tovihoudji et al., 2022). Yet, maize cultivation is heavily threatened by diverse factors including unpredictable rainfall patterns, persistent drought, pest and disease invasion, poor soil fertility and poorly managed application of fertilizer (Asare-Nuamah, 2022; Barrett & Bevis, 2015). These threats pose a serious challenge to the effective production of maize needed to feed the growing population in Africa. Projections show that Africa would need to at least double its current food supply to meet the food security needs of its population by 2050 (AGRA, 2023; Searchinger et al., 2018). Undoubtedly, low productivity and poor yields associated with maize production in Africa urgently need to be addressed.

Multiple agricultural innovations have been developed and implemented by international agricultural research for development institutions (e.g., CIMMYT – International Maize and Wheat Improvement Center, IITA – International Institute for Tropical Agriculture) in partnership with national agricultural research centers in Africa to tackle the persistent challenge of low maize productivity on the continent (Fisher et al., 2015; Makumbi et al., 2018). Critical among them is the development of improved maize varieties (i.e., drought tolerant, early maturing and pest resistant varieties) (Beyene et al., 2013)(Setimela et al., 2017). According to Yeboah et al. (2019), the adoption of improved maize verities among smallholder farmers is due to their inherent characteristics such as early maturing and climatic endurance as well as and improvement in the quantity and quality of yields. Indeed, the literature highlights the benefits associated with improved maize varieties (Lunduka et al., 2017; Makate et al., 2017). However, the adoption of improved maize varieties alone is insufficient to deal with the adverse effects of harsh climatic conditions farmers experience across different settings in Africa (Tovihoudji et al., 2022). It is essential to complement the adoption of improved maize varieties with good agronomic practices, integrated crop water management and effective soil management etc. This is particularly true for smallholders in Africa where poor agricultural and soil management practices are high coupled with high fertilizer cost and the associated ineffective application.

Microdosing – the application of a small dose of fertilizer (usually 2 – 6 g) during planting or immediately after planting, has been reported as a promising approach to tackle the dual challenge of soil infertility and low yields (Buerkert et al., 2001). According to Bationo & Buerkert (2001), fertilizer microdosing is promising for addressing soil organic carbon deficiencies common in African soils. Microdosing also address the issue of high fertilizer cost faced by vulnerable and poor farmers in Africa as the practice significantly reduces the amount of fertilizer required per hectare of land (Tovihoudji et al., 2019; Twomlow et al., 2010). The practice is also reported to be efficient in enhancing soil nutrient and water use (Tovihoudji et al., 2018) and promote quality yields (Tovihoudji et al., 2017). Given its potential for sustainable agriculture, food security and poverty in Africa, several studies, particularly involving experimental trials, have reported the positive environmental and socioeconomic benefits associated with microdosing.

In an on-station trial in Northern Benin, (Tovihoudji et al., 2022) analyzed the socioeconomic and environmental effects of fertilizer microdosing on drought tolerant maize varieties in comparison with no fertilizer application and the application of the recommended fertilizer rate. The study observed that microdosing increased biomass, leaf area, stover and grain yields by 85%, 71%, 98% and 171%, respectively compared with no fertilizer applications. The authors further report that observations from two cropping seasons also revealed an exponential impact of microdosing on yields, resulting in total maize yields of 658 kg per hectare and a gross return of USD$203. While the results are consistent with Tovihoudji et al. (2017) who noted that fertilizer microdosing increases yields by 64% to 93%, there is the tendency for microdosing to reduce fertilizer use efficiency by about 4.6 – 19 kg grain kg−1 fertilizer with increasing soil amendments, such as manure. In Ghana, through split plot trial involving cowpea-maize rotation and continuous cropping systems , Okebalama et al. (2016) assessed the resource use efficiency and economic effect of NPK fertilizer microdosing on maize in two different soils (Plinthic Acrisol and Gleyic Plinthic Acrisol) of the humid forest zone in the country. The results from the study show that across the two soil types and cropping systems, the effect of microdosing on maize yields resulted in about 32% to 99% increment in yields. Under the continuous cropping system, the rate of maize increment was higher on Gleyic Plinthic Acrisol (99%) than Plinthic Acrisol (76%) while that of cowpea-maize rotation was 46% for Plinthic Acrisol and 74% for Gleyic Plinthic Acrisol. The study concluded that microdosing effects on grain yields and nutrient use efficiency are higher in a crop rotation system than continuous cropping system.

The study by Laminou et al. (2022) also confirms the positive effects of fertilizer microdosing on soil properties and yields, although the extent of impact is highly dependent on the season (year) and a better soil nutrients’ exploitation. Their experiment involved two variants (different doses) of fertilizer microdosing (0.5g each of NPK and urea; and 1g of NPK and 0.5g of urea), the recommended dose (200 kg of NPK and 150kg of urea per hectare), and an absolute control with no fertilizer in maize cropping system. The results show an increase in the height of maize insertion due to microdosing compared to the control. Similarly, comparing the yields from microdosing relative control and recommended dose, the study observed 89% increase in yields from microdosing compared to absolute control while that of recommended dose was about 26%. For soil properties, the study reported differential effects of microdosing on soil pH, potassium, nitrogen and phosphorous. In addition, microdosing’s value-to-cost ratio was recorded as 4.47 and 9 for the two different doses. The results are consistent with Mashingaidze et al. (2013) who noted that microdosed soils have higher stability and nitrogen content with reduced leaching compared with ammonium nitrate. While recognizing the positive influence of microdosing on yields, Twomlow et al. (2011) show that for microdosing to be economically profitable to smallholder farmers, they must obtain about 4kg to 7kg of yields per kilogram of Nitrogen applied and farmers can earn about 15 to 45kg of grain per every 17kg of N inputs applied per hectare. The authors therefore argued that the major challenge affecting grains production in Africa is largely due to low Nitrogen content of soils and not necessary the lack of or erratic rainfall. Hence, their results provide evidence of how microdosing can be used to address nitrogen deficiency in soil and increase productivity.

Other studies have also examined the interactive effective of microdosing in intercropping systems (Abdoul‑Karim et al., 2022; Tovihoudji et al., 2022; Twomlow et al., 2011). For instance, Abdoul‑Karim et al. (2022) assessed the economic and agronomic performance of microdosing in millet and cowpea intercropping system in Niger. The study report about 43% to 168% increment in cowpea yields between 2020 and 2021 under microdosing treatment in intercropping system while the sole cropping without microdosing yielded about 29% to 98% for the same period. For millet, while sole cropping millet resulted in about 18% to 78% increment, that of intercropping with microdosing had a higher yield ranging between 2.7% and 113%. According to the authors, the economic gains from microdosing ranged between USD$40 and USD$212. For the control, the economic gain was about USD$19 to USD$26. Nevertheless, the study observed dominant influence of millet in intercropping compared to cowpea, resulting in an increase in millet yields with or without microdosing compared to cowpea. Nevertheless, microdosing is associated with trade offs (Hayashi et al., 2008; Kuyah et al., 2021; Twomlow et al., 2011) including being time consuming and labour intensive (Vandamme et al., 2018) as well as increasing nutrient mining particularly in highly depleted cropping systems, especially for potassium and phosphorous given that plants cannot biologically fix these nutrients from the atmosphere (Ibrahim et al., 2016). Nziguheba et al. (2016) report the possibility of nutrient imbalance as crop nutrient uptake may not match with what microdosing adds to the soil, which may decrease crop yields over time (Adams et al., 2016).

Given the economic and environmental benefits associated with microdosing, its application in parkland systems such as the Guinea and Equatorial Savannah agroecological zones in Northern Ghana, remain limited. Given that farmers in these agroecological zones work on highly poor and arid soils and face some of the extreme climatic shocks and stressors, affecting their agricultural yields, food security and income (Antwi-Agyei et al., 2018, 2023), it is crucial to promote the adoption of microdosing. Yet, the presence of trees, particularly shea *“Vitellaria paradoxa”* on these agroecological may have influence (negative and/or positive) on the performance of microdosing and maize yields. Advancing knowledge on the interactive effects of shea tree and microdosing on maize performance can significant contribute towards informed decision-making among farmers. In view of this, the DecLaRe (Decision support for strengthening land resilience in the face of global challenges) project, funded by the German Federal Ministry of Education and Research (BMBF) aims at testing the efficacy of microdosing and maize in the parkland system in the Savannah region of Ghana.

To enhance the upscale and adoption of the innovation, we perform cost-benefit analysis using decision analysis (forecast model) to enables decision makers, particularly farmers, to make the right decision to adopt microdosing innovation. Three main scenarios or options are forecasted for the farmer to make an informed decision. These decision options include:

1. Maize + shea tree (status quo) without any fertilizer added
2. Maize + shea tree with recommended fertilizer (RF) applied (i.e., 200 kg of NPK per hectare)
3. Maize + shea tree + microdosing (1.5g of NPK per hill or 93.7kg of NPK per hectare)

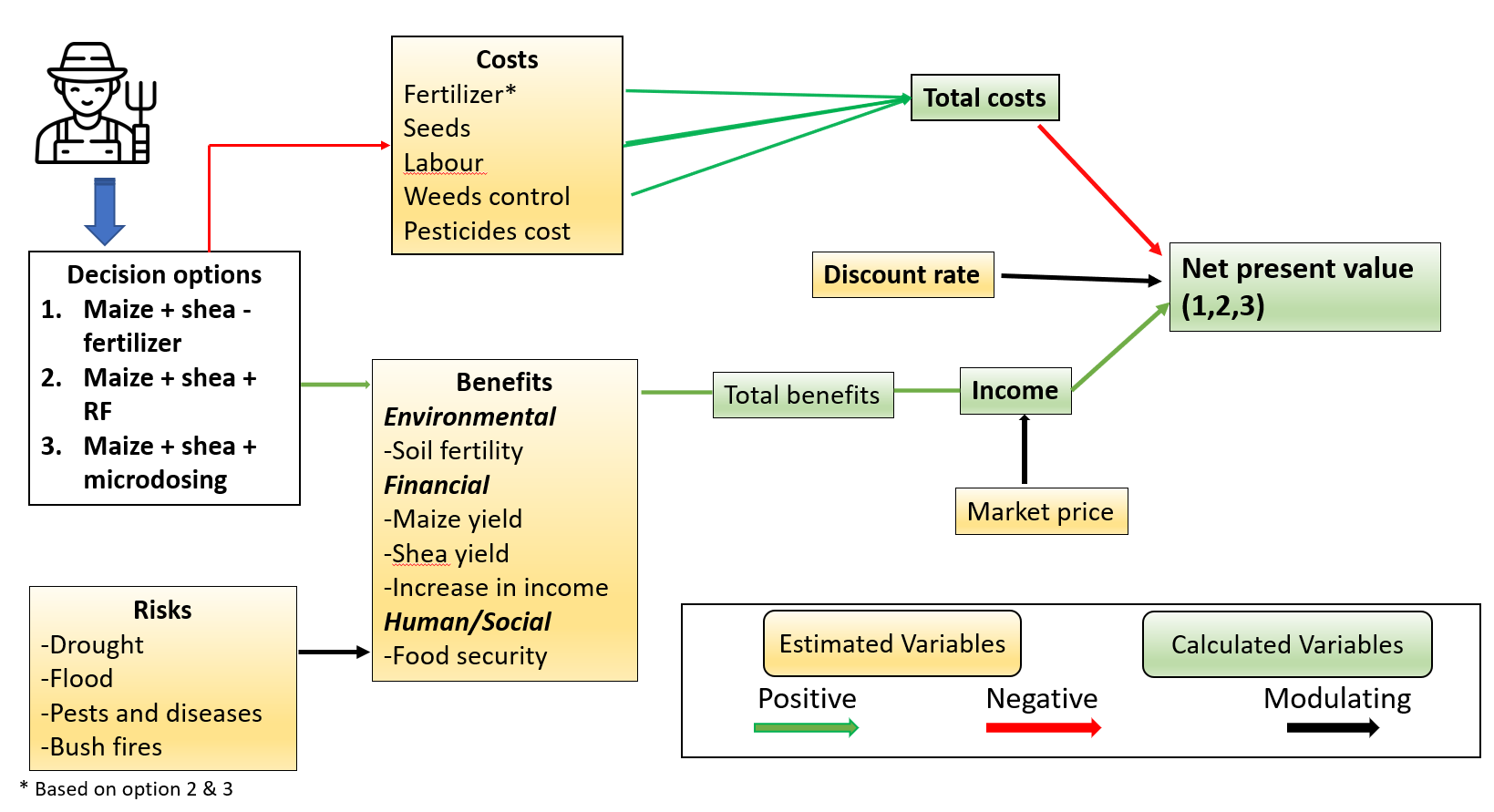


Figure 1. Conceptual model for the decision options

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