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Technological University Dublin, Ireland

*CORRESPONDENCE
Eugene Dela Setsoafia
✉ eugene.setsoafia@wur.nl

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Applying mulch and manure in smallholder cropping systems: challenges, realities, limitations, and opportunities

Eugene Dela Setsoafia[1,2,3]*, Harro Maat[2], Mohamed El Gharous[3], Prem Bindraban[4], Comfort Freeman[5] and Paul C. Struik[1]

[1]Centre for Crop Systems Analysis, Wageningen University and Research, Wageningen, Netherlands, [2]Knowledge, Technology and Innovation Group, Wageningen University and Research, Wageningen, Netherlands, [3]Agricultural Innovation and Technology Transfer Center, Mohammed VI Polytechnic University, Ben Guerir, Morocco, [4]Africa Rice Center (AfricaRice), Abidjan, Côte d'Ivoire, [5]Department of Agricultural Extension, University of Ghana, Accra, Ghana

Introduction: Soil fertility plays an important role in crop production. However, continuous cropping with minimal fertilizer application has resulted in declining soil fertility and correspondingly low crop yields in smallholder cropping systems. The decline in soil fertility can be partially mitigated by applying local, organic sources of nutrients.

Methods: Through focus group discussions, this paper explored soil fertility management, focusing on mulch and manure, bringing fresh attention to practical, farmer-led solutions. This study links agronomic practices with the Social Practice theory to show farming as socially embedded rather than purely technical.

Results: We found that the use of mulch was primarily limited to specific crops—pepper, tomato, garden egg, and yam, planted on less than 0.4 ha of farm field. Manure was applied preferably to maize fields due to the high nutrient requirement of maize and its important role as a staple. Farmers' understanding of mulch and manure applications reflected a blend of traditional knowledge and scientifically recognized benefits.

Discussion: These practices were valued for their role in protecting perishable crops from pests and drought-related stress and providing a sustained nutrient supply, offering a more affordable alternative to chemical fertilizers. Farmers demonstrated varying levels of competence in their assessment of the quantity of manure required for maize crop production and the timing and mode of application of mulch and manure. The emergence of weeds in fields treated with manure and the lack of competence to manage these weeds, however, require skills and competency development to enable the sustained application of manure.

KEYWORDS

mulch, manure, soil fertility, smallholder farmers, skills, Social Practice

1 Introduction

Smallholder farmers play a crucial role in global food security and agricultural sustainability and are vital for rural and national economies (Giller et al., 2021; van Ittersum et al., 2016). Enhancing productivity of smallholder agriculture can therefore greatly reduce poverty and enhance global food security in line with the Sustainable Development Goals. A major bottleneck is soil fertility. In northern Ghana, a major agricultural zone and home of thousands of smallholders, soil fertility programs have focused on the use of mineral fertilizers (Adzawla et al., 2021), cultivar or variety improvement (Adjei-Nsiah et al., 2019; Adjei-Nsiah et al., 2007), the application of organic fertilizers (Daadi and Latacz-Lohmann, 2021a), compost (Bellwood-Howard, 2012), and mulching (Erenstein, 2002).

Nonetheless, relying solely on fertilizers may not achieve the desired productivity increase in the farming systems of these areas. Quite apart from nutrient limitations, crop production is also limited by water since many farmers rely on rainfall for cultivating their crops (Asamoah et al., 2024; Kassim et al., 2025; Kouame et al., 2023). Nutrient-water interactions and their limitations therefore require urgent attention in smallholder cropping systems.

In many smallholder contexts, the effectiveness of mineral fertilizers is compromised by poor soil structure, low organic matter, and inadequate water retention. This leads to low nutrient uptake by crops and poor returns on investment (Chianu et al., 2012). Mineral fertilizers are most effective when used in combination with organic amendments such as compost or manure, water management (mulching) to ensure nutrients are available to plants, weed control to reduce competition for nutrients, and improved crop varieties that respond better to nutrient inputs. Nonetheless, many smallholder farmers face financial barriers to purchasing enough mineral fertilizers and then complementing them with organic amendments and other required agronomic practices. Without the aforementioned complementary practices, the limited amounts of fertilizers farmers can afford often yield minimal benefits (Chianu et al., 2012; Ricker-Gilbert, 2020).

In Ghana, as in much of sub-Saharan Africa, most soils are deficient in nitrogen and phosphorus, with some areas low in potassium, sulfur or micronutrients (Kouame et al., 2023; Adzawla et al., 2024). However, the relative importance of these limitations varies with soil type and past crop and soil management practices (Vanlauwe et al., 2010). Nutrient deficiencies can be tackled with a combination of mineral and organic fertilizers. Organic fertilizer options appear to have been marginalized due to poor availability of manure and mulch, and the laborious nature of applying these resources (Daadi and Latacz-Lohmann, 2021b; Daadi and Latacz-Lohmann, 2021c). Whereas these shortcomings are overall well documented, there is less attention for cross-linkages between soil fertility management and farm operations addressing other limitations to crop production. An example is water management.

In northern Ghana, particularly the Guinea Savannah agro-ecological zone of Ghana, crop yields are not only limited by nutrients but also by water availability, as crop production is rainfed (Nketia et al., 2022). The variability in rainfall during the growing season exposes crops to periods of both low and high water availability. Additionally, soils in this region are sandy, with about 80% of the area having less than 6% clay and a depth of less than 50 cm, resulting in low water holding capacity. Organic matter content is also generally low due to high mineralization under warm and humid climate and continuous cropping (Asamoah et al., 2024) and associated tillage (Buah et al., 2017). Adding organic material to the soil thus potentially improves the availability of nutrients and water.

Incorporating agronomic practices like mulching and manure application are considered to significantly enhance soil nutrient uptake and improve crop productivity (Vanlauwe et al., 2010; Vanlauwe et al., 2015). Both mulch and manure applications offer valuable opportunities to enhance the physical and chemical properties of the soil, creating a favorable environment for nutrient absorption.

Mulch and manure applications enable the addition of organic material to the soil. Mulching, the practice of providing protective soil cover during crop establishment, can be implemented using several materials, either organic or inorganic. Mulching offers soil surface protection, reducing erosion and enhancing moisture availability for the crops (Erenstein, 2002).

In a study conducted to assess agricultural practices for generating maximum maize productivity in drought prone agro-ecological zones, mulching ranked second to supplementary irrigation in boosting grain yield and yield components, likely due to improved soil nutrition from organic matter added through mulch decomposition (Uwizeyimana et al., 2018).

In another study, mulching did not directly increase maize yields, likely due to phosphorus (P) immobilization. However, it improved internal P use efficiency, partially offsetting yield limitations. While experiments in the study could not confirm that combining NPK with mulch was the best strategy for sustainable farming, it suggested that applying lower rates of NPK—less than 60 kg N, 43 kg P, and 50 kg K per hectare—might be more economical for local maize varieties (Saïdou et al., 2003).

Elsewhere, however, the positive effect of mulch was greater when combined with mineral fertilizer, implying a synergistic rather than a substitutional effect and demonstrating its applicability, even for farmers able to afford inputs. Mulch had a greater effect on lower fertility soils than on higher fertility soils, ceteris paribus. This highlights its potential usefulness for smallholder farmers who are often marginalized to low fertility land (Kuonen and Norgrove, 2022).

Manure, which is commonly animal dung and urine, is derived mainly from cattle and small ruminants such as goat, sheep, and poultry birds, and is applied mainly for nutrient and organic matter augmentation to crops (Daadi and Latacz-Lohmann, 2021a).

In many areas of semi-arid West Africa, manure demand outstrips supply due to feed limitations which effectively sets a limit on livestock population growth (Williams, 1999). Nonetheless, within the constraints in which smallholder farmers operate in this region, manure will remain an important component of soil fertility management strategies for the foreseeable future (Harris, 2002).

In sub-Saharan Africa, solid manure is typically applied in planting holes, furrows, or broadcast and incorporated into the soil. Immediate incorporation after application is recommended to retain nutrients—especially nitrogen—for improved crop uptake. The use of manure as a fertilizer is generally beneficial to the soil and can improve crop yield (Ndambi et al., 2019).

Despite the development and dissemination of these productivity-enhancing technologies and innovations, increased crop productivity in smallholder agricultural systems remains elusive and daunting. What is not yet understood is the knowledge and practices of farmers regarding mulch and manure applications. Very little is currently known about the mulching practices of smallholder farmers, the materials for mulching, and crop choices for which mulch is applied and the purposes that shape mulching practices. The same applies to manure.

The objective of this paper is to provide a better understanding of the connections between soil fertility management practices and the wider crop production system of smallholder farmers. We explore these connections by focusing on the use of mulch and manure.

We address two questions; firstly, what drives mulch and manure application in smallholder farming systems and what adaptations are needed for implementing mulching and manure fertilization? Secondly, how do the realities of smallholder farming systems influence the effectiveness of mulch and manure practices?

1.1 An integrated social and agronomic approach to soil fertility management

Studies which investigated soil fertility management from the perspectives of farmers in Ghana and elsewhere mostly relied on surveys and interviews (Ansong Omari et al., 2018; Adjebeng-Danquah et al., 2020; Kenfack Essougong et al., 2020; Malongza Bukari, 2013; Quansah et al., 2001; Sungbaahee and Kpieta, 2021; Spurk et al., 2020; Tesfahunegn et al., 2021; Boateng et al., 2016; Dalton et al., 2014). Whereas these studies provide relevant information about factors, including farmers' knowledge, affecting soil fertility management, there is less clarity about how much control farmers have over these factors when dealing with the many challenges of running a farm.

An integrated perspective on practice requires the theorized integration of different aspects. In this paper, we apply the Social Practice theory to understand the skills and knowledge of smallholder farmers in the process of creating conducive or optimal conditions in their fields to meet their crop production goals. Social Practice theory offers a useful and innovative lens to interpret how farmers' practices are reproduced and transformed.

At the heart of this theory is the recognition that these practices exist as performances and it is through their performance, through the immediacy of doing, that the 'pattern' provided by the practice-as-an-entity is filled out and reproduced. An understanding of the meanings and objectives smallholder farmers ascribe to their practices is necessary to establish how scientific research, development and policy initiatives can enhance the capacity of farmers to perform under difficult circumstances, for example the capacity to manage soil fertility, which is the focus of our study.

Social practice theory (Shove et al., 2012) addresses interactions between (a) materials, encompassing technologies, the body, objects, and other tangible physical entities, (b) competences, including skill, practical know-how, and techniques and (c) meanings, consisting of symbolic meanings, emotions, ideas, and the embodied understanding of the social significance of practices (Bassi et al., 2019; Abdulai, 2022).

Interactions between these elements are overall unpredictable for farmers. For that reason, Richards (1993) proposed to view farming as a dynamic and adaptive performance rather than a step-by-step application of available resources based on existing knowledge. He noted that members of the farm household judged the success of their on-farm actions by whether they furthered their social projects more generally. This suggests that farmers, although having specific knowledge about soil fertility, act from a wider perspective on farming, resulting in a more improvised soil fertility management practice.

This improvisation in soil fertility management underscores the social embeddedness of farming practices. The challenge according to Richards (1993) is how researchers, aiming for specific, measured interactions, and farmers' improvisational skills can be matched, likely resulting in more modest targets for assistance to agricultural activities inextricably bound up in larger social processes.

Based on an improvisational understanding of practice, this paper presents mulch and manure application practices of farmers in the Savannah, Northern and North East Regions of Ghana. We seek to uncover how farmers appreciate the state of their soils and assemble knowledge and competences around mulch and manure applications to keep farming, and how this connects to other farm activities.

2 Methodology

Focus group discussions and in-depth interviews were conducted in this study. The participants for the interviews and focus group discussions were selected originally to participate in soil fertility management trials under the Fertilizer Research and Responsible Implementation (FERARI) program. These farmers were smallholders cultivating a variety of crops. FERARI was a public-private program in Ghana that integrated an on-the-ground implementation program to develop the fertilizer value chain with transdisciplinary research.[1] The overall objective of the program was to develop the evidence base for the need of a systematic approach to support widespread adoption of balanced fertilizers by farmers in the less developed markets of sub-Saharan African countries, specifically Ghana, to improve their food and nutrition security.

Over two growing seasons, 2022 and 2023, eight lead farmers and 63 farmers were interviewed from eight communities across the Savannah Region, Northern Region and North East Region of Ghana. These farmers were selected following an exploratory study in their communities in 2021. The farmers and their respective communities were selected based on their participation in baseline studies that formed part of a research program to characterize smallholder farmers in terms of fertilizer use and food and nutrition security (Adzawla et al., 2021; Adzawla et al., 2021). The interviewed farmers implemented soil fertility management practices ranging from the sole or combined application of mineral fertilizers, mulch, and manure.

Data were collected during field visits in 2022 and 2023. In all, there were 27 field visits in 2022 and 14 field visits in 2023. During these field visits, the applications of mulch and manure were observed, and data was captured through field notes. Eight key informant interviews were conducted with the lead farmers while 63 farmers participated in focus group discussions (Figure 1). The lead farmers were selected purposively to provide in-depth information on soil fertility management practices in their respective communities. By virtue of their social capital, leadership and farming experience, these lead farmers were considered custodians of knowledge within their communities.

The interviews lasted between 30 and 45 min and were conducted in the local languages spoken by the farmers. An interview guideline with a list of questions covering themes such as the history of mulching and manure practices, the resources required, the purpose, application methods and decisions regarding crop or land choice was used to moderate the interviews (See Supplementary material for details).

1 www.ferari.com

FIGURE 1
Focus group discussion conducted in Nlaalaayili, a community in the Northern Region of Ghana. Farmers discussed mulching and manuring practices.

Focus group discussions were conducted in each community using the same interview guidelines used for the lead farmer interviews. A total of 9 focus group discussions were conducted. In each community, between 6 and 9 farmers participated in one focus group discussion. The discussions were moderated by the lead researcher with support from a field assistant. The agricultural extension officers of the respective communities provided language translation. The discussions lasted an hour on average across the communities and were conducted in the local languages of the communities.

Field visits from May to October in 2022 and 2023 enabled the observation of farmers' practices. Mulch applications were observed, with a focus on the type of mulching materials, the area of field covered with mulch, and the crop choice for which mulch was applied. Farmers were observed for the transportation of manure to the field and for manure applications. Through these methods, we were able to learn about mulch and manure application by observing how farmers performed these practices, and their narratives on the purpose of implementing these practices.

Before the study commenced, ethical clearance was secured through a formal review and approval of the research proposal and protocols. The lead author also completed relevant training in research ethics, including courses on *Ethics for Social Science Research*, *Ethics in Plant and Environmental Sciences*, and *Scientific Integrity*, all offered by the Wageningen Graduate School at Wageningen University and Research. Participation in the study was entirely voluntary, and written informed consent was obtained from all participating farmers. Importantly, no minors participated in the research.

The interviews were transcribed and analyzed thematically. The transcripts were analyzed manually using a coding approach that allowed the organization of farmers' responses into themes. By applying sequential and descriptive coding, guided by the interview and discussion guidelines and questions, we identified passages in the transcript that illustrated descriptions or explanations of the implementation of mulching and manure application. We also coded for connections between mulching, manure application and materials involved in their application, as well as the competences and purposes that determined how and when mulch and manure were applied.

The coding of the data was inductive and performed independently by the lead researcher. To ensure the consistency and credibility of the coding process and to ensure that the coding was not overly subjective, all co-authors validated the themes and the interpretations of the results. The interpretation of the results and emerging discrepancies were discussed to reach consensus and improve clarity of the themes. This process helped ensure that the themes identified were not solely dependent on individual interpretation, thereby enhancing the trustworthiness of the findings.

In this study, we paid attention to ensuring diversity across participants—such as differences in region, gender, and farm size—to confirm that saturation reflected the full range of perspectives relevant to soil fertility management. This approach ensured that the data collected was sufficiently rich and comprehensive to address the research questions. Focus group discussions were held in eight communities across three regions with between 6 and 9 farmers participating in the discussions in each community. Interviews were transcribed and coded concurrently, allowing for the continuous identification of emerging themes.

No further interviews or discussions were conducted once all eight lead farmers and communities participated in the focus group discussions. Data saturation was therefore achieved through an iterative process of data analysis and saturation was considered reached when subsequent analysis no longer yielded new insights, and responses began to consistently reinforce previously identified themes. Themes presented in the results and discussion were derived directly from the data, rather than being imposed beforehand.

In uncovering the materials associated with mulch and manure application, we identified sources of mulching materials and manure. We also paid attention to the farm fields that were treated with mulch or manure and the crops that mulch and manure were applied to. The skills and techniques of mulch and manure collection, transportation and ultimately spreading on farm fields highlighted the competences associated with mulch and manure application. We assessed the timing of mulch and manure applications and decisions regarding which field and what crop was suitable for both practices. Finally, we interrogated the goals and purposes that drove the application of mulch and manure in farmers' fields. We highlighted expected outcomes and uncovered the extent to which the application of these practices contributed to achieving the goals for which they were applied in crop production.

3 Results

In this section, we provide a narrative covering the history of mulch and manure application, the sources of mulch and manure, how they are prepared, collected, stored, and transported to the fields for application. We also present the purposes and meanings farmers attach to their application and how they determine the crop or field to be treated with mulch and manure. The timing of application of mulch and manure and the challenges associated with the practices are also presented. We then discuss these narratives within the framework of Social Practice Theory presented earlier.

3.1 Mulch

Traditionally, mulching was implemented for highly perishable crops such as pepper, garden egg, and yam (Table 1). These crops are sensitive to temperature, moisture, and physical damage. They are usually high-value crops but with short life and require careful handling to maintain quality during cultivation, harvesting and storage.

According to a farmer in the Northern Region, "*about 90% of farmers in this community (Nlaalaayili) perform nursery mulching for pepper, tomato, garden egg.*" In another community in the same region, a farmer noted that "*mulching was done only on yam in this community and the field was 100% mulched. But farmers do not cultivate more than one acre of yam. It is either one acre or less.*"

Farmers reported mulching pepper to prevent destruction by poultry. In the production of pepper, mulch was applied after the transplanting of seedlings. Farmers explained that the absence of rain after transplanting seedlings necessitated the application of mulch. Seed beds were mulched to conserve moisture and avoid direct heating of the seedbeds by sunlight. The farmers explained that "*during mulching, the entire beds are covered, and the mulching materials are removed after crop establishment.*" The residue is then spread over the field. Farmers, however, noted that mulching could be practiced in other cropping systems but not on a large scale (See Table 2 for competences on mulching).

Whilst some farmers explained that they may not have known that mulching could be extended to other crops such as cereals, they pointed out that mulching was implemented mostly for raised beds that were transplanted with pepper and tomatoes. The purpose was "*to prevent damage by fowls and to keep moisture for the germination of seeds.*" Mulching was thus applied by farmers who cultivated perishable crops and crops with a vulnerable transplanting phase.

In the case of yam, a farmer offered the following reasons for mulching; "*those cultivating yam usually apply mulch. Yam fields are usually mulched; the time of planting yam is when rainfall is not enough and that is when the ground is hot. We mulch to reduce this heat.*" Farmers observed that mulched areas and crops appeared moist and fresh (unwilted) compared with areas and crops that were not mulched, recognizing that mulching was beneficial to the crops (See Table 2 for competences on mulching).

TABLE 1 Crop choice, area and rate of mulch and manure applications in the study communities.

Region/ community	Mulch			Manure		
	Yes	Hardly	Crops and area mulched	Yes	Hardly	Crops and rate
Northern Region						
Woribogu	✓		Pepper, tomato (<0.4 ha)	✓		Maize, pepper (6–12 t/ha)
Dimabi	✓		Yam (<0.4 ha)	✓		Maize, soybean (10 t/ha)
Nlaalaayili	✓		Pepper, tomato, garden egg (0.4 ha)	✓		Maize, sorghum, millet, soybean, yam (10 t/ha)
North East Region						
Loagri		✓		✓		Maize, soybean (10 t/ha)
Bugyapala		✓		✓		Maize (4 t/ha)
Zangum		✓		✓		Maize (30 t/ha)
Savannah Region						
Abukarikura		✓			✓	Maize (0.4 t/ha)
Sumpini		✓			✓	Maize (0.5 t/ha)

TABLE 2 Materials, competences and meanings associated with mulch and manure application.

Materials	Competences	Meanings
Land	Fertility status	Fertility management
Cultivated crop	Nutrient requirements	Yield improvement
Mulch material	Suitability, timing of application	Moisture conservation, nutrient augmentation, protection from crop damage
Manure sources	Quantity (application rate) and timing of application	Nutrient augmentation, long-term soil fertility management, household food security
Labor	Manure handling and application rate	Labor productivity during critical crop management stages
Transport mechanism (tricycles, donkey-drawn carts, motorbikes, bicycles, head pans)		Timely application

FIGURE 2
Mulch (false yam leaves) applied in a maize field 3 weeks after crop emergence in Nlaalaaayili, a community in the Northern Region of Ghana.

In the Savannah Region where groundnut, rice, and maize constituted the major crops, a farmer mentioned that for future mulching, "*maize was considered the preferred crop to be mulched.*" Groundnut is cultivated early in the season and is believed to require minimal moisture and considered moderately sensitive to heat and so mulching for groundnut was considered unnecessary. Rice is, however, cultivated in waterlogged areas and so the need to conserve soil moisture was not expected.

Across the three regions of our study, Savannah, Northern and North East Regions, the application of mulch, especially in cereal production systems was new to the farmers. According to the farmers, mulching as implemented in maize cropping (referencing trials under the FERARI program) was quite a new practice for them (Figure 2).

According to majority of the farmers, the materials used for mulching included grass, thatch, crop residues (groundnut husks, vines and maize stover), false yam leaves and neem tree leaves. Other farmers did not use crop residues for mulching. According to those farmers, "*we cut or harvest fresh leaves or grasses to be used for mulching.*" (See Table 2 for details on materials for mulching).

However, having participated in field trials where mulching was applied in maize production, a farmer hinted that they will "*do it because they have seen that mulching maintains soil moisture, supplies nutrients, and prevents direct effect of the sun reaching and heating up the soil.*" Providing reasons why they would continue to apply mulch, a farmer pointed out that "*many farmers applied mulch to moisten the base of the maize plant for it to survive drought conditions and to increase the activities of beneficial organisms at the plant base.*" For this farmer, when drought becomes an issue, they may consider mulching (See Table 2 for details on meanings attached to mulch application).

A farmer noted that "*mulched areas looked good during drought periods.*" Some farmers also noted that "*the decaying of mulch* *materials helped the crops by supplying some nutrients.*" They also observed that the stalks of mulched crops looked bigger and stronger.

Farmers identified challenges such as the availability of mulching material and the labor-intensiveness of mulching as reasons for their inability to apply mulch to large farm fields. Apart from the availability of mulching material, the means to convey the material to the field was another challenge highlighted by the farmers. In the North East Region, a farmer echoed some challenges associated with mulching, noting that "*access to mulching material was a challenge and unless groundnut is harvested, it is extremely difficult to gather materials for mulching.*"

3.2 Manure

Data on manure applications are exclusively sourced from the Northern and North East regions, as manure was not applied in the Savannah Region, except for a recent experimental intervention (See Table 1 for details). In contrast to the Northern and North East regions, manure application was introduced for the first time as part of crop and soil fertility management practices by farmers in the communities of Sumpini, and Abukarikura, located in the Savannah Region. According to participating farmers, their involvement in the Fertilizer Research and Responsible Implementation (FERARI) program marked their initial engagement with manure application as a component of their agricultural practices. Manure application gained prominence through the introduction of the program. Farmers reported limited prior knowledge of the agronomic benefits associated with manure application, indicating that its perceived value was minimal before their participation in the program.

During their participation in field trials under the FERARI program, farmers began to observe tangible effects of manure application on their fields. They reported improvements in crop yields and noted that maize crops appeared healthier compared to those cultivated with chemical fertilizers. Additionally, the presence of larger millipedes was frequently observed, which farmers associated with enhanced manure decomposition and fertile soil. Despite these positive outcomes, the high cost and logistical challenges of transporting manure remained a significant barrier to its widespread adoption. Nevertheless, farmers indicated that, following their initial experience, efforts have been initiated to collect and store manure in dug-out pits on their fields in preparation for the subsequent planting season.

According to a lead farmer in the region, "*due to the lack of training, farmers are not sure of the quantity of manure to apply and the timing of application.*" According to this farmer, on average, 1 hectare of farm field was treated with 1,250 kg of manure. He added that for some other farmers, they could apply about 1,000 kg of manure per ha of farmland. According to the farmers, manure was either broadcasted or heaped and ploughed into the soil. They believed that manure ploughed into the soil performed better than side-placed manure (See Table 2 for competences on manure application).

In the Northern and North East Regions, manure application has been an established component of farmers' crop management practices (Figure 3). In the North East Region, particularly in the communities of Loagri, Zangum, and Bugyapala, farmers reported using manure for over two decades, with adoption beginning in the early 2000s. In contrast, farmers in the Northern Region indicated that manure use began more recently, around 2015, coinciding with a significant rise in the cost of mineral fertilizers. According to a lead farmer, this shift was largely driven by economic necessity (i.e., when fertilizer prices are high and therefore

FIGURE 3
The spreading and drying of manure, prior to transportation and application in maize fields.

unaffordable, farmers look for other crop nutrition options such as manure and compost). The adoption of manure application practices in both regions was facilitated through the efforts of non-governmental organizations, the Department of Agriculture, Agricultural Extension Officers, and various research institutions.

Despite the presence of manure application in the Northern and North East Regions, its use was not universal among farmers. According to two lead farmers in the Northern Region, manure was predominantly used by those who owned livestock, as they had direct access to the resource. Farmers without livestock often rely on soliciting manure from others, although the quantities received are typically insufficient to meet their needs. Additionally, farmers whose fields were located near their homesteads were more likely to apply manure due to ease of transport.

A lead farmer from Woribogu, a community in the Northern Region, noted that those who sought manure were typically unable to afford mineral fertilizers, whereas farmers with the financial means to purchase fertilizers rarely considered using manure. He further explained that men generally applied manure to maize and pepper fields, while women primarily used it on pepper crops.

A lead farmer in the North East Region noted that manure use predated the widespread adoption of chemical fertilizers, which gained popularity following the introduction of government subsidy programs. He explained that the availability of subsidized fertilizers led to a decline in manure use. However, the recent escalation in fertilizer prices has prompted a renewed interest in organic alternatives. Similarly, a lead farmer in Zangum, also in the North East Region, traced the adoption of manure to farmers' early observations that manure and compost application significantly enhanced crop yields. This realization encouraged broader attention to organic resources as viable inputs for soil fertility management.

Farmers in the study areas rear various types of livestock—including cattle, sheep, goats, and poultry—which serve as primary sources of manure. Among these, cattle were identified as the most significant contributors due to the volume of manure they produce. Farmers typically confine cattle in kraals prior to the onset of the growing season to facilitate manure collection. While poultry manure was regarded as more nutrient-rich, its collection posed challenges. Farmers noted that housing poultry could enable the accumulation of substantial quantities of manure; however, birds are generally kept under free-range systems, making systematic collection difficult. According to a lead farmer in Loagri, North East Region, large animals such as cattle are usually confined to designated areas, and the manure is subsequently transported to fields using tricycles.

Farmers employ a range of strategies to manage and apply manure effectively. In some cases, livestock owners rotate their cattle across different plots, allowing manure to be deposited directly onto the soil until the entire field is covered. This practice is more common for fields located near homesteads or within the community. Alternatively, livestock are confined in kraals, where manure is collected and stored in heaps until the onset of field preparation.

Manure is transported to the fields using various means, including tricycles, donkey-drawn carts, motorbikes, bicycles, or manually in head pans. As one farmer explained, "*Manure is gathered in one place and transported to the field when the rains begin, as spreading it too early could result in it being washed away.*"

According to one farmer, manure is commonly transported using donkey-drawn carts, and it is estimated that nearly 50% of farmers in the Northern Region apply manure regularly, even on fields located at considerable distances from their homesteads. In both the Northern and North East regions, farmers consistently cited soil fertility improvement as the primary motivation for using manure (Table 2). A lead farmer from Loagri, North East Region, noted that "*those who apply manure are typically farmers who recognize the declining fertility of their soils and lack the financial means to purchase chemical fertilizers*."

Several farmers expressed a preference for manure due to its perceived long-term benefits. Unlike mineral fertilizers, manure was valued for its sustained nutrient release, which contributed to improved soil fertility over time. For many farmers, it also represented the most affordable nutrient source available. As one farmer succinctly stated, "*farmers use manure because it is the cheapest source of nutrients.*" (See Table 2 for meanings for manure application).

Importantly, manure use was not confined to livestock owners or those managing nutrient-depleted soils. As one farmer explained, "*all farmers strive to use manure because of the high cost of fertilizer*." Manure was widely regarded as a valuable source of crop nutrition, contributing both to yield improvement and soil enrichment. Consequently, fields perceived to have declining fertility were often prioritized for manure application.

Crop selection played a significant role in determining which fields received manure application. Maize was often prioritized, particularly by men, as it is the primary staple for household consumption and men are traditionally responsible for ensuring household food security. As one farmer explained, "*manure was also applied to maize because it is the most consumed crop, and for men, it is their responsibility to supply household nutrition.*" However, a lead farmer from Woribogu in the Northern Region noted that fewer than 40% of households had access to manure, highlighting a key limitation in its widespread use.

The primary factor influencing manure application was the perceived fertility status of the soil. Fields with declining productivity were typically targeted for manure treatment. One farmer described the practice as a rotational strategy, stating that "*manure is rotated amongst fields, and we apply it mostly on maize fields and soybean fields, although more is applied on maize fields.*"

Farmers who applied manure provided insights into their crop-specific practices. Maize and soybean were identified as the primary crops receiving manure, while groundnut and cassava fields were typically excluded. One farmer explained, "*maize and soybean are the crops treated most with manure, but we do not apply it on groundnut or cassava; manure is usually applied to soils that have lost their fertility.*" Another farmer emphasized that "*maize and soybean are treated with manure—maize mainly—and fields with low soil fertility are also usually treated with manure.*" Further elaborating on this preference, a farmer noted that "*maize is the dominant crop treated with manure because it is a heavy feeder and requires a high level of nutrients.*"

Manure was primarily applied through broadcasting and subsequently incorporated into the soil by ploughing, typically at the onset of the rainy season. In some cases, farmers applied manure after crop emergence using side placement techniques. The method of application often depended on the quantity of manure available: farmers with larger volumes favored broadcasting and ploughing, while those with limited amounts opted for side placement to target specific crops. A lead farmer in the Northern Region explained that "*broadcasting and ploughing are preferred because the nutrients remain in the soil and are less likely to be washed away, unlike side-placed manure.*" He further noted that "*cattle manure is usually ploughed into the soil, whereas sheep and goat manure are more commonly applied through side placement, although this is not always the case.*"

The quantity of manure applied to farm fields was largely determined by its availability. One farmer noted that, on average, 10 tricycle loads of manure were considered sufficient to supply adequate nutrients for one acre of farmland, regardless of the crop type—equivalent to approximately 10 tons per hectare for maize. A lead farmer in the Northern Region further explained that application rates varied based on the amount of manure collected, the fertility status of the field, and the crop to be cultivated. While six or more tricycle loads per acre were generally deemed adequate for maize production, 12 loads per acre were considered optimal to meet the crop's nutrient requirements.

Farmers identified two primary challenges associated with manure application: limited availability in sufficient quantities and the difficulty of transporting it to farm fields. Another concern frequently mentioned was the increased incidence of weed infestation following manure use. According to one farmer, "*some animals graze on grass seeds that are not digested and later germinate in the field.*" This observation underscores the importance of early weed control when manure is applied. Farmers noted that both chemical and non-chemical weed management strategies could be employed; while chemical methods were considered more time-efficient, non-chemical approaches were perceived as more effective in controlling weed growth.

A farmer from Nlaalaayili in the Northern Region however identified the suppression of *Striga hermonthica*—a parasitic weed affecting maize—as a key motivation for manure application. Farmers observed that manure enhanced crop vigor, enabling maize plants to survive the infestation of *Striga* and mitigate its negative impact on yields.

4 Discussion

This study addressed two key questions: (i) What motivates smallholder farmers to apply mulch and manure, and what adaptations are necessary for their effective implementation? (ii) How do the practical realities of smallholder farming systems influence the success of mulching and manure practices?

Our findings show that in the Northern and North East Regions of Ghana, manure application is widely practiced. It originated from farmers' own experimentation and has been reinforced by support from the Department of Agriculture, extension services, and research institutions. Manure is sourced from cattle, small ruminants, and poultry, typically collected in kraals or pits, and applied at the beginning of the rainy season.

A recent review highlighted manure's potential to improve crop yields and support sustainable agriculture in sub-Saharan Africa. However, policy frameworks remain fragmented, with unclear mandates and limited coordination among responsible ministries, hindering effective promotion and regulation of manure management practices (Ndambi et al., 2019).

In our study, we found that manure application methods vary depending on the quantity available; broadcasting and ploughing for larger volumes, and side placement for smaller amounts. Maize is the primary crop receiving manure, due to its significance in household food security. Similar methods of manure application were reported in smallholder systems. According to Ndambi et al. (2019), solid manure is commonly applied to agricultural fields in holes, in furrows or spread/broadcasted and incorporated. Paul et al. (2013) also recommended that manure be incorporated into the soil immediately after application, as it will retain more nutrients (nitrogen) that will later be available to crops.

In contrast, manure use in the Savannah Region remains limited, largely due to a lack of awareness of the benefits associated with the use of manure and the itinerant nature of farming systems. The itinerant nature of farming in the Savannah Region involves farmers traveling, settling and cultivating new parcels of land every now and then. As a result, keeping livestock tends to inhibit easy movement and settlement for farmers who practice this kind of farming.

While farmers in the Savannah Region are open to using manure, they require new arrangements with herders to facilitate collection. In the Northern and North East Regions, farmers typically apply between 6 and 16 tricycle loads of manure per acre of farm field, with each load carrying approximately 0.4 tons—resulting in application rates of 6–15 tons per hectare. Notably, 15 tons per hectare is double the recommended rate for maize production in northern Ghana (Adu et al., 2014).

Despite its benefits, manure applications present several challenges. These include limited availability, transportation difficulties, and the introduction of weed seeds, which raise concerns about manure storage and treatment. Manure management practices are rarely followed in sub-Saharan Africa due to limited labor, financial constraints, and insufficient farmer knowledge at the farm level (Ndambi et al., 2019).

Farmers in our study currently rely on chemical and manual weeding to manage weeds that emerge because of manure applications. However, manure use has also been linked to the suppression of *Striga hermonthica*, a parasitic weed affecting maize. This study, however, did not quantify the population of *Striga* in the fields of farmers who applied manure to verify the claims of suppression of the weed.

Our findings highlight a critical tension in the use of manure in smallholder farming systems: while it offers significant agronomic benefits, particularly in improving soil fertility and potentially suppressing *Striga hermonthica*, it also introduces weed management challenges that can undermine its effectiveness.

The introduction of weeds occurs when livestock consumes weed-infested fodder or graze on weedy pastures. Manure is applied without adequate composting or treatment, allowing viable seeds to persist. This leads to increased weed pressure, which competes with crops for nutrients, water, and light, and higher labor demands for manual weeding or increased reliance on herbicides—both of which raise production costs. This results in a potential disincentive for farmers to adopt manure use, especially if weed infestation offsets the benefits of improved soil fertility. Little wonder crop farmers in the eastern highlands of Ethiopia who could afford synthetic fertilizers had lower rates of manure use because they found manure application to be more laborious in comparison to synthetic fertilizers (Ketema and Bauer, 2011).

Interestingly, in our study, manure application has been linked to the suppression of *Striga hermonthica*, a parasitic weed that significantly reduces maize yields in sub-Saharan Africa. A similar observation was reported for rice cultivation by farmers in Tanzania. Ultimately, different types of fertilizers (both mineral and organic) were found to have variable and differential effects on parasitic weeds. Nonetheless, it was recommended that these fertilizers should be combined with additional parasitic weed control measures (Tippe et al., 2020). Striga is known to thrive in low-nitrogen, degraded soils (Tippe et al., 2017).

Manure application will therefore improve soil fertility and microbial activity, potentially creating conditions that are less favorable for Striga germination and attachment. This could position manure as a biological tool in integrated Striga management, offering a sustainable alternative to chemical control methods. However, further studies are needed to enhance the benefits of manure while mitigating weed-related risks.

Other strategies for managing weed in small holder farming systems have been reported. Early sowing was reported as the most promising approach for enhancing wheat yields in South East Asia (Jain et al., 2023). The effectiveness of sowing time and its outcomes were, however, found to vary depending on the crop species and the specific ecosystem (Tippe et al., 2017).

Mulching, on the other hand, is not widely practiced across the three regions in our study and is primarily used for moisture conservation in perishable crops such as pepper, garden eggs, tomatoes and yam. In other smallholder systems, mulching has been shown to improve soil physical structure, reduce peak soil temperatures (Kaur and Arora, 2019), enhance crop yields (Gill, 1996), and support runoff control and water retention (Okeyo et al., 2014).

Whereas limited access to mulching materials restricts its application to small plots, groundnut residues present a promising alternative, particularly in the Savannah Region. Farmers recognize the benefits of mulching and often prioritize its use for high-value and perishable crops over staple cereal crops like maize. This preference is largely due to the greater economic returns and sensitivity of these crops to moisture stress and temperature fluctuations.

Among the practices of mulching, reduced tillage, and crop rotation, mulching was identified as the most effective for enhancing crop yields under sub-humid tropical conditions (Kodzwa et al., 2020). However, while mulching also offers benefits such as weed suppression, this advantage is often limited for smallholder farmers due to the minimal crop residues typically retained on their fields (Ranaivoson et al., 2018). Overall, mulching contributes to improved soil moisture retention, temperature regulation, and nutrient availability—factors that are essential for optimal crop growth and yield (Ahmad et al., 2022).

While farmers in our study generally performed mulching, the decision to mulch appeared to involve several trade-offs that required a balance of convenience. For instance, fields located far from homesteads were less likely to be mulched due to the difficulty of transporting materials. Mulching was also labor-intensive, which was usually a constraint during peak agricultural periods when labor was needed for planting or weeding. These dynamics are very important when considered within the limits of available time from land preparation (i.e., ploughing) to planting, and especially if mulch must be applied before planting (the recommended approach). Additionally, the availability of suitable mulching materials—such as crop residues or grasses—may be limited, especially in areas where livestock compete for the same resources. This is the situation in our study area. Finally, farmers must weigh the potential yield benefits of mulching against the opportunity cost of using labor and materials elsewhere on the farm.

Overall, mulch and manure application formed part of measures applied by farmers to create optimal conditions for the growth and development of their crops. These crop management practices have been studied extensively, but largely through researcher-managed trials, with recommendations for farmers to include these practices in their production systems. We delve deeper into the materials and competence required for mulching and manure application and the purposes they serve for smallholder farmers.

Building on our findings, we apply Social Practice Theory (Shove et al., 2012; Abdulai, 2022) to explore how smallholder farmers' experiences and narratives deepen our understanding of mulch and manure application. Specifically, we examine the factors that influence farmers' decisions to use these practices, the purposes they serve, and the social, cultural, and institutional frameworks that either support or constrain their implementation. We also analyze the dynamics of inclusion and exclusion, identifying which practices farmers can engage in and which are left out. Finally, we reflect on the informal rules, norms, and protocols that have emerged around mulch and manure use within the study communities.

At the heart of Social Practice Theory is the recognition that practices are shaped by the purposes they serve. Understanding these purposes is essential not only for evaluating the outcomes of a given activity but also for assessing whether the activity is appropriate and effective in achieving its intended goals. Beyond purpose, the theory emphasizes the importance of competence—the skills and knowledge required to conduct the activity. In the context of mulch and manure application, this includes how such competence is developed, shared, and applied by farmers. The third core element of the theory is materials—the physical resources and tools necessary to perform the activity. These materials must be accessible and suitable to support the practice. In examining these elements (Table 2), we highlight how each contributes to achieving the broader objectives of soil fertility management and sustainable crop production.

The need to ensure household nutrition through crop production was a key factor motivating farmers to invest in soil fertility management. By applying mulch and manure, farmers aimed to enhance the nutrient content of their soils, conserve moisture, and protect crops from drought and pests—thereby securing food for their families. For smallholder farmers, whose livelihoods are closely tied to agricultural productivity, maintaining fertile and productive soils is not just a technical task but a fundamental goal. This need strongly influences their commitment to adopting and sustaining essential agronomic practices.

According to Daadi and Latacz-Lohmann (2021a), farmers are aware of a wide range of agronomic strategies available to help them achieve their production goals. These include the application of mineral fertilizers, crop rotation, land fallowing, and the use of organic nutrient sources. However, due to increasing pressure on arable land and the need to intensify cultivation, traditional practices such as fallowing have become less feasible in contemporary farming systems.

Moreover, the cost of mineral fertilizers remains relatively high for many smallholder farmers (Adzawla et al., 2021), including those in our study areas, despite the presence of government subsidies. Access is further constrained by logistical challenges, particularly in remote farming communities located far from urban centers where agricultural input suppliers are typically based. As a result, while most farmers rely on mineral fertilizers as their primary external nutrient source, a considerable number also supplement them with organic soil amendments to enhance soil fertility and reduce dependency on costly inputs (Daadi and Latacz-Lohmann, 2021b).

In maize production, to supply 90 kg N/ha from organic sources, farmers in Ghana are advised to apply either 7 t/ha of cow dung or 4 t/ha of chicken manure or 5 t/ha of good quality compost to the crop (Adu et al., 2014). Recommendations following soil tests from farms in some parts of northern Ghana suggest that farmers may require about 10 t/ha of manure or compost while complementing it with 170 kg NPK and 80 kg Urea per ha, underscoring the need for these farmers to build organic matter and improve residue management.

Our study revealed that farmers place high value on the long-term nutrient benefits of manure and actively seek to incorporate it into their crop production systems. As Bationo and Mokwunye (1991) noted, organic amendments such as manure remain in the soil for more than one cropping cycle, releasing nutrients more gradually than inorganic fertilizers. This slow-release characteristic highlights the interconnectedness of biophysical and socioeconomic factors in agricultural systems. By extending the nutrient supply over multiple seasons, manure has the potential to reduce input costs for farmers, making it a more economically sustainable option.

According to Daadi and Latacz-Lohmann (2021c), farmers' decisions regarding organic fertilizer use are shaped by a range of background factors, including their human capital (such as education and experience), physical resource endowments, the farming environment (soil quality and biodiversity), and the external environment, which encompasses institutional support, social networks, political conditions, technological access, and economic context.

Our findings align with this perspective. While some farmers were able to obtain manure from livestock owners, success in doing so often depended on whether the livestock owners had sufficient land of their own to apply the manure. Even when manure was shared freely, the quantities were typically insufficient to meet the full nutrient requirements of recipient farmers. This highlights the role of social, cultural, and community norms in shaping access to manure and influencing its use.

Moreover, manure solicitation and application were found to be gendered practices. Men were more likely to seek out manure and apply it to maize fields whilst women preferred manure for pepper, garden eggs, and legumes cultivated on fields close to the homestead, reflecting gendered preferences in crop management. Conversely, farmers who owned livestock had a clear advantage of accessing manure, while those who could afford adequate quantities of mineral fertilizers often chose not to use manure at all.

These observations support the findings of Daadi and Latacz-Lohmann (2021a) and Daadi and Latacz-Lohmann (2021b), who reported that farmers capable of applying substantial amounts of mineral fertilizer to their cereal crops are generally less inclined to adopt either integrated livestock-manure systems or organic approaches driven by fertilizer cost constraints. Labor constraints may be responsible for this substitution. Similar observations were made by Ketema and Bauer (2011).

While we observed that in the Northern and North East Regions, farmers had established systems for managing livestock—particularly cattle—to collect and store manure at the onset of the growing season, such arrangements were largely absent in the Savannah Region. Although some farmers in the Savannah Region owned livestock, they lacked organized practices for gathering manure for use in crop production.

Farmers' understanding of mulching reflected a blend of traditional knowledge and scientifically recognized benefits. Their motivations for mulching aligned with findings by Bationo and Mokwunye (1991), who noted that mulching with crop residues can reduce wind and water erosion by minimizing surface runoff and the impact of raindrops on the soil. Additionally, mulching helps regulate soil temperature. In our study area, this temperature regulation was especially important for perishable crops such as pepper, garden egg, and yam—making it the primary reason farmers applied mulch to these crops.

These crops were typically grown on small plots, often less than one acre, which made mulching more manageable and practical for farmers. However, scaling up mulch application to cereal crops or larger fields presents a significant challenge due to limited access to suitable mulching materials. Despite this, the increasing threat of droughts and dry spells may encourage farmers to consider expanding mulching practices to include cereals and other crops as a strategy for conserving soil moisture.

Our study identified several essential materials required for the effective application of mulch and manure. These include both fertile and infertile farm fields, livestock as the primary source of manure, organic materials such as tree leaves, grasses, and crop residues—particularly groundnut vines and husks—the specific crops being cultivated (for which mulch and manure may be needed), and the labor needed to carry out farming activities.

Farmers demonstrated a range of competences related to mulch and manure application. These included determining the appropriate quantity of manure needed for different crops, understanding the optimal timing and methods for applying both manure and mulch, assessing soil fertility levels, allocating manure accordingly, and aligning crop choices with specific nutrient requirements (Table 2). However, the persistent challenge of weed emergence—particularly weeds introduced through untreated manure—suggests that some gaps in knowledge and skills remain, especially in weed management.

In a parallel study, we found that due to the FERARI program, mulch became a scarcer and more expensive commodity. Suddenly mulch increased in economic value and that might impede further use. The same might be true to some extent for manure, making it less available for less endowed farmers.

Overall, the meanings, values, and purposes associated with mulch and manure use were closely tied to farmers' goals of ensuring household food security through increased yields and healthier crops. These practices were also valued for their role in providing a sustained nutrient supply, offering a more affordable alternative to chemical fertilizers, and protecting perishable crops from pests and drought-related stress.

In this study, we have highlighted the social embeddedness of mulch and manure applications, including the motivations behind their use, the resources required for effective implementation, and the skills necessary for their application. These practices are shaped not only by agronomic considerations but also by social norms, labor dynamics, and local knowledge systems. However, we acknowledge a key limitation: the absence of systematic, quantitative data on crop yields and soil properties, which restricts our ability to directly link these practices to measurable improvements in crop productivity and soil fertility. Addressing this gap presents an important opportunity for future research, particularly through integrated studies that combine qualitative insights with quantitative field trials.

Further research is needed to investigate the systems and strategies that could facilitate the collection of adequate manure for crop production. An especially compelling area for future exploration is the emergence of unusual and hard-to-control weeds introduced through manure use. Additional research could examine how cropping systems might be optimized to ensure efficient recycling of crop residues within smallholder farming systems.

5 Conclusion

In this study, we explored the processes involved in the application of mulch and manure, tracing their historical use, the arrangements farmers make to access these resources, the decision-making around crop and farm field selection, and the timing and methods of application. By framing these soil fertility management practices through the lens of Social Practice Theory, we emphasized the negotiation required to access mulch and manure, the underlying purposes that motivate their use, and the meanings farmers associate with these practices.

We also highlighted the competences demonstrated by farmers, reflected in their understanding of the agronomic benefits, their observations of improved crop performance, and their recognition of new challenges, such as weed emergence, which arise from implementing these practices. This approach underscores the dynamic, socially embedded nature of mulch and manure application in smallholder farming systems.

Our findings have two key implications for future practice and policy. First, soil fertility management initiatives must account for the integral role of livestock in smallholder crop production, including the need for improved housing systems that support better manure collection, storage, and treatment. Accounting for livestock integration in this manner also addresses the tensions associated with crop residues used for livestock feed or mulching purposes. Second, policy efforts should prioritize the accessibility of technologies that facilitate the transport and application of mulch and manure on farm fields.

We recommend the implementation of targeted subsidies to support the transport and application of manure and mulch, recognizing the labor and logistical challenges that often limit their use. Additionally, we advocate for training programs on residue management to promote the efficient use of crop residues, enhance soil fertility, and reduce waste. These interventions can help improve the accessibility and effectiveness of organic soil amendments, contributing to soil fertility management and more sustainable farming systems.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors without undue reservation.

Ethics statement

Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

Author contributions

ES: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Writing – original draft, Writing – review & editing. HM: Conceptualization, Formal analysis, Methodology, Supervision, Validation, Writing – review & editing. MEG: Conceptualization, Funding acquisition, Project administration, Resources, Supervision, Writing – review & editing. PB: Conceptualization, Funding acquisition, Project administration, Resources, Supervision, Writing – review & editing. CF: Conceptualization, Formal analysis, Methodology, Supervision, Validation, Writing – review & editing. PS: Conceptualization, Formal analysis, Funding acquisition, Methodology, Resources, Supervision, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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References

Abdulai, A.-R. (2022). Toward digitalization futures in smallholder farming systems in sub-Sahara Africa: a social practice proposal. *Front. Sustain. Food Syst.* 6:866331. doi: 10.3389/fsufs.2022.866331

Adjebeng-Danquah, J., Martey, E., Manu-Aduening, J., Gracen, V., Asante, I. K., and Offei, S. K. (2020). Farmers' perception on drought constraints and mitigation strategies in cassava cultivation in northern Ghana: implications for cassava breeding. *Sustain. Futures* 2:100041. doi: 10.1016/j.sftr.2020.100041

Adjei-Nsiah, S., Kumah, J. F., Owusu-Bennoah, E., and Kanampiu, F. (2019). Influence of P sources and *Rhizobium* inoculation on growth and yield of soybean genotypes on ferric Lixisols of northern Guinea savanna zone of Ghana. *Commun. Soil Sci. Plant Anal.* 50, 853–868. doi: 10.1080/00103624.2019.1589489

Adjei-Nsiah, S., Kuyper, T. W., Leeuwis, C., Abekoe, M. K., and Giller, K. E. (2007). Evaluating sustainable and profitable cropping sequences with cassava and four legume crops: effects on soil fertility and maize yields in the forest/savannah transitional agro-ecological zone of Ghana. *Field Crop Res.* 103, 87–97. doi: 10.1016/j.fcr.2007.05.001

Adu, G. B., Abdulai, M. S., Alidu, H., Nustugah, S. K., Buah, S. S., Kombiok, J. M., et al. (2014). Recommended production practices for maize in Ghana. Tamale: CSIR/AGRA.

Adzawla, W., Atakora, W. K., Kissiedu, I. N., Martey, E., Etwire, P. M., Gouzaye, A., et al. (2021). Characterization of farmers and the effect of fertilization on maize yields in the Guinea Savannah, Sudan Savannah, and transitional agroecological zones of Ghana. *EFB Bioecon. J.* 1:100019. doi: 10.1016/j.bioeco.2021.100019

Adzawla, W., Kissiedu, I. N., Edward, M., Etwire, P. M., Atakora, W. K., Gouzaye, A., et al. (2021). Baseline study on fertilizer use and food/nutrition security in the Sudan Savannah, Guniea Savannah and transitional zones of Ghana: IFDC Contract No.: No.5. Accra: International Fertilizer Development Center.

Adzawla, W., Setsoafia, E. D., Setsoafia, E. D., Amoabeng-Nimako, S., Atakora, W. K., Camara, O., et al. (2024). Fertilizer use efficiency and economic viability in maize production in the Savannah and transitional zones of Ghana. *Front. Sustain. Food Syst.* 8:8. doi: 10.3389/fsufs.2024.1340927

Ahmad, A., Yaseen, M., Hussain, H., Tahir, M. N., Gondal, A. H., Iqbal, M., et al. (2022). Effects of mulching on crop growth, productivity and yield. Singapore: Springer, 215–229.

Ansong Omari, R., Bellingrath-Kimura, S., Sarkodee Addo, E., Oikawa, Y., and Fujii, Y. (2018). Exploring farmers' indigenous knowledge of soil quality and fertility management practices in selected farming communities of the Guinea Savannah agro-ecological zone of Ghana. *Sustainability* 10:1034. doi: 10.3390/su10041034

Asamoah, E., Heuvelink, G. B. M., Chairi, I., Bindraban, P. S., and Logah, V. (2024). Random forest machine learning for maize yield and agronomic efficiency prediction in Ghana. *Heliyon* 10:e37065. doi: 10.1016/j.heliyon.2024.e37065

Bassi, E. M., Goddard, E., and Parkins, J. R. (2019). "That's the way We've always done it": a social practice analysis of farm animal welfare in Alberta. *J. Agric. Environ. Ethics* 32, 335–354. doi: 10.1007/s10806-019-09777-0

Bationo, A., and Mokwunye, A. U. (1991). Role of manures and crop residue in alleviating soil fertility constraints to crop production: with special reference to the Sahelian and Sudanian zones of West Africa. Netherlands: Springer, 217–225.

Bellwood-Howard, I. (2012). Donkeys and bicycles: capital interactions facilitating timely compost application in northern Ghana. *Int. J. Agric. Sustain.* 10, 315–327. doi: 10.1080/14735903.2012.666030

Boateng, P., Appiah, D., Adjei, P., and Mensah, H. (2016). Perceptions of socio-ecological changes and their implications on changes in farming practises and agricultural land uses in the savannahs of Northeast Ghana. *Environments* 3:33. doi: 10.3390/environments3040033

Buah, S. S. J., Ibrahim, H., Derigubah, M., Kuzie, M., Segtaa, J. V., Bayala, J., et al. (2017). Tillage and fertilizer effect on maize and soybean yields in the Guinea savanna zone of Ghana. *Agric. Food Secur.* 6:17. doi: 10.1186/s40066-017-0094-8

Chianu, J. N., Chianu, J. N., and Mairura, F. (2012). Mineral fertilizers in the farming systems of sub-Saharan Africa. A review. *Agron. Sustain. Dev.* 32, 545–566. doi: 10.1007/s13593-011-0050-0

Daadi, B. E., and Latacz-Lohmann, U. (2021a). Organic fertilizer use by smallholder farmers: typology of management approaches in northern Ghana. *Renew. Agric. Food Syst.* 36, 192–206. doi: 10.1017/S1742170520000228

Daadi, B. E., and Latacz-Lohmann, U. (2021b). Organic fertilizer adoption, household food access, and gender-based farm labor use: empirical insights from northern Ghana. *J. Agric. Appl. Econ.* 53, 435–458. doi: 10.1017/aae.2021.8

Daadi, B. E., and Latacz-Lohmann, U. (2021c). Assessing farmers' attitudes to, and the behavioural costs of, organic fertiliser practices in northern Ghana: an application of the behavioural cost approach. *Heliyon* 7:e07312. doi: 10.1016/j.heliyon.2021.e07312

Dalton, T. J., Yahaya, I., and Naab, J. (2014). Perceptions and performance of conservation agriculture practices in northwestern Ghana. *Agric. Ecosyst. Environ.* 187, 65–71. doi: 10.1016/j.agee.2013.11.015

Erenstein, O. (2002). Crop residue mulching in tropical and semi-tropical countries: an evaluation of residue availability and other technological implications. *Soil Tillage Res.* 67, 115–133. doi: 10.1016/S0167-1987(02)00062-4

Gill, K. (1996). Tillage, mulch and irrigation effects on corn (*Zea mays* L.) in relation to evaporative demand. *Soil Tillage Res.* 39, 213–227. doi: 10.1016/S0167-1987(96)01061-6

Giller, K. E., Delaune, T., Silva, J. V., Descheemaeker, K., van de Ven, G., Schut, A. G. T., et al. (2021). The future of farming: who will produce our food? *Food Secur.* 13, 1073–1099. doi: 10.1007/s12571-021-01184-6

Harris, F. (2002). Management of manure in farming systems in semi-arid West Africa. *Exp. Agric.* 38, 131–148. doi: 10.1017/S0014479702000212

Jain, M., Barrett, C. B., Solomon, D., and Ghezzi-Kopel, K. (2023). Surveying the evidence on sustainable intensification strategies for smallholder agricultural systems. *Annu. Rev. Environ. Resour.* 48, 347–369. doi: 10.1146/annurev-environ-112320-093911

Kassim, Y. B., Pinto, F., Maccarthy, D. S., Bindraban, P., Chirinda, N., Stomph, T., et al. (2025). Can drone images predict within-field variability in soil fertility? A case study in the northern region of Ghana. *Front. Soil Sci.* 5:5. doi: 10.3389/fsoil.2025.1548645

Kaur, R., and Arora, V. (2019). Deep tillage and residue mulch effects on productivity and water and nitrogen economy of spring maize in north-west India. *Agric. Water Manag.* 213, 724–731. doi: 10.1016/j.agwat.2018.11.019

Kenfack Essougong, U. P., Slingerland, M., Mathé, S., Vanhove, W., Tata Ngome, P. I., Boudes, P., et al. (2020). Farmers' perceptions as a driver of agricultural practices: understanding soil fertility management practices in cocoa agroforestry systems in Cameroon. *Hum. Ecol.* 48, 709–720. doi: 10.1007/s10745-020-00190-0

Ketema, M., and Bauer, S. (2011). Determinants of manure and fertilizer applications in eastern highlands of Ethiopia. *Q. J. Int. Agric.* 50, 237–252. doi: 10.22004/ag.econ.155533

Kodzwa, J. J., Gotosa, J., and Nyamangara, J. (2020). Mulching is the most important of the three conservation agriculture principles in increasing crop yield in the short term, under sub humid tropical conditions in Zimbabwe. *Soil Tillage Res.* 197:104515. doi: 10.1016/j.still.2019.104515

Kouame, A. K. K., Bindraban, P. S., Kissiedu, I. N., Atakora, W. K., and El Mejahed, K. (2023). Identifying drivers for variability in maize (*Zea mays* L.) yield in Ghana: a meta-regression approach. *Agric. Syst.* 209:103667. doi: 10.1016/j.agsy.2023.103667

Kuonen, L., and Norgrove, L. (2022). Mulching on family maize farms in the tropics: a systematic review. *Curr. Res. Environ. Sustain.* 4:100194. doi: 10.1016/j.crsust.2022.100194

Malongza Bukari, F. I. (2013). Indigenous perceptions of soil erosion, adaptations and livelihood implications: the case of maize farmers in the Zampe community of bole in the northern region of Ghana. *J. Nat. Resour. Dev.* 3, 114–120. doi: 10.5027/jnrd.v3i0.10

Ndambi, O. A., Pelster, D. E., Owino, J. O., De Buisonjé, F., and Vellinga, T. (2019). Manure management practices and policies in sub-Saharan Africa: implications on manure quality as a fertilizer. *Front. Sustain. Food Syst.* 3:29. doi: 10.3389/fsufs.2019.00029

Nketia, K. A., Asabere, S. B., Ramcharan, A., Herbold, S., Erasmi, S., and Sauer, D. (2022). Spatio-temporal mapping of soil water storage in a semi-arid landscape of northern Ghana – a multi-tasked ensemble machine-learning approach. *Geoderma* 410:115691. doi: 10.1016/j.geoderma.2021.115691

Okeyo, A. I., Mucheru-Muna, M., Mugwe, J., Ngetich, K. F., Mugendi, D. N., Diels, J., et al. (2014). Effects of selected soil and water conservation technologies on nutrient losses and maize yields in the central highlands of Kenya. *Agric. Water Manag.* 137, 52–58. doi: 10.1016/j.agwat.2014.01.014

Paul, S., Meer, H., Onduru, D., Ebanyat, P., Zake, J., and Wouters, B. (2013). Effects of cattle and manure management on the nutrient economy of mixed farms in East Africa: a scenario study. *Afr. J. Agri. Res.* 8, 5128–5129. doi: 10.5897/AJAR10.009

Quansah, C., Drechsel, P., Yirenkyi, B. B., and Asante-Mensah, S. (2001). Farmers' perceptions and management of soil organic matter – a case study from West Africa. *Nutr. Cycl. Agroecosyst.* 61, 205–213. doi: 10.1023/A:1013337421594

Ranaivoson, L., Naudin, K., Ripoche, A., Rabeharisoa, L., and Corbeels, M. (2018). Is mulching an efficient way to control weeds? Effects of type and amount of crop residue in rainfed rice based cropping systems in Madagascar. *Field Crop Res.* 217, 20–31. doi: 10.1016/j.fcr.2017.11.027

Richards, P. (1993). "Cultivation: knowledge or performance?" in An anthropological critique of development: the growth of ignorance. ed. M. Hobart (London: Routledge), 61–78.

Ricker-Gilbert, J. (2020). Inorganic fertiliser use among smallholder farmers in sub-Saharan Africa: implications for input subsidy policies. Cham: Springer, 81–98.

Saïdou, A., Janssen, B. H., and Temminghoff, E. J. M. (2003). Effects of soil properties, mulch and NPK fertilizer on maize yields and nutrient budgets on ferralitic soils in southern Benin. *Agric. Ecosyst. Environ.* 100, 265–273. doi: 10.1016/S0167-8809(03)00184-1

Shove, E., Pantzar, M., and Watson, M. (2012). The dynamics of social practice: everyday life and how it changes. London: SAGE Publications Ltd.

Spurk, C., Asule, P., Baah-Ofori, R., Chikopela, L., Diarra, B., and Koch, C. (2020). The status of perception, information exposure and knowledge of soil fertility among small-scale farmers in Ghana, Kenya, Mali and Zambia. *J. Agric. Educ. Ext.* 26, 141–161. doi: 10.1080/1389224X.2019.1656089

Sungbaahee, S. B., and Kpieta, A. B. (2021). Smallholder farmers' perception of sustainable land management practices (SLMPs) in the upper west region, Ghana. *Afr. Geogr. Rev.* 40, 444–458. doi: 10.1080/19376812.2020.1845216

Tesfahunegn, G. B., Ayuk, E. T., and Adiku, S. G. K. (2021). Farmers' perception on soil erosion in Ghana: implication for developing sustainable soil management strategy. *PLoS One* 16:e0242444. doi: 10.1371/journal.pone.0242444

Tippe, D. E., Bastiaans, L., Van Ast, A., Dieng, I., Cissoko, M., Kayeke, J., et al. (2020). Fertilisers differentially affect facultative and obligate parasitic weeds of rice and only occasionally improve yields in infested fields. *Field Crop Res.* 254:107845. doi: 10.1016/j.fcr.2020.107845

Tippe, D. E., Rodenburg, J., Schut, M., Van Ast, A., Kayeke, J., and Bastiaans, L. (2017). Farmers' knowledge, use and preferences of parasitic weed management strategies in rain-fed rice production systems. *Crop Prot.* 99, 93–107. doi: 10.1016/j.cropro.2017.05.007

Tippe, D. E., Rodenburg, J., Van Ast, A., Anten, N. P. R., Dieng, I., Kayeke, J., et al. (2017). Delayed or early sowing: timing as parasitic weed control strategy in rice is species and ecosystem dependent. *Field Crop Res.* 214, 14–24. doi: 10.1016/j.fcr.2017.08.013

Uwizeyimana, D., Mureithi, S. M., Karuku, G., and Kironchi, G. (2018). Effect of water conservation measures on soil moisture and maize yield under drought prone agro-ecological zones in Rwanda. *Int. Soil Water Conserv. Res.* 6, 214–221. doi: 10.1016/j.iswcr.2018.03.002

van Ittersum, M. K., van Bussel, L. G., Wolf, J., Grassini, P., van Wart, J., Guilpart, N., et al. (2016). Can sub-Saharan Africa feed itself? *Proc. Natl. Acad. Sci. USA* 113, 14964–14969. doi: 10.1073/pnas.1610359113

Vanlauwe, B., Bationo, A., Chianu, J., Giller, K. E., Merckx, R., Mokwunye, U., et al. (2010). Integrated soil fertility management: operational definition and consequences for implementation and dissemination. *Outlook Agric.* 39, 17–24. doi: 10.5367/000000010791169998

Vanlauwe, B., Wendt, J., and Diels, J. (2015). "Combined application of organic matter and fertilizer" in Soil Science Society of America and American Society of Agronomy, London: SAGE Publications Ltd. 247–279.

Williams, T. O. (1999). Factors influencing manure application by farmers in semi-arid West Africa. *Nutr. Cycl. Agroecosyst.* 55, 15–22.