2-1 Suboptimal performance of farmers' NPK fertilizer application in the upland cropping systems of central Burkina Faso

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Abstract

A growing body of literature has evaluated the optimal application rates of inorganic fertilizers and their impact on major staple crops such as maize in sub-Saharan Africa. However, farmers' limited adoption and effectiveness of fertilizers, particularly for key upland crops other than maize, has not been adequately investigated. Using data from a multi-season survey of smallholder crop production in central Burkina Faso, this paper examines the yield response to farmers' NPK fertilizer application and its cost-effectiveness compared to non-fertilization for sorghum and cowpea, two vital local food and cash crops. The findings reveal that farmers experienced yield responsiveness to compound fertilizer for sorghum and cowpea during seasons with relatively favorable rainfall. However, similar responsiveness was not observed in seasons with poor rainfall. In neither season was the net income of the fertilized crops found to be superior to that of the non-fertilized crops. Due to limited fertilizer use efficiency, the yield gains appear insufficient to offset the cost of fertilizers, regardless of some rainfall variability. Nevertheless, our analysis suggests that significant increases in net income cannot be achieved solely by reducing fertilizer costs; substantial yield improvements are also necessary. Therefore, in addition to fertilizer price reduction measures such as subsidies, innovative strategies are needed to enhance profitability and incentivize farmers' fertilizer investments, including the implementation of effective agronomic practices that complement fertilization and marketing approaches designed to boost crop sales.

1. Introduction

Soil fertility management is crucial for enhancing agricultural productivity in sub-Saharan Africa (SSA), where nutrient deficiencies severely constrain crop yields and contribute to declining per-capita food production. The region's soils are often characterized by inherently low natural fertility, necessitating the effective use of fertilizers to sustain or improve soil nutrient levels and support sustainable agricultural practices. However, sole reliance on organic amendments poses challenges due to their limited availability and the logistical constraints of transportation. Consequently, applying inorganic fertilizers, such as NPK (nitrogen, phosphorus, potassium), is widely promoted to overcome soil fertility constraints and increase crop productivity.

Despite the recognized importance of inorganic fertilizer use, several challenges impede its effective

implementation. The high cost of fertilizers remains a significant barrier for smallholder farmers in SSA, limiting their capacity to apply adequate quantities for optimal yields. Even when fertilizers are applied at recommended levels, farmers may experience unexpectedly low agronomic performance. Studies have documented "non-responsiveness," where fertilizer application at recommended rates fails to produce satisfactory yield gains (Roobroeck et al., 2021). Empirical evidence shows that the yield response to inorganic fertilizers in SSA often falls below expectations in farmers' fields, leading to suboptimal profitability (Burke et al., 2020).

Although numerous studies have assessed fertilizer use efficiency and the agronomic and economic performance of major food staples, primarily maize (e.g., Burke et al., 2019; Dabessa Iticha et al., 2021; Kiwia et al., 2022), relatively few on-farm investigations have evaluated the actual productivity and profitability gains achieved by farmers using fertilizers for other upland food and cash crops. In the extensive dryland areas of SSA, which are less suitable for maize production, there is a need to focus on investments in more drought-tolerant cropping systems. For instance, in the Sahel, farmers predominantly cultivate other cereals, such as sorghum, and legumes, such as cowpea, as their primary food and income sources. Given the severe impact of soil erosion and nutrient depletion on their production, judicious fertilizer application is vital for mitigating food and income insecurity in this region. However, the responsiveness and cost-effectiveness of fertilizers for these dryland crops in farmers' fields remain underexplored in the literature. To address this knowledge gap, further research is needed to investigate the constraints of fertilizer input and output in dryland environments.

Based on detailed multi-season production surveys of Sahelian cropping systems in central Burkina Faso, this paper aims to highlight trends in farmers' fertilizer selection and targeted crops and to examine the yield and profitability effects of fertilization across seasons. It clarifies significant challenges in actual fertilizer use and proposes promising interventions to support farmers in adopting and expanding fertilizer applications.

2. Materials and methods

We conducted an exhaustive field survey encompassing 237 plots cultivated by 20 randomly selected smallholder farm households in the rural area of Saria, located in the Boulkiemde province, Centre-Ouest region of Burkina Faso, over two consecutive years (2019 to 2020 cropping seasons). We visited all plots in both seasons and directly measured the cultivated area and crop harvests for accurate yield evaluation. Additionally, to collect accurate data on field crop management, we instructed every household to measure and record daily amounts and costs of inputs (seeds, fertilizers, herbicides, and insecticides) used and the number of persons, hours, and wages paid for each crop production activity, by providing measurement and recording materials along with careful instructions on their use. Our field staff regularly monitored and assisted with the measurement and recording activities and cross-checked the data before we double-checked it for approval. This elaborate data

collection and inspection procedure was adopted primarily to avoid issues of farmers' recall and measurement errors. These issues have been found to undermine the reliability of agricultural output, input, and productivity variables (Wollburg et al., 2021).

Using the collected data, this chapter first discloses farmers' actual use of fertilizers, focusing on the most commonly used fertilizer in the study area. We highlight the application area, application rates, and target crops across two cropping seasons characterized by contrasting rainfall regimes: relatively favorable rainfall in the 2019 cropping season and unfavorable rainfall in the 2020 cropping season. Next, the relationship between fertilizer application rates and yields of the target crops is examined. The results of the two cropping seasons are compared to better understand the influence of rainfall variability on fertilizer use intensity and responsiveness. We also evaluate crop yields and profitability between fertilized and non-fertilized fields to underscore the advantages (or disadvantages) of actual fertilizer use. Additionally, the fertilizer prices or yields at which the profitability of fertilized plots significantly surpass that of unfertilized plots will be examined.

3. Results

The primary fertilizer farmers use at the study site is imported NPK compound fertilizer (mostly 14-23-14 and 15-15-15). A few farmers apply limited quantities of animal dung or manure to the homestead plots. Although the application of NPK fertilizer is the principal means for farmers to improve or maintain soil fertility, only 21.4% of the total cultivated area received this fertilizer in 2019 and 15.7% in 2020 (Table 1). Notably, nearly 90% of the fertilized crop fields were dominated by cowpeas. Given that cowpeas are one of the major cash crops in the study site, it appears that farmers aim to enhance income by concentrating fertilizer investment on this crop. This underscores the critical importance of examining the economic return on fertilizer use in the study site alongside agronomic response. The average application rates of NPK fertilizer on cowpeas were 94.6 kg/ha in 2019 and 41.6 kg/ha in 2020, both below the recommended application rate of approximately 100 kg/ha (Omoigui et al., 2018). Notably, the area and rate of application were relatively low in 2020, a year with less rainfall than 2019, even though the fertilizer prices in those two years were comparable. This suggests that farmers may have adjusted fertilizer use in response to rainfall conditions. The cropping systems for cowpeas are grown mainly by monocropping or mixed cropping with sorghum, a major staple food in the study site.

Table 1. NPK fertilizer application by farmers in 2019–2020 cropping seasons

	2019	2020
Percentage of NPK fertilized area in total cultivated area	21.4	15.7
Percentage of cowpea area in NPK fertilized area	89.6	85.3
Avg. application rate of NPK fertilizer in cowpea fields (kg/ha)	94.6	41.6

For NPK fertilizer application rates and grain yields in cowpea monoculture and mixed cropping with sorghum, both cowpea and sorghum yields increased with the rate of fertilizer applied in 2019 when sufficient rainfall was received, but not in 2020 when rainfall was relatively scarce (Figure 2). These results indicate varying yield responses to fertilizer under different rainfall conditions. However, even in 2019, when rainfall conditions were relatively favorable, the average yield of fields where NPK fertilizer was applied was not substantially higher than those without fertilizer. For instance, in cowpea monoculture, the average yield of fertilized fields was 510 kg/ha, slightly higher than that of unfertilized fields (458 kg/ha).

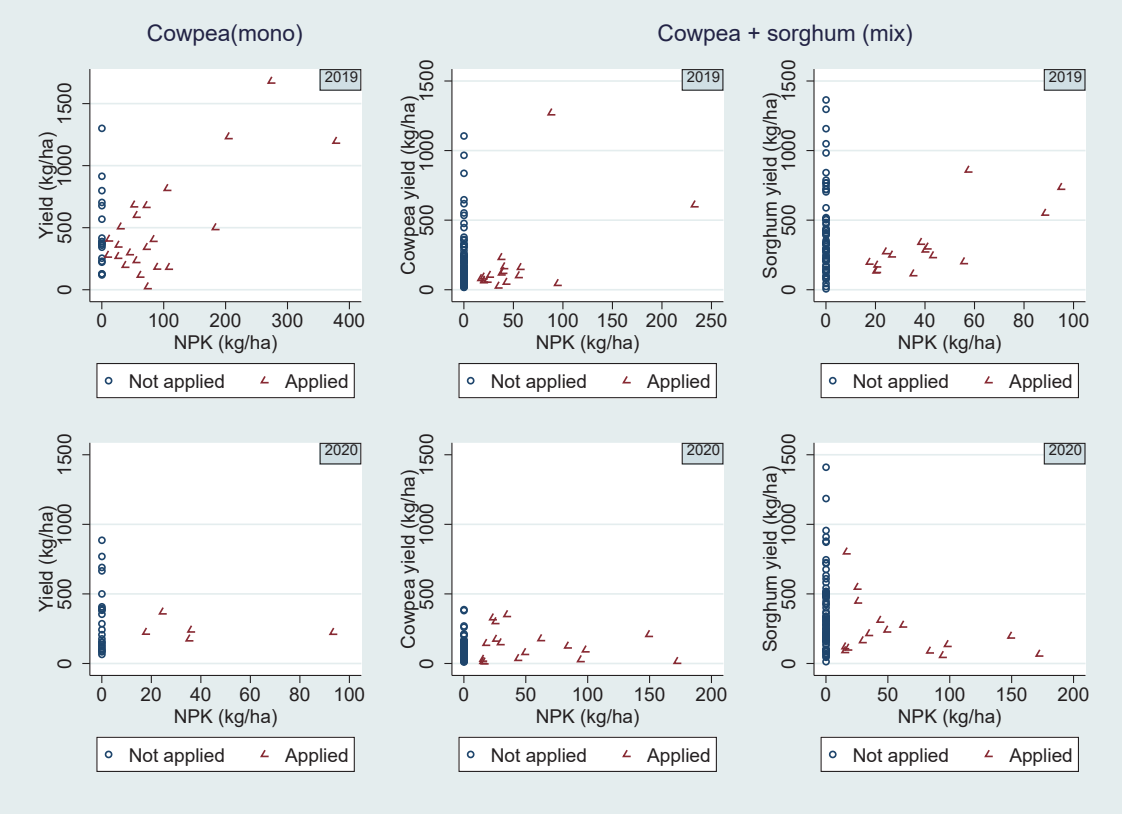

Figure 2. NPK application rates and yields of cowpea monocropping and mix cropping with sorghum in the 2019 cropping season (above) and the 2020 cropping season (below)

Due to the limited yield response to compound fertilizer and the associated acquisition costs, no significant differences were observed in the net income levels between fertilized and unfertilized fields (Figure 3). In cowpea monocropping and mixed cropping with sorghum, the average net income was slightly higher in non-fertilized fields than in fertilized ones. Furthermore, this lack of economic advantage in fertilized fields was observed not only in 2020, when rainfall was relatively scarce but also in 2019, when rainfall conditions were relatively favorable. As previously mentioned, a certain

degree of yield response to fertilizer was observed in 2019; however, it was insufficient to offset fertilizer costs and generate income gains. Consequently, farmers' fertilizer application did not improve profitability regardless of rainfall conditions. This limited economic performance may have deterred farmers from expanding fertilizer use, compounded by financial constraints on its acquisition. In other words, the current behavior of farmers who do not overly rely on fertilizer application may be considered rational.

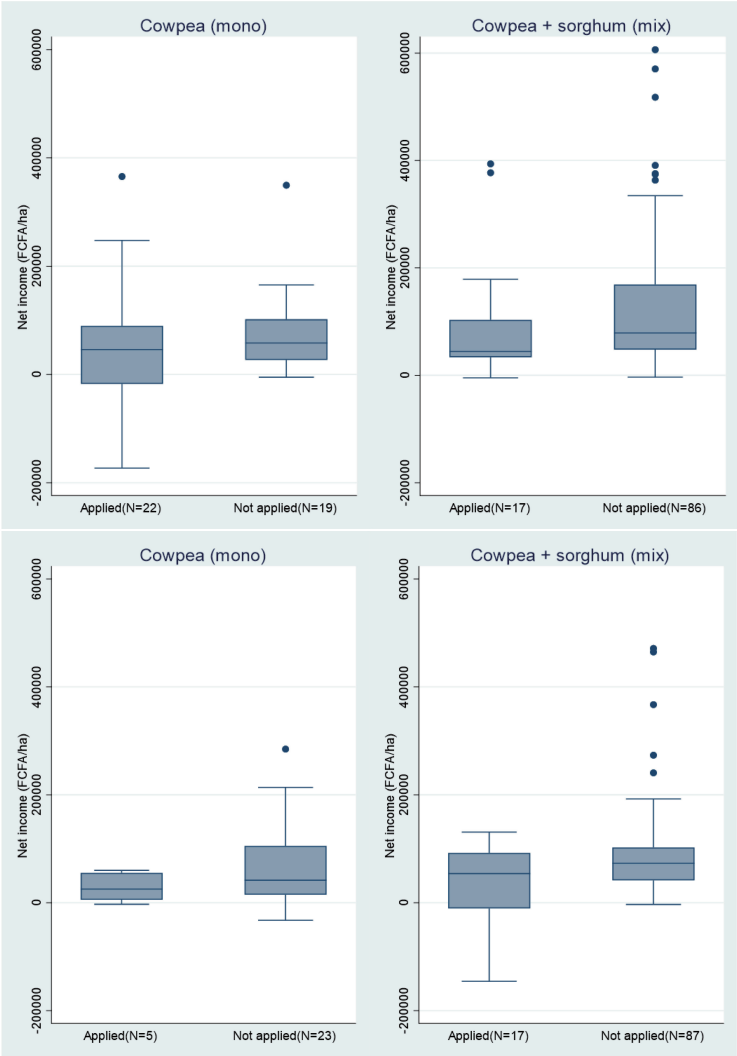

Figure 3. Net income of cowpea monocropping and mixed cropping with sorghum between NPK fertilized and non-fertilized fields in the 2019 cropping season (above) and the 2020 cropping season (below)

Net income: Gross income − Paid-out costs,

FCFA: Franc of the Communauté Financière Africaine (Currency)

To address the issue of the lack of economic advantage in fertilizer use, it would be informative to evaluate the extent to which reductions in fertilizer prices or increases in crop yields would be required to achieve this advantage. Therefore, we examined the fertilizer prices or yields at which the net income of fertilized plots significantly surpassed that of unfertilized plots (t-test, $p<0.05$). Unfortunately, even during the 2019 season, which exhibited relatively favorable fertilizer responses due to good rainfall, solely reducing fertilizer costs to zero (maintaining the observed yields) did not result in a significant difference; the average net income of fertilized plots—whether for cowpea monocropping or cowpea-sorghum mixed cropping—only slightly exceeded that of unfertilized plots. Under the current fertilizer pricing structure, a significant difference in net income between fertilized and unfertilized plots would only be observed if the yields of fertilized plots increased by approximately 93% for monocropping and 101% for mixed cropping. Even with a hypothetical subsidized fertilizer price, such as adopting half of the current price, a significant difference in net income would require the yields of fertilized plots to increase by 76% for monocropping and 93% for mixed cropping. Therefore, in addition to reducing fertilizer prices, innovative measures are necessary to substantially improve the profitability of fertilized production. These measures may include effective combinations of agronomic practices that complement fertilization and marketing strategies to enhance crop sale prices.

4. Concluding remarks

Consistent with previous studies documenting the suboptimal performance of fertilizer application in SSA, this study underscored the current inefficacy of compound NPK fertilizers in boosting farmers' economic returns. A substantial portion of the applied fertilizer was directed toward cowpea, a key cash crop in the study region, indicating farmers' attempts to maximize income from this high-value crop. However, the extent of NPK fertilizer application remained constrained, with application rates falling below the recommended levels. The reduction in application and application rates in 2020, a year characterized by relatively insufficient rainfall, implies that farmers adjusted their fertilizer usage in response to climatic conditions.

Our analysis indicates that although fertilizer application increased yields, particularly in 2019 when rainfall was adequate, these gains were insufficient to provide a substantial advantage over unfertilized production. In cowpea monocropping and mixed cropping with sorghum, the yield from fertilized plots was only marginally higher than that from unfertilized plots. Moreover, the average net income was slightly higher in unfertilized fields. This consistent lack of economic benefit from fertilizer application, observed in 2019 and 2020 despite varying rainfall conditions, likely dissuades farmers from expanding their use of fertilizers.

To address the economic shortcomings of current fertilizer use, it is essential to evaluate conditions that would render its application economically viable. Our analysis indicates that significant

improvements in net income cannot be achieved solely by reducing fertilizer costs. Substantial economic benefits would require nearly doubling the crop yields for monocropping and mixed cropping under current price structures. Even with a hypothetical reduction in fertilizer prices to half the current level, realizing a significant economic advantage would require considerable yield increases. It is essential to determine the feasibility of such yield improvements through agronomic studies that examine the potential yields of fertilized crops.

Under current practices, merely increasing the application of fertilizers may not lead to improved crop yield or profitability; therefore, it is essential to advocate for appropriate agronomic practices that include the rational use of fertilizers. Practices that fully exploit the yield potential and significantly surpass the profitability of non-fertilized crops would be effective in incentivizing farmers to invest more in fertilizers and expand their usage.

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