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Economic effects of digestate and compost soil amendments on farmers' income in Burkina Faso: A mathematical programming approach

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Abstract

This study compares the benefits of using digestate and compost in Burkina Faso. A mathematical programming model was used to simulate the advantages under three scenarios. The baseline scenario reflected the typical situation of farmers, followed by the introduction of digestate and compost as soil amendments. The model applied these to improve poor soils and recover fallow land.

As a result, the production of maize, cotton, rice, millet and sorghum increased, while groundnut cultivation and fallow land decreased. Gains were most notable with digestate. During poor cropping seasons, income rose by 238% with digestate and by 132% with compost. During good seasons, income increased by 164% and 98%, respectively. The use of digestate and compost helped reduce poverty and promote food security, although credit and labour constraints remain important considerations.

Key words: biodigestate, compost, household income, mathematical programming model, Burkina Faso

1. Introduction

Over the past century, West African agricultural systems have experienced significant environmental, demographic, socioeconomic, and political changes (Beucher & Bazin 2012; Wood *et al*. 2014; Sultan *et al*. 2019). These shifts have not only transformed rural livelihoods, but also intensified farmer–herder conflicts, deepened poverty and food insecurity, and prompted both internal and cross-border migration. Faced with ongoing poverty and increasing climatic and environmental pressures, rural households have diversified their livelihood strategies, with mixed crop–livestock farming becoming a key part of resilience (Peterson *et al*. 2020; Walker 2020). Mixed crop–livestock farming value chains create employment opportunities for a wide range of rural and urban actors (Kazianga & Udry 2006).

Beyond supporting livelihoods, mixed crop–livestock production significantly contributes to Burkina Faso’s national economy through both domestic markets and export revenues (Sanfo & Gérard 2012; Zidouemba & Gerard 2018). However, despite these economic benefits, mixed crop–livestock farming practiced by smallholders remains vulnerable to multiple stressors. Addressing these challenges requires a shift toward climate-smart and site-specific practices that combine crop and livestock production, thereby promoting sustainable intensification and strengthening the adaptive capacity of smallholder agriculture (Thornton & Herrero 2015).

Digestate applications supply readily available nitrogen, phosphorus, potassium and organic matter, generally enhancing soil fertility (Scheer *et al*. 2021; Karimi *et al*. 2022; Liu *et al*. 2023). Digestate has been shown to significantly boost crop yields compared to unfertilised controls and often performs equally well as mineral fertilisers with similar nutrient inputs (Tambone & Adani 2017; Velasquez *et al*. 2023). At the household level, biodigesters produce biogas for cooking and sometimes electricity, reducing reliance on fuelwood, lowering costs, and improving indoor air quality (World Bank 2019; Gbadeyan *et al*. 2024). Together, biogas and digestate enhance soil health, increase yields, provide renewable energy, and support income generation (Bonokwane & Ololade 2022).

Composting of organic residues is a common agroecological practice in West Africa, especially in the Sahel regions, and it boosts soil fertility, improves crop yields and supports local livelihoods. Studies indicate that compost improves soil physical properties, thereby increasing soil organic carbon and resilience under changing pedoclimatic conditions (Diacono & Montemurro 2010; Villarino *et al*. 2025). Agronomically, compost raises yields, especially in degraded soils, and, when used with mineral fertilisers, promotes sustainable intensification (Albano *et al*. 2023; Velasquez *et al*. 2023). Economically, composting decreases reliance on synthetic fertilisers, reduces waste-disposal emissions, and generates modest income and job opportunities, although benefits vary by context and are limited by labour requirements.

Digestate and compost are climate-smart practices that can improve soil health, increase yields and support rural income (Curadelli *et al*. 2023). However, while compost has been widely studied in terms of technical details, agronomic impacts and socio-economic effects (Doruska *et al*. 2024; Kebalo 2024), digestate has received comparatively little attention from a socio-economic standpoint (Akter *et al*. 2021; Gurmessa *et al*. 2024). Most previous studies were focused on energy production, crop yields and agronomic impacts. Furthermore, some methods used in these studies have certain limitations. For example, cost-benefit analysis cannot simulate future scenarios, and computable general equilibrium (CGE) models are limited to macroeconomic analysis, excluding biophysical factors. This study aims to evaluate the socio-economic effects of digestate and compost on farmers' income in Burkina Faso. Using a bio-economic model, we compared a baseline scenario without digestate or compost to two other scenarios that included either digestate or compost. We assessed how these practices affected farmers' incomes. After providing a detailed description of the study area (Section 1), we introduce the model used to analyse the technologies (Section 2) and discuss the findings (Section 3). The study concludes with recommendations presented in Section 4.

2. Methods

2.1 Study area

This study was carried out in three villages (Tambiri, Soriane and Pontieba) in the Ioba province of southwestern Burkina Faso (Figure 1). The average yearly rainfall is 850 mm. The main rainfed crops include maize, sorghum, millet, cotton, cowpea, groundnut and sesame. Sorghum, cotton and maize are grown on the most fertile soils, while millet is usually cultivated on shallower soils. Cowpeas are often grown alongside cereal crops. Rice is produced in lowland areas that flood during the rainy season, and maize can also be grown in lowlands where the risk of flooding is lower. Traditional soil and water conservation methods are scarce in the region, and leaving land fallow is becoming increasingly uncommon.

In the mid-1990s, the average fallow period was about six years, but it has since shortened to three years. The use of organic fertiliser remains low because farmers face challenges in accessing bank credit. Fertiliser is mainly applied to cotton, as the cotton company offers credit for inputs and deducts the cost from farmers' revenues after harvest. Despite the increasing need in the region due to demographic pressure, declining soil fertility and lower yields, the supply of digestate and compost is limited by manure availability, and their use remains highly restricted. Although there is a high demand (e.g. 16 844 farmers in 2008), the adoption and use of digestate and compost remain limited, and both land and labour productivity are still very low.

2.2 Data sources and sampling procedures

Data about farm households in the southwestern region of Burkina Faso were gathered from multiple sources and at various levels, including national, village, household and farm levels. Expert and stakeholder interviews, along with field trials conducted over three years, enabled us to collect data on yields, production costs, and the prices of agricultural products and livestock. Additional data, such as rainfall, soil type, population and other socio-economic information, were obtained from national institutes (National Demography Institute, National Meteorological Agency, National Soil Office, Ministry of Agriculture and Livestock, National Stock Management Company and municipalities). Complementary surveys were carried out among 60 households, evenly distributed across the three selected villages (Tambiri, Soriane and Pontieba). These surveys were conducted in three phases to describe farmers' activities and constraints and to generate data to help parameterise the farm-level bio-economic model.

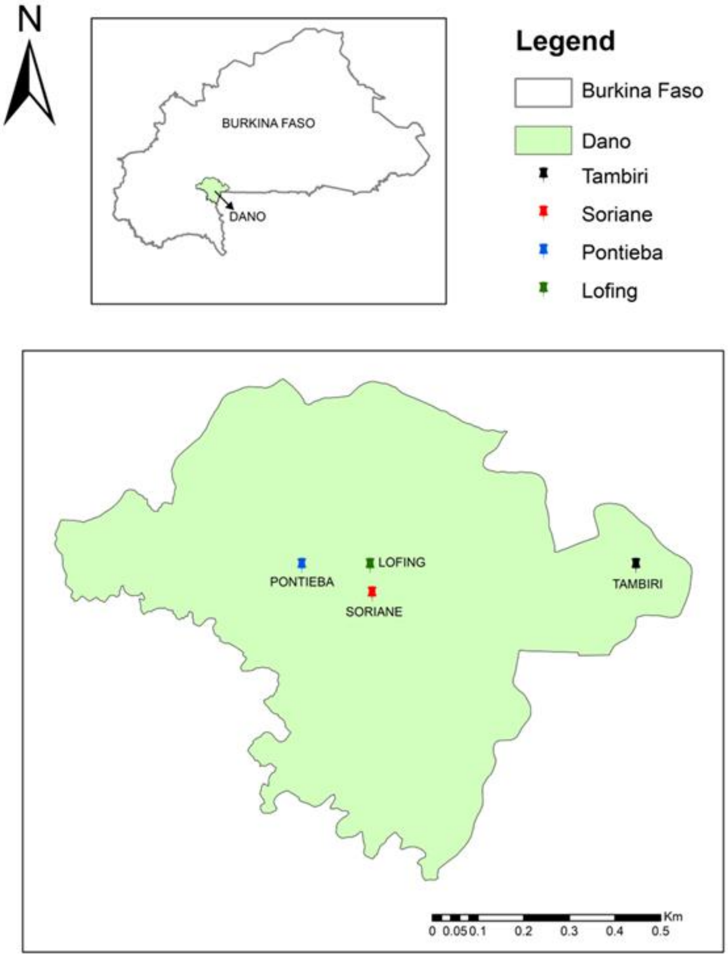

Figure 1: Map of Burkina Faso showing the study area

In the first phase, three focus group discussions (FGDs) were conducted (one in each village) to identify communities vulnerable to heavy rainfall, soil erosion, prolonged dry spells and floods. Participants for the FGDs were selected based on four criteria: i) the participating farmer must have a next of kin enrolled in at least high school[1]; ii) the participating farmer must have owned farmland for at least five years[2]; iii) the farmland must have at least one of the following features: high erosion potential from runoff, high waterlogging potential, or highly degraded arable land[3]; and iv) the participating farmer is an agro-pastoralist or owns at least some animals (women volunteer farmers willing to contribute to the activities were encouraged).[4] In the second phase, data were collected on

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[1] The guidance on the use of digestate and compost was available in French or English from WASCAL and the technical services of the Ministry of Agriculture, emphasising the role of family members. While literacy is important for understanding the advice, farmers – who are often illiterate – can rely on their next of kin, who are often enrolled in school, to provide accurate and meaningful translations of the advice into the local language. This support system ensures that all farmers can benefit from the guidance.

[2] Land serves as the primary means of production in agriculture within the study area. A farmer cannot invest in compost or digestate without having secure land ownership. Without assurance that they can use the land in the long term, farmers are unlikely to invest in compost and digestate to restore degraded farmland. Therefore, stable land ownership motivates producers to invest in and adopt new practices, as they know they will reap the benefits of their investments.

[3] The study suggested that digestate and compost are climate-smart practices that can improve soil health, boost crop yields and enhance rural incomes. To illustrate this, it is essential to choose farmland with low fertility, including areas with a high risk of erosion due to runoff, significant waterlogging potential, or severely degraded arable land.

[4] Composting and digestate production require animal waste. Having animals means there is waste available, which will facilitate production.

the socio-economic characteristics of selected households, the farm's technical itinerary, and the functional structure of the agricultural system. This included information on labour needs, inputs, yields, land allocation, labour costs, crop sales and purchase prices, as well as credit. These data were used to build the baseline scenario. The third phase consisted of distributing and constructing biodigesters and compost pits.

All 60 farmers were included: 20 received biodigesters (the 'digestate scenario') and 20 received compost pits (the 'compost scenario'), forming the treatment groups. Their farms served as sites for trials demonstrating the application of digestate and compost during the 2019, 2020 and 2021 rainy seasons. The remaining 20 farmers did not receive biodigesters or compost pits and formed the control group (the 'baseline scenario'). For the treatment groups, trial plots were ¼ hectare in size, taken from each farmer's total farmland, focusing on degraded portions of the land. Agricultural technicians provided farmers with training in the use of digestate and compost.

During the rainy season, in collaboration with agricultural extension agents, farmers applied digestate and compost (at a rate of five tons per hectare) on their selected plots. In addition, they established operational farm accounts for in situ data collection. Information was gathered on the use of digestate and compost, yields, prices of agricultural products, and labour. These data were used to parameterise the model for simulating the effects of soil amendment with digestate and compost on farmers' income.

2.3 Analytical model

To examine the effects of digestate and compost on farmers' income, we used a dynamic mathematical programming optimisation model. This approach benefits from reintroducing 'history' into farm modelling, aligning with the principles of new development economics. The mathematical programming used in this modelling system explicitly captures all opportunities and constraints faced by smallholder farming systems. Dynamic simulations enable the validation of new technologies and facilitate the analysis of key farm-level variables, including production, consumption, income and investments. These simulations also facilitate the testing of innovations and the assessment of their potential for adoption (Sanfo 2010; Sanfo & Gérard, 2012). The model's theoretical foundation is based on translating exact or approximate relationships between two or more parameters and variables into mathematical form (Sanfo & Gerard 2012). This translation requires a thorough understanding of the farming system being represented.

Building this type of model requires both quantitative and qualitative knowledge of the farming system. The bio-economic optimisation model used in this study aims to represent the interactions between a stock of natural capital and the economic activity it supports (Pacini *et al*. 2004). In this context, natural capital refers specifically to organic fertilisers, including biodigestate and compost produced from biodigesters and compost pits. Bio-economic models are ex-ante assessment tools that help describe the combination of activities that maximise income and are more likely to be adopted by farmers (Hazell & Norton 1986; Pacini *et al*. 2004; Torkamani 2005).

These models also support testing key innovations, such as the use of compost and digestate. Research in the study areas indicates that agricultural households often do not aim to maximise profit, mainly due to market failures and limited information. Instead, their goal is to achieve maximum satisfaction, which occurs when they attain the highest net present value (NPV) of their annual net cash incomes. By using a household utility function, we incorporated additional features that reflect socio-economic and biophysical realities, such as fertiliser types, soil types and rainy-season conditions (the state of nature). The model is dynamic and calculates both annual available income and the NPV of annual income over a 20-year simulation period, using the discount rate disc (t). We chose 20 years because of our focus on the long-term effects of the biodigester.

Farming is inherently risky and, in the model, agricultural households are considered to operate with limited information, or 'blind'. This means they do not know in advance whether the weather during the cropping season will be good or bad. A bad cropping season results in below-normal harvests, while a good season yields up to above-normal harvests. Solving this household decision problem helped establish the baseline scenario, which reflects the actual situation of the identified agricultural households. The model was then used to predict household behaviour under various scenarios by determining the NPV of incomes across combined household farms. In addition, the model's stochastic structure was linearised. The problem faced by a given household in the study areas can be expressed as follows:

$$\text{Max NPV} = \sum_{t} \text{ADINC}_{t} \times \text{disc}_{t} \qquad (1)$$

Equation (1) specifies that farmers seeks to maximise the NPV of their total available income, including both farm and off-farm sources. Here, NPV represents the net present value of the household income, $ADINC_t$ the available/disposable income per year (t), and $disc_t$ is the discount rate applied each year (t).

$$\text{AINC}_{\text{t}} = \sum_{c} \text{SELLC}_{\text{c,t}} \times \text{ps}_{\text{c}} - \sum_{c,tec,s} \text{X}_{\text{c,tec,s,t}} \times \text{input}_{\text{c,tec,s}} - \sum_{c,p} \text{PC}_{\text{c,t}} \times \text{pp}_{\text{c}} - \sum_{p} HLABOR_{\text{p,t}} * clabor - rate \times CRED_{t} \qquad (2)$$

Equation (2) calculates the annual farm income of the household to be maximised. The total amount of farm sales is given by $\sum_{c} \text{SELL}_{\text{c,t}} \times \text{sp}_{\text{c}}$, where $(\text{SELL}_{\text{c,t}})$ is the quantity of agricultural products sold per crop (c) and per year (t), and (sp_{c}) is the unit sale price of each crop (c). The equation also accounts for the total cost of inputs required to cultivate the agricultural land, crop area $(X_{c,tec,s,t})$ multiplied by the inputs cost per land cultivated $(\text{input}_{c,tec,s})$, cereal purchases for household consumption $(AC_{c,t})$ multiplied by purchase price (pxa_{c}), the total cost of labour to be hired, seasonal credit (CRED_{t}) and financial costs (rate).

The model considered a set of farming constraints, including land, labour, liquidity (cash and credit), production, food consumption and risk.

$$\sum_{tec,c} \text{X}_{\text{c,tec,s,t}} \leq Land_{s} \qquad (3)$$

Equation (3) describes the land constraint. It stipulates that the sum of cultivated areas on each type of soil $(\text{X}_{\text{c,tec,s,t}})$ must not exceed the household's available agricultural land. The model distinguished four soil types: good soil, bad soil, slightly flooded soil and flooded soil.

$$\sum_{c,s,tec} \text{X}_{\text{c,tec,s,t}} \times \text{labour}_{\text{c,tec,p}} \leq \text{tmp}_{\text{p}} \times \text{pop} \times \text{pmp} + \text{HLABOUR}_{p,t} \qquad (4)$$

Equation (4) describes the labour constraint. It states that the total labour requirement for all crops $(\sum_{c,s,tec} \text{X}_{\text{c,tec,s,t}} \times \text{labour}_{\text{c,tec,p}})$ must not exceed the sum of labour available from active household members $(\text{tmp}_{\text{p}} \times \text{pop} \times \text{pmp})$ and hired farm labour $(\text{LABOURH}_{p,t})$. The model allowed households to hire labour, $(\text{LABOURH}_{p,t})$, when labour demand as high and family labour was insufficient.

$$\sum_{tec,s} \text{yield}_{\text{c,tec,s}} \times \text{X}_{\text{c,tec,s,t}} = \text{AU}_{c,t} + \text{SELLC}_{c,t} \qquad (5)$$

Equation (5) summarises the production constraint. The total quantity of household production – calculated as yields ($\mathrm{yield}_{c,tec,s}$) multiplied by land areas ($X_{c,tec,s,t}$), must equal the sum of self-consumption ($AU_{c,t}$) and sales ($SELLC_{c,t}$).

$$\sum_c (AU_{c,t} + PURC_{c,t}) \times fp_c \geq fr \times pop \tag{6}$$

Equation (6) specifies that the sum of household self-consumption ($AU_{c,t}$) and cereal purchases ($PURC_{c,t}$), each weighted by the food preference (fp_c), should cover the household's total food needs ($fr \times pop$).

$$AINC_t + icash_t + CASH_{t-1} + CRED_t \geq CASH_t + INV_t + ADINC_t + CRED_{t-1} \tag{7}$$

The cash flow constraint expresses the transfer of cash between two years. Equation (7) estimates the expected cash and investment at the end of each year (t). Any transaction involving cash should be recorded in the farmer's cash at the time of the transaction. This approach accounts for the model's dynamic nature by considering both the start and end of each agricultural season. For example, crops harvested in year (t) are sold and recorded in the cash box of year (t + 1) for farm investment and the purchase of inputs.

$$ADINC_t = INCmin \tag{8}$$

The risk constraint, as outlined in Equation (8), requires the model to maintain a minimum level of disposable income even during poor crop seasons. This ensures that producers meet a minimum level of food security. To manage risk and uncertainties, the model also uses a uniform distribution for prices and crop yields. Table 1 summarises the model's structure and key elements.

2.4 Simulation model

The two proposed scenarios aim to assess the effect of organic soil amendments on household incomes. The first scenario depicts the baseline situation, representing farmers' current practices. This farming system reflects regional norms: it is not livestock-focused, and the use of organic fertilisers (biodigestate and compost) remains limited. In the second scenario, biodigesters and compost pits are introduced. They supply digestate and compost, respectively, for soil amendment. In addition, biodigesters provide biogas for cooking and lighting. The model assumes farmers can purchase and install biodigesters and build compost pits, which would supply digestate and compost for soil improvement.

In Burkina Faso, the national biodigester programme was launched in 2009 to improve access to this technology. The most popular models are the Nepalese model (manufactured by Gobar company) and the FASO BIO 15, both averaging a 20-year lifespan. These models typically have a volume of 6 m^3 and produce about 1.8 m^3 of biogas daily, and is the most common size built in Burkina Faso. The average purchase price is USD 466, with a fixed subsidy of USD 268. The raw material used is cow dung. This renewable technology helps address food, nutrition and energy insecurity, reduces poverty, and supports climate change mitigation. The total opportunity costs of these services have been quantified.

Table 1: Description of indices, parameters, variables and equations of the model

Indices	**Definition**
C	Annual crops
P	Period of cropping system
S	Soil/land types
T	Years of simulation
TEC	Type of organic amendment sources/technology
Parameters	
tmp_p pmp	Total number of man-days available per economically active household member at period ‘p’ Proportion of total man-days available for agricultural use per each agricultural activity period
pop	Total family members
$clabor$	Wage rate of agricultural labour
fr	Average consumption rate per person and per year
$ps_{c,t}$	Sale price of crop ‘c’ in year ‘t’
$pp_{c,t}$	Purchase price of crop ‘c’ in year ‘t’
$yield_{c,tec,s,t}$	Yields of annual crop ‘c’, depending on the soil amendment technic, ‘tec’, and the type of soil, ‘s’, per year ‘t’.
$icash_t$	The total financial capital available to the farmer at the beginning year of the agricultural season
$labor_{c,tec,p}$	Labour requirement to produce crop ‘c’ using technology ‘tec’ in period ‘p’
$input_{c,tec,s}$	Cost of agricultural inputs used on land/soil type ‘s’ per technology ‘tec’ and per ha
$land_s$	Land availability by quality of soil type (good, marginal, slightly flooded, regularly flooded)
fp_c	Food preference
$rate$	Loan interest rate
$disc_t$	The discount rate
$INCmin$	Household minimum income
Variables	
$HLABOR_{p,t}$	Hired labour used in period ‘p’ (man-day)
$AU_{c,t}$	Household annual own consumption (kg)
$AC_{c,t}$	Household annual consumption from market (kg)
$SELLC_{c,t}$	Quantity of produced crop ‘c’ sold at year ‘t’(kg)
$AINC_t$ $ADINC_t$	Net annual income for a given year ‘t’ (USD) Household annual disposable income (USD)
$X_{c,tec,s,t}$	Land allocated to crop ‘c’ in soil type ‘s’, using technology ‘tec’ per year ‘t’ (USD)
$CRED_t$	The credit used to finance agricultural activities or equipment for a growing year ‘t’ (USD)
$CTEC_t$	Cost of technology in the year ‘t’ (USD)
Z	Utility (USD)
Main equations	
$Max\ NPV = \sum_t AINC_{\mathrm{t}} * disc_t$ (1)	Objective function
$AINC_t = \sum_c \mathrm{SELLC_{c,t}} \times \mathrm{ps_{c,t}} - \sum_{c,tec,s} \mathrm{X_{c,tec,s,t}} \times \mathrm{input_{c,tec,s}} - \sum_{c,p} \mathrm{PC_{c,t}} \times \mathrm{pp_{c,t}} - \sum_p HLABOR_{\mathrm{p,t}} * clabor - rate \times\ CRED_t$ (2)	Yearly income
$\sum_{tec,c} \mathrm{X_{c,tec,s,t}} \leq Land_s$ (3)	Land constraint
$\sum_{c,s,tec} \mathrm{X_{c,tec,s,t}} * labor_{c,tec,p} \leq tm_p * pop * pmp\ +\ HLABOR_{p,t}$ (4)	Labour constraint
$\sum_{tec,s} \mathrm{yield_{c,tec,s}} \times\ \mathrm{X_{c,tec,s,t}} \ =\ \mathrm{AU}_{c,t} +\ SELLC_{c,t}$ (5)	Production
$\sum_{\mathrm{c}}(\mathrm{AU_{c,t}} + \mathrm{AC_{c,t}}) * fp_c\ \geq fr\ \times\ pop$ (6)	Consumption constraint
$AINC_t + icash_t +\ CRED_t \geq\ INV_t + ADINC_t +\ CRED_{t-1}$ (7)	Cash flow
$ADINC_t =\ Rmin$ (8)	Risk constraint

The modelled compost pits are the most common method used in the aerobic composting processes. Aerobic composting involves the breakdown or fermentation of organic materials, such as crop residues and animal waste, under controlled conditions by microorganisms, producing a stable product rich in humic compounds (Culot & Lebeau 1999; FAO 2005). The estimated cost of a compost pit is USD 60. Compost enhances the biological and physicochemical properties of the soil (Culot & Lebeau 1999; FAO 2005). For each scenario, the model calculates a range of variables, including crop allocation, income per soil type, consumption, labour use and more.

3. Results and discussion

3.1 Baseline, compost and digestate scenarios

The baseline, compost and digestate scenarios estimated the allocation of agricultural land to different crops, agricultural production, food consumption, labour, the distribution of capital between activities, and household disposable income each year.

3.1.1 Land allocation to crops

In the baseline scenario, land allocation to various crops closely mirrored farmers' usual practices in the region. Millet and sorghum are grown on marginal land, occupying 20% and 34% of available land, respectively, with sorghum serving as the main staple. To ensure food security in years of poor rainfall, sorghum is also cultivated on good land. Maize and cotton are typically grown on good land, representing 30% and 4% of total land, respectively (Table 2). Rice is cultivated in slightly flooded lowlands and regularly in heavily flooded areas, accounting for 5%. Cowpea and groundnut together occupy 4% of cultivated land, with cowpea sometimes intercropped with millet and sorghum. Only 3% of land remains fallow, likely to be used in the future due to demographic pressures.

Table 2: Comparative cropped area (observed and simulated)

Crops/Area	Observed	Percentage	Simulated	%	Difference in %
Sorghum	2.24	37.33	1.88	34.29	3.04
Millet	1.15	19.17	1.09	19.86	-0.69
Maize	1.65	27.50	1.63	29.63	-2.13
Rice	0.34	5.67	0.29	5.26	0.41
Cotton	0.25	4.17	0.22	4.03	0.14
Cowpea	0.12	2.00	0.13	2.37	-0.37
Groundnut	0.11	1.83	0.11	2.01	-0.18
Fallow	0.14	2.33	0.14	2.55	-0.22

The introduction of digestate and compost in the model slightly alters land allocation to crops. Farmers applied digestate and compost to improve marginal lands, recovering 3% of the marginal lands, previously left fallow in the baseline (Figure 2). With soil amendments, all soil types were restored to similar fertility levels, allowing crops like maize to be grown on previously marginal soils. The application of digestate increased the area cultivated with cotton, maize, rice and millet, with maize, cotton and rice expanding by 17%, 9% and 45%, respectively, compared to the baseline. Compost amendments favoured maize, cowpea and rice at the expense of millet, groundnut and sorghum, increasing their areas by 17%, 8% and 45%, respectively. Maize, cowpea and rice are partially sold and are more profitable than sorghum, millet and groundnut.

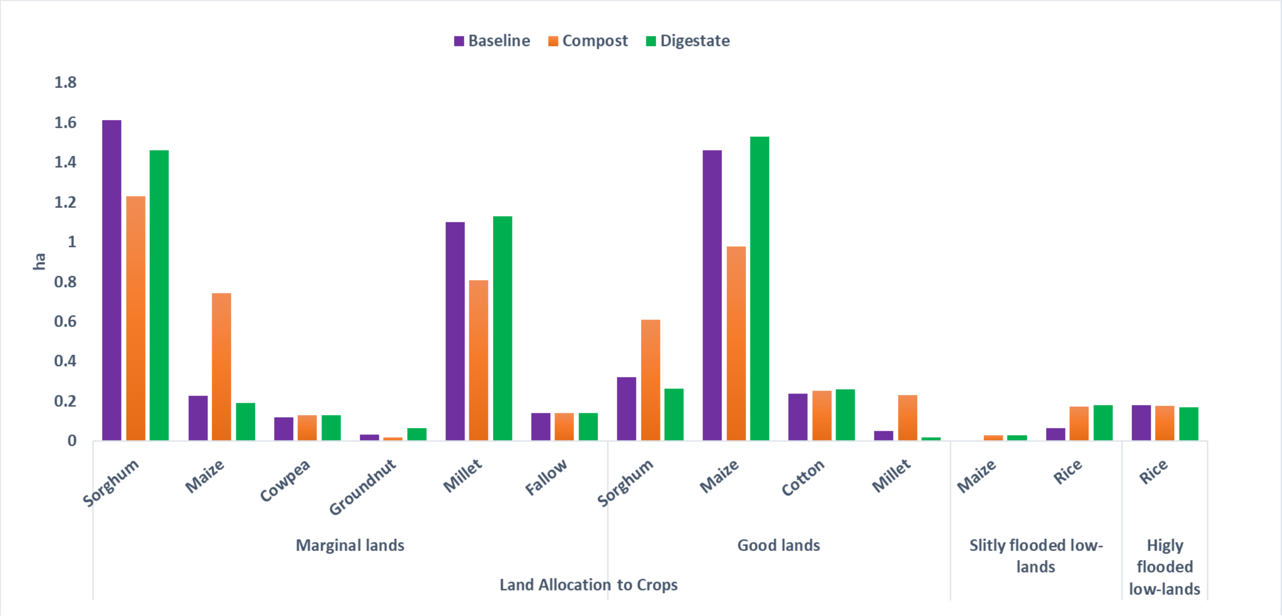

Figure 2: Comparative harvested area (all scenarios)

Both digestate and compost expanded the cultivated area for maize and rice by the same percentage, indicating similar effects on farmers' land allocation choices. The model's calibration and assumptions influenced these simulation outcomes, allowing farmers to decide how much land to allocate to maize or rice based on expected yields and profitability. Land allocation in the model responds to anticipated returns, much as in reality, and is ultimately limited by land availability. With land resources constrained by demographic pressures, farmers are unable to expand their cultivated areas. Although digestate increases yields, land constraints continue to be a limiting factor. Building a biodigester was more expensive than constructing a compost pit. To make biodigester adoption profitable, the model encouraged growing cash crops with digestate to offset costs and generate income. In a free trade scenario for agricultural markets, households could ensure food security through either market purchases or self-consumption. Food security can be maintained by prioritising cereal cultivation using compost and digestate. Digestate and compost not only secure food through maize and rice production, but also generate income from selling cotton and surplus maize and rice.

3.1.2 Household income

The household average net income during good cropping seasons was estimated at USD 766 (Figure 3a). Incomes fluctuated not only with the quality of the cropping season, but also with variations in agricultural product prices. Good cropping seasons were associated with higher incomes, while poor seasons resulted in significantly lower incomes. During bad cropping seasons, household net cash income dropped by 59%. Even though agricultural product prices tended to increase during bad years, the gains from higher prices were too small to offset yield losses. In addition, during bad cropping seasons, farmers had little grain to sell and could not benefit from higher prices.

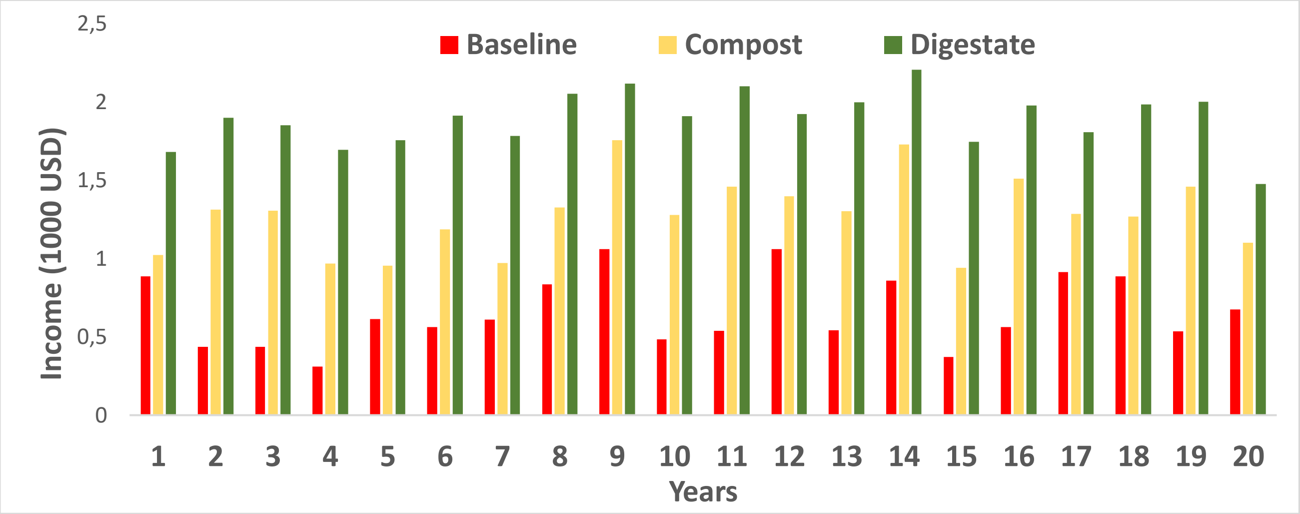

Figure 3a: Income trends (all scenarios)

This vicious cycle experienced by Sahelian farmers is well documented. In the model, grain prices were considered exogenous, but they were linked to crop yields and total production. For example, during the bad 2017 cropping season, yields and production of sorghum, maize and rice decreased by 27%, 14% and 12%, respectively, while prices rose by 38%, 46% and 31%, respectively. Households in the model prioritised their own consumption, especially for cereals such as sorghum, millet and maize; only surplus grain was sold. Cotton was the only purely cash crop and was entirely marketed. Good lands were fully used. The marginal average value of 1 ha of good soil was estimated at USD 25.22, meaning that an additional hectare would increase household income by this amount. The marginal average values of the marginal and flooded lowlands were estimated at USD 0.4 and USD 124.68, respectively.

Labour, cash and risk were limiting factors. During peak periods such as planting, weeding and harvesting, labour becomes especially scarce. The model allowed households to hire labour as long as the marginal value did not exceed the average market cost, which was USD 3. However, financial constraints made this difficult. Cash and credit were used for agricultural investment and input purchases; however, farmers were often caught in a vicious cycle of poverty and underinvestment in agriculture (Sanfo & Gérard 2012). Only cotton cultivation is heavily financed through SOFITEX, the cotton company that extends credit for seeds, fertilisers and pesticides. The system around cotton works well because production is sold entirely to SOFITEX, which deducts the credit before paying farmers. In addition, cotton is not consumable, reducing the risk of moral hazard (Bonjean *et al.* 2003). Risk was also a limiting factor, as farmers cannot afford an income that is too low, even during poor cropping seasons. For this reason, farmers grow some sorghum on good land, and particularly millet, to avoid the negative impact of droughts. Household disposable income was higher under the digestate and compost scenarios than under the baseline scenario, in which farmers operate as usual (Figure 3b).

The benefits of using digestate and compost were greater during bad cropping seasons. In these seasons, income increased by 238% and 132% with digestate and compost, respectively, while in good seasons, annual household disposable income grew by 164% and 98%, respectively. Household disposable income, as defined in the model, refers to the amount remaining after taxes, which households use for food, labour, debt repayment, and social events such as funerals, baptisms and weddings. The biodigester also supplied biogas for cooking and lighting, as reflected in the model. Maize cultivation was particularly more profitable. The area mainly grows cotton, and much of the fertiliser used for cotton is often shifted to maize farming. In addition, being close to Ghana (where maize is widely consumed) makes maize trade highly lucrative for the region. Ghana, as a neighbouring country, imports maize from Burkina Faso, creating a sales opportunity for local farmers. Farmers made rational decisions to use compost and digestate to produce more maize than other crops.

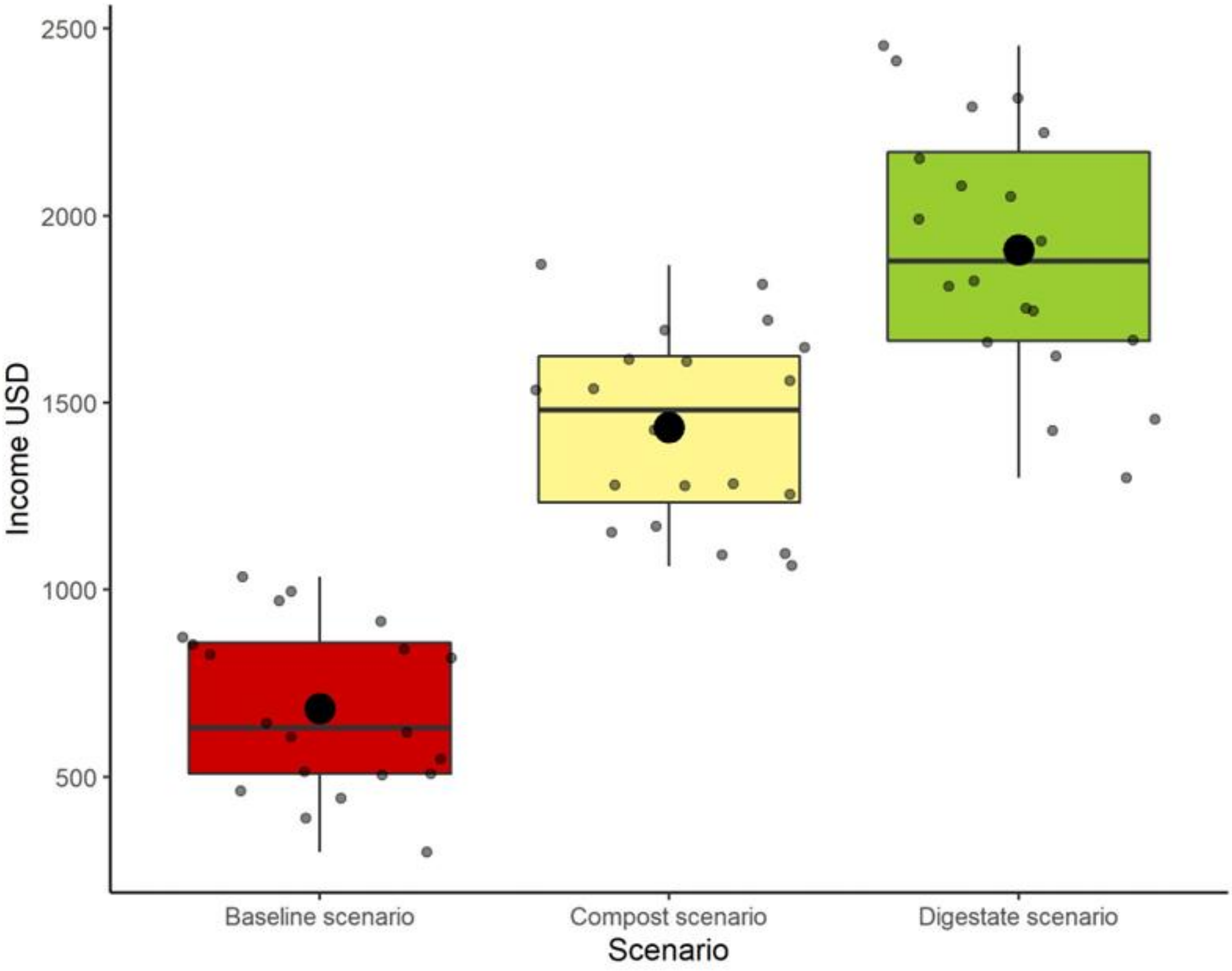

Figure 3b: Comparative household incomes (all scenarios)

Building compost pits and biodigesters requires a significant amount of time, and seasonal labour shortages remain a persistent challenge for farmers in Burkina Faso. Artisanal gold mining attracts many unemployed youth, further reducing the available agricultural workforce. For example, the marginal value of labour in land preparation, sowing, weeding and harvesting under the digestate scenario was USD 3, matching the observed daily wage rate for unskilled labour in the area. In addition, farm households face a poverty trap, and building biodigesters and compost pits would require external financial assistance or subsidised loans (Mwirigi *et al*. 2014).

Organic soil amendments, such as compost and digestate, can improve soil fertility and nutrient levels, leading to higher crop yields and increased farmers' incomes (Abdulai & Huffman 2014; Roba 2018). This results in more produce for sale, boosting sales potential and profits. Organic amendments also decrease dependence on costly chemical fertilisers and pesticides, which lowers input costs over time (Rose *et al*. 2014; Ye *et al*. 2020). Farmers can further reduce input costs and increase profit margins by using locally available digestate and compost (Zheng *et al*. 2021).

This is especially important for small-scale farmers with limited resources (Yengoh 2012). In addition, digestate and compost amendments improve soil structure and increase water retention, which enhances crop resilience to drought and reduces the risk of crop failure. However, the economic effects of digestate and compost may vary, depending on factors such as the availability of organic inputs, market demand for organic produce, access to training and resources, and the specific context of each farming system. Further research and context-specific analysis are necessary to tailor interventions and maximise economic benefits for farmers in Burkina Faso.

4. Conclusions

Southwestern Burkina Faso presents opportunities to enhance agricultural productivity, raise household incomes and improve food security. However, the region's farming system depends mainly on subsistence farming, leading to low yields. The limited application of digestate and compost for soil enrichment partly explains the decline in soil fertility and the poor harvests. These amendments offer a valuable chance to restore degraded land and increase yields and productivity. The main goal of this study was to use an optimisation modelling approach to evaluate the effect of digestate and compost on household incomes. The results indicate that the model used digestate and compost to improve poor soils and revive fallow lands. The production of maize, cotton, rice, millet and sorghum increased, often replacing groundnut and fallow fields. Gains were especially notable with digestate, which also provides benefits like lighting and biogas. During good cropping seasons, income increased by 238% with digestate and 132% with compost; during poor seasons, increases of 164% and 98% were observed, respectively. Biodigesters and compost pits are promising technologies for integrating agriculture and livestock, adapting to climate change and enhancing food security. However, addressing credit and labour constraints remains necessary.

In the face of an economic crisis and budget constraints, the government can still take steps to promote the adoption of biodigesters. Collaboration with the private sector and non-governmental organisations should be encouraged. The government could: (i) support the development of local companies focused on designing and installing biodigesters and compost pits to lower installation costs; and (ii) use data to refine policies and programmes aimed at increasing the use of digestate and compost in rural areas to maximise social benefits. More research in different agroecological zones and specific analyses are necessary to tailor interventions and maximise economic gains for farmers in Burkina Faso.

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