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Profitability of Gliricidia-Maize System in Selected Dryland Areas of Dodoma Region, Tanzania

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Abstract: Declining soil fertility and climatic extremes are among major problems for agricultural production in most dryland agro-ecologies of sub-Saharan Africa. In response, the agroforestry technology intercropping of Gliricidia (*Gliricidia sepium* (Jacq.)) and Maize (*Zea mays* L.) was developed to complement conventional soil fertility management technologies. However, diversified information on the profitability of Gliricidia-Maize intercropping system in dryland areas is scanty. Using data from the Gliricidia and maize models of the Next Generation version of the Agriculture Production Systems sIMulator (APSIM), this study estimates the profitability of the Gliricidia-Maize system relative to an unfertilized sole maize system. Results show significant heterogeneity in profitability indicators both in absolute and relative economic terms. Aggregated over a 20-year cycle, Gliricidia-Maize intercropping exhibited a higher Net Present Value (NPV = Tsh 19,238,798.43) and Benefit Cost Ratio (BCR = 4.27) than the unfertilized sole maize system. The NPV and BCR of the latter were Tsh 10,934,669.90 and 3.59, respectively. Moreover, the returns to labour per person day in the Gliricidia-Maize system was 1.5 times those of the unfertilized sole maize system. Sensitivity analysis revealed that the profitability of the Gliricidia-Maize system is more negatively affected by the decrease in output prices than the increase in input prices. A 30% decrease in the former leads to a decrease in NPV and BCR by 38% and 30%, respectively. Despite the higher initial costs of the agroforestry establishment, the 30% increase in input prices affects more disproportionally unfertilized sole maize than the Gliricidia-Maize system in absolute economic terms, i.e., 11.1% versus 8.8% decrease in NPV. In relative economic terms, an equal magnitude of change in input prices exerts the same effect on the unfertilized sole maize and the Gliricidia-maize systems. This result implies that the monetary benefits accrued after the first year of agroforestry establishment offset the initial investment costs. The Gliricidia-Maize intercropping technology therefore is profitable with time, and it can contribute to increased household income and food security. Helping farmers to overcome initial investment costs and manage agroforestry technologies well to generate additional benefits is critical for the successful scaling of the Gliricidia-Maize intercropping technology in dryland areas of Dodoma, Tanzania.

Keywords: APSIM; Gliricidia-Maize system; soil fertility; profitability; dryland areas

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1. Introduction

The sustainable productivity of field crops such as cereals and pulses in most dryland areas of sub-Saharan Africa (SSA) is limited by declining soil fertility and high vulnerability to weather and natural disasters [1–4]. Most cereal food crops such as maize are produced under low nitrogen (N) and phosphorous (P) conditions that have contributed to the yield gap of between 200% and 300% [5–8]. Additionally, maize yields are sensitive to changes in climate. For instance, earlier studies [9–11] projected that by 2050, the temperature increase of 2 °C will decrease grain yields of maize by 13% in SSA, including Tanzania.

Central to the problems of soil fertility and climatic change in SSA are the critical questions of increased human population and the sub-optimal or lack of use of mineral fertilizers [5,7]. The former has resulted in a reduction in per capita land availability, increased continuous cropping, and a breakdown of natural fallow soil fertility restoration methods [12,13]. In Tanzania, arable land per capita has dropped by 40% since 1961, from 0.5 to 0.3 ha per person, and has contributed to as high as 3.3% of annual rate of deforestation as the increased population claims more farmland (https://data.worldbank.org/indicator/AG.LND.ARBL.ZS?locations=TZ, (accessed on 16 September 2020).

The sub-optimal or lack of use of mineral fertilizers is exacerbated by low availability, high prices, and low N fertilizer use efficiency of cereal crops in drought-prone environments [4,5,12,14,15]. Although 75% of farmland is experiencing soil fertility degradation in Tanzania, as few as 3–13% of smallholder cereal food producers apply around 8% of the recommended amount of fertilizer per hectare [16,17]. The situation on fertilizer use is expected to be worsened by the adverse impact of COVID-19 on fertilizer prices as a result of fertilizer importation [8].

The use of the low-input agro-ecological technologies to improve soil fertility, adapt to climatic change, and increase crop yields has been widely promoted [12,14,18]. In response, researchers from the World Agroforestry (ICRAF) researched Gliricidia agroforestry intercropping technology in the dryland areas of Kongwa district, to inform scaling up and farmer adoption. The latter was facilitated by enhancing knowledge about Gliricidia agroforestry intercropping through farmer participation in research as learned from other researchers [19–25].

Gliricidia was chosen based on its three major strengths over other fertilizer tree species. First, a high compatibility with the maize root system because of low root density (460 cm^{-3}) on the top (0–30 cm) layer of the soil where most of the maize roots are concentrated [5,26,27]. Second, Gliricidia sprouting ability enhances long-term (>10 years) biomass production that reduces the cost of agroforestry re-establishment [5,12,27–29]. Third, Gliricidia reduces termite damage on maize [12,30,31]. Like other fertilizer tree species, Gliricidia contributes to increased soil organic matter [15,27,32], fixes atmospheric N, and improves P supply to plants [5,26], improves soil chemical, physical and biological conditions [26,33–37], and sequesters carbon to mitigate the effects of climate change [38,39].

As a strategy for agro-ecological intensification of smallholder agriculture, research experiments were conducted for six consecutive production seasons (2015–2020) to establish the effect of Gliricidia intercropping on biophysical and economic parameters. The positive impact of Gliricidia agroforestry intercropping on grain yields of maize were established [15,40]. However, despite the fact that biophysical performance provides the basis for socio-economic decisions such as adoption and scaling up, higher yields do not always translate into higher profit [41,42]. Several authors have expressed their doubt that the higher yields resulting from the adoption of improved agricultural technologies might be associated with the higher cost of production [2,12,27,42–45]. This suggests that there is a need to consider resource allocative efficiency in production.

Studies in Zambia [12] revealed the increase, up to three times, in financial returns of maize in the Gliricidia-Maize system over the unfertilized sole maize system. However, [4,40,46] argue that due to site-specific factors such as climate the effect of the improved agricultural technologies on biophysical and economic components varies with agro-ecological zones. Therefore, [47,48] recommended the consideration of context variations in developing agroforestry technologies across the wide range of farming agro-ecologies. Studies on economics of agroforestry technologies in Tanzania were limited to the assessment of financial returns of *Acacia crassicarpa* (A. Cunn. ex Benth), *Acacia jurifera (Benth),* and *Acacia leptocarpa* rotational woodlot systems [22]. According to [12,49–51], soil fertility and conservation impacts that influence the productivity and profitability of agroforestry technologies vary among fertilizer tree species and systems. This provides impetus to assess profitability of the Gliricidia-based systems in the dryland agro-ecologies of Dodoma region.

The integration of biophysical and economic models has been suggested to enhance the quantification of benefits of various agricultural technologies [45,52–55]. Simulation models such as APSIM employ an integrated farming systems approach to evaluate food security impacts, viability or otherwise, and tradeoffs of agricultural technologies such as agroforestry [8,29,42,55,56]. Several studies [8,45,57–59] used data from biophysical crop models including APSIM to assess the economic impacts of agricultural technologies.

Therefore, this paper employs data from Gliricidia and maize models of APSIM to estimate profitability of the Gliricidia-Maize system relative to the unfertilized sole maize system in the dryland agro-ecology of the Dodoma region, Tanzania. The profitability of the Gliricidia-Maize system was compared with that of the unfertilized sole maize system because the latter represents the standard farmers' practice in the study site.

The rest of the paper is organized as follows; the next section describes the theoretical and conceptual frameworks, while Section 3 presents the methodology including a description of the study site, an overview of the research experiments, data, and data analysis. Section 4 presents the results and discussion, whereas the last section draws conclusions and recommendations.

2. Theoretical and Conceptual Framework

This study anticipates that feasible agro-ecological technologies, such as Gliricidia agroforestry intercropping, are vital for addressing soil fertility and climatic change problems facing farmers in dryland areas. Farmers adopting Gliricidia agroforestry intercropping technology are likely to gain more farm income than their counterparts (Figure 1).

As learned from others [19–25], involving farmers in *on-farm testing* of technologies was important for increased *diffusion*, *adoption,* and consequently, *sustainable* implementation of best-bet soil fertility management technologies (SFM). The sustainability of SFM is achieved through setting a strong base on *welfare economics* particularly on the concept of *transaction costs in relation to productivity*. It was important to review the effect of the Gliricidia agroforestry intercropping technology on farm-level productivity and profitability as it can influence the welfare of farmers and other commodity market agents.

Several theories were considered relevant for underpinning the theoretical foundation of this study. The *theory on diffusion of innovation* was relevant as Gliricidia agroforestry intercropping is a new technology that can spread within the community. Feder et al. [60], Rogers [61], Kadigi et al. [8], and Swamila et al. [4] argue that individual farmers' adoption of improved agricultural technologies in a long-run equilibrium depends on access to full information about relative advantages. According to [45,62], a relative advantage of this technology compared to others is its short (≤5 years) and long-term (>10 years) profitability. Therefore, this paper estimates the profitability of the Gliricidia-Maize system, in both absolute and relative economic terms, to inform farmer adoption and scaling-up decisions.

Farm-level technologies such as Gliricidia agroforestry intercropping increase output and profit [15,63]. In other words, greater output is achieved given the same level of input. In this paper, input is referred to as the technological options under consideration i.e., the unfertilized sole maize and Gliricidia-Maize intercropping. Additionally, *production and profit maximization theories* were used as the base, since technical efficiencies can be improved that lead to farmers operating on a higher profit frontier function [64]. Moreover, *decision theory* was used to interpret technology choices in a variety of climatic conditions. This theory was envisaged in the simulation of yields for profit estimation that leads to informed adoption decisions. According to [29,46], a robust forecast and decision-making analysis requires the integration of climatic shocks in economic viability studies. Therefore, the current study used the APSIM simulated yields that employed historic climate and plot-level data from the agroforestry experiment in Dodoma [15].

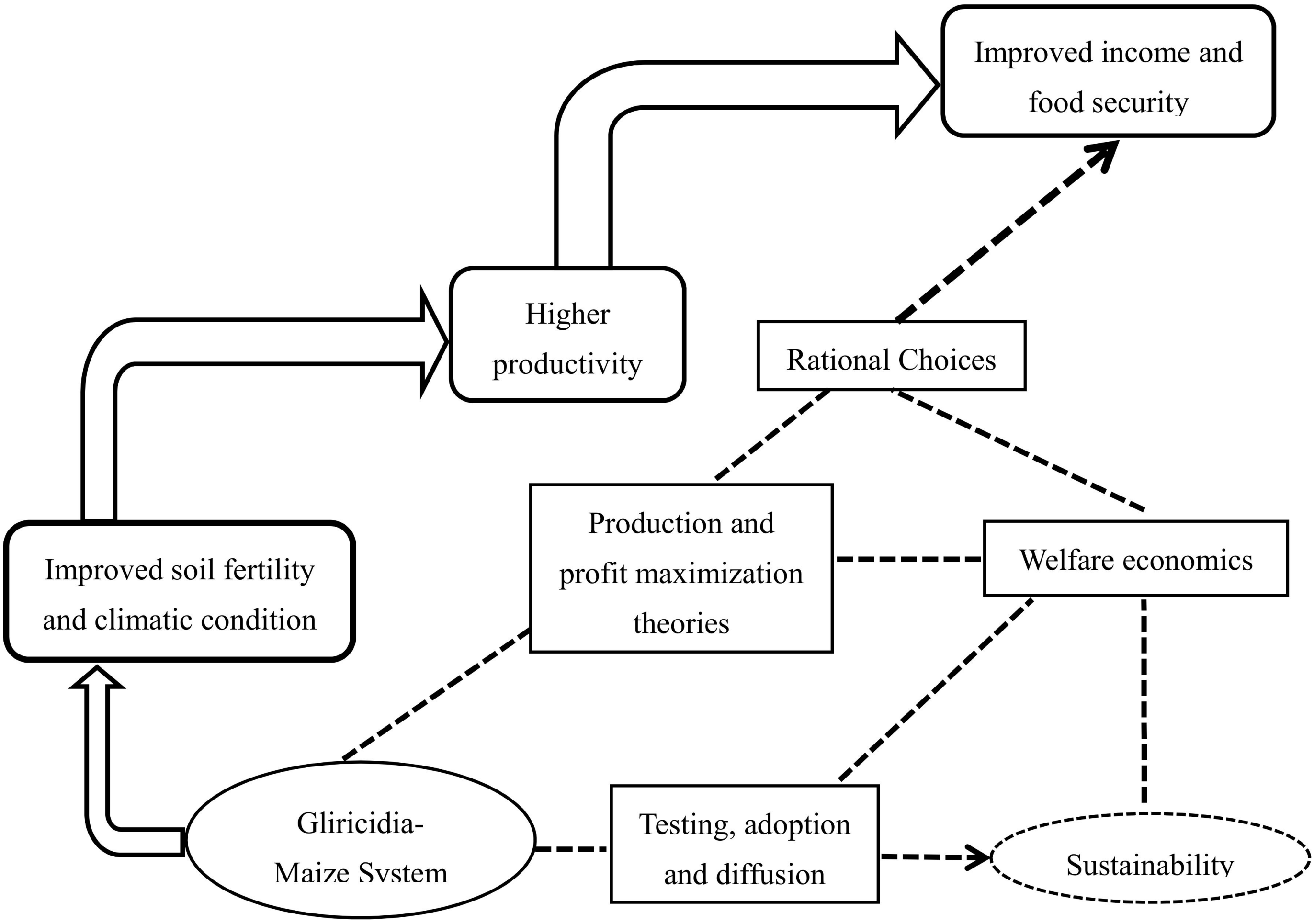

Figure 1. Conceptual and theoretical framework.

3. Methodology

3.1. Description of the Study Site

This study is part of the research conducted since 2015 on unfertilized continuously cultivated farmland in Manyusi village (5°33′56.16123″ S and 36°17′29.85319″ E, elevation 1206.6 m). The rainfall is unimodal, with a short rainy period between November and May. The mean 30-year (1989–2019) annual rainfall was 635 mm, with a dry season of between 6 and 7 months. However, the maize production season that extends from December to June has a mean rainfall of 425 mm [65]. The mean temperature is about 26.5 °C, whereas 11 °C is the minimum value.

Soil analyses conducted at the beginning of field experiments, detailed in [15], observed low levels of total N (<0.1%), Bray-1 extractable P (<7 mg kg^{-1}), and organic matter (0.54 $\pm$ 0.16) that required an integrated soil fertility management approach, including the integration of leguminous trees such as Gliricidia, to correct nutrient deficiencies and increase soil organic matter.

3.2. Overview of the Research Experiments

The original field experiments consisted of five factor combinations (sole maize, sole pigeonpea, Maize-pigeonpea, Maize-Gliricidia, and Maize-Gliricidia-Pigeonpea) described in [15]. However, based on objectives, this study is focused on the unfertilized sole maize and the Gliricidia-Maize systems. The former represents the standard farmer practice in the study site.

The treatments were arranged in a randomized complete block design (RCBD) with three replicates. The sole maize and Gliricidia-Maize treatments were randomly assigned to plots of 16 m × 16 m, separated by a 2-m-wide path. Gliricidia trees were planted at 4 m × 4 m spacing, providing a total of 25 trees per plot (625 trees ha^{-1}). Maize was sown at a spacing of 75 cm and 60 cm between and within rows, respectively, yielding 44,444 plants ha^{-1} after thinning from three to two plants per hole during the maize vegetative growth. The intercropping of maize with Gliricidia was additive, i.e., the planting density of maize was the same in Gliricidia-Maize and sole maize plots.

Farm managerial operations were conducted according to the common farmer practices to reflect field realities. For example, from the second production season (2016) onwards, Gliricidia was intensively pruned to 50 cm height twice a year during the maize cropping season to minimize above-ground competition for light and growing space. The same timing of pruning is reported in related studies in Tanzania and elsewhere in SSA [5,22,26,27]. Thereafter, the wood component of coppiced regrowth was removed at harvesting while foliage biomass was incorporated into the soil as green manure by ox-ploughing. Moreover, the most common farm implements at each study site were used, e.g., plots were clean weeded using hand hoes.

3.3. Data and Modelling Overview

This study uses two types of data. The first type is yield data (https://doi.org/10.7910/DVN/F1CNKY, (accessed on 30 September 2021) of the unfertilized sole maize and Gliricidia-maize systems simulated by using maize and Gliricidia models of the Next-Generation version of APSIM [66]. Current versions of these models are available at https://apsimnextgeneration.netlify.app/modeldocumentation/, (accessed on 17 June 2021). Procedures used to simulate yields and other biophysical parameters are described in [29]. However, before using APSIM data, simulated grain yields of maize were validated with those observed from experiments as recommended by [67]. The objective was to check the robustness, accuracy, and forecasting ability that confirm the useful functionality of maize and Gliricidia models in APSIM. Like in other studies [7,8,29], test statistics were used to compare observed and APSIM simulated yields. The results of tests failed to reject the hypothesis that the means of observed and simulated yields were statistically the same, at the 95% level of confidence.

The maize and Gliricidia models employed 5 years (2015–2019) of production data from replicated field experiments, the details of which are provided in [15]. Furthermore, experimental trials provided data on the quantity of materials and labour inputs used in production. The latter were collected for different activities each time an operation was conducted, and included information on the type of activity, duration in hours, and the number of people involved. The total time spent on the farm operation is the sum of time for all activities conducted. For example, the total time spent on planting included the time spent on digging holes and seeding. The measured time duration for each farm operation was converted into the universal standard unit of person-days ha^{-1}. In the study site, farmers worked for around 7 h per day, from 6 am to 12 pm, during the maize production season.

In addition to production data from the experiments, the maize and Gliricidia models employed data on soil parameters, historic (1985–2019) weather including daily maximum and minimum temperature (°C), rainfall (mm) and radiation (MJ m^{-2} d^{-1}), and management (plant population; dates of farm operations, i.e., planting, weeding, pruning and harvesting; spacing, and cultivars). Soil and weather data were collected from the World Soil Data Hub (ISRIC) and Climate Hazard Group Infrared Precipitation with Station data (CHIRPS), respectively, and validated with those measured in the field during the years of the research experiments.

The second type of data was input (biochemical and labour) and output (maize grain and fuel wood) prices. Material input prices were collected from the agricultural input markets at the nearby village town centres in Kibaigwa, Kongwa, and Dodoma during a survey conducted in March 2018. The prices of labour for various farm operations were obtained from key informants including agricultural officers and lead farmers.

Secondary 4-year (2015–2018) data on the price of maize were collected at the marketing department in the Kongwa district council that stores daily price data of different agricultural commodities. The price of firewood was obtained from key informants.

Table 1 presents input and output parameters used to estimate the profitability of the Gliricidia-Maize and sole maize systems.

Table 1. Input and output parameters for the Gliricidia-Maize and sole maize systems.

Variable	Parameter [a]	Source of Information
Land		
Value of land	74,140 Tsh ha^{-1}	Farmers' estimate
Labour		
Land clearing	13,500 Tsh ha^{-1}	Farmers' estimate
Ploughing	61,750 Tsh ha^{-1}	Farmers' estimate
Transplanting	15,000 Tsh ha^{-1}	Farmers' estimate
Planting in sole cropping system	37,050 Tsh ha^{-1}	Farmers' estimate
Planting in intercropping system	46,930 Tsh ha^{-1}	Farmers estimate
First weeding	24,700 Tsh ha^{-1}	Farmers' estimate
Second weeding	19,760 Tsh ha^{-1}	Farmers' estimate
Pruning of Gliricidia	40,000 Tsh ha^{-1}	Farmers' estimate
Harvesting	18,525 Tsh ha^{-1}	Farmers' estimate
Threshing	27.27 kg^{-1}	Farmers' estimate
Wage rate	5000 Tsh person day^{-1}	Farmers' estimate
Biochemicals		
Maize seeds	400 Tsh kg^{-1}	Agro-input shops
Maize seeds rate	25 kg ha^{-1}	Researchers' estimate
Gliricidia seeds	66.67 Tsh kg^{-1}	Tanzania Tree Seed Agency (TTSA)
Gliricidia seedling	500 Tsh seedling^{-1}	Farmers' estimate
Gliricidia trees rate	625 trees ha^{-1}	Researchers' estimate
Outputs		
Price of Gliricidia firewood A headload of Gliricidia firewood = 11.6 kg	2000 Tsh headload^{-1}	Farmers' estimate
Price of maize grains	375 Tsh kg^{-1}	Kongwa District Council

[a] Tsh: Tanzanian shilling (US$1 = Tsh 2037.165) (2015).

3.4. Data Analysis

Benefit Cost Analysis (BCA) was conducted using input including APSIM-simulated yields and output data. The values of inputs used and outputs under consideration were estimated at the prevailing market prices, based on literature recommendations and empirical evidence from related studies [12,22,51,68]. Labour was estimated at the prevailing wage rate for unskilled labour in the study site. Biochemical inputs including maize seeds were estimated at prices obtained from a survey of agro-input shops. The value of maize was estimated using average three-monthly prices at around harvest, that is, the average of June–August prices. This is because over 90% of smallholder maize production is either consumed or sold immediately after harvest at the study site. Sullivan et al. [49], Franzel et al. [51], Senkondo et al. [68], Gittinger [69], recommend the use of constant prices, assuming that the general inflation rate exerts the same relative effect on costs and benefits. Therefore, the average June–August prices of 2015 to 2018 were indexed to the average June–August price of 2015 to generate the relative prices. Then, the median price of maize was estimated and used in the discounting equations.

Profitability indicators i.e., NPV, BCR, and IRR (internal rate of return) were estimated using a 20-year project planning cycle. The 20 year-cycle was used because it marks the complete usefulness period of Gliricidia trees in agroforestry combinations [5,26,27]. An interest rate of 6% representing the 2015 Tanzania inflation rate, here referred to as the reference year, was used to discount the values of inputs and outputs (https://www.statista.com/statistics/447617/inflation-rate-in-tanzania/, (accessed on 18 August 2021)).

The formulas for calculating profitability indicators are presented in Equations (1)–(3). The Net Present Value is the sum of the discounted net returns over the lifetime of the project (Equation (1)). The project is considered to be viable/and or worth undertaking if the NPV is greater than or equal to zero.

The Benefit Cost Ratio is the ratio of discounted net returns to the discounted total production costs (Equation (2)). The project becomes viable with a BCR value greater than or equal to 1. The Internal Rate of Return is the discounting rate that equates the NPV to zero (Equation (3)). The Internal Rate of Return is used in small farm projects such as smallholder agroforestry for comparison with the average market interest rate [68,70].

$$NPV = \sum_{t=1}^{20} \frac{(Bt - Ct)}{(1+r)^t} \quad (1)$$

$$BCR = \sum_{t=1}^{20} \frac{Bt}{(1+r)^t} / \sum_{t=1}^{20} \frac{Ct}{(1+r)^t} \quad (2)$$

$$IRR = \sum_{t=1}^{20} \frac{Bt - Ct}{(1+r)^t} \quad (3)$$

Sensitivity analysis was conducted to assess the response of profitability indicators to changes in output and input prices, based on a 4-year (2015–2018) trend analysis that noted the fluctuating market price of maize at an average rate of 30% between seasons.

4. Results and Discussion

4.1. Grain Yields of Maize

Aggregated over six cropping seasons, the intercropping of maize with Gliricidia increased grain yields of maize by 4.4%, from 2.71 t ha^{-1} (unfertilized sole maize) to 2.83 t ha^{-1} (Gliricidia-Maize). Maximum grain yields of maize in the Gliricidia-Maize (3.73 t ha^{-1}) and the unfertilized sole maize system (3.77 t ha^{-1}) were recorded in 2015 and 2019, respectively. Minimum grain yields of maize of 1.49 t ha^{-1} and 1.31 t ha^{-1} for the Gliricidia-Maize and the unfertilized sole maize systems, respectively, were recorded in 2017. A significant difference ($p < 0.05$) in the grain yield of maize was observed in 2019, with the unfertilized sole maize system producing higher grain yields of maize (3.77 t ha^{-1}) than those (3.2 t ha^{-1}) in the Gliricidia-Maize system (Figure 2).

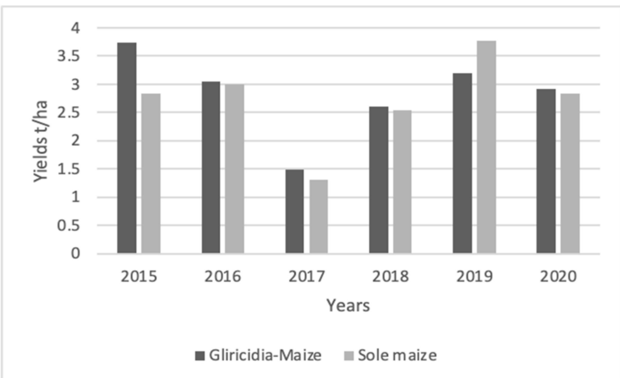

Figure 2. Observed grain yields of maize.

Not surprisingly, these results indicate no significant effect of Gliricidia on the grain yields of maize during the first six years of the Gliricidia-Maize intercropping. These results coincide with the rates reported, ranging from 0% (Year 0–1) to around 4% (by year 6) in [49] for the annual increment in yields in agroforestry-based systems. According to studies in Zambia, Kenya, and Malawi [12,27,29], it takes more than 5 years for a significant yield advantage of Gliricidia to develop over other conventional soil fertility management technologies. Makumba et al. [27] and Smethurst et al. [29] noted the significant increase in the grain yields of maize during 11 years of simultaneous intercropping of maize with Gliricidia.

The small yield advantage of Gliricidia during the first six years of agroforestry may be associated with two main inter-linked factors. The first factor is the low Gliricidia biomass production during the early years of Gliricidia-Maize intercropping. There is evidence of a strong correlation (r = 0.91, $p < 0.001$) between the years of tree establishment, biomass production, and yields in the Gliricidia-based systems [27]. The second factor is rainfall distribution during a particular growing season [5], which may explain why the lowest grain yields of maize were recorded in 2017 when as little as 150 mm of rainfall was recorded during planting in December/January. The low rainfall might have affected the decomposition of Gliricidia prunings incorporated into the soil one week before planting. Makumba et al. [27] argue that annual rainfall of less than 600 mm leads to slow decomposition of pruning materials and low N fertilizer equivalent of Gliricidia. Furthermore, a high rainfall (>1200 mm) can lead to waterlogging, leaching, high emissions of N, and consequently, a low N fertilizer equivalent of Gliricidia.

Average grain yields (2.71 t ha^{-1}) of the unfertilized sole maize system were 80% to 171% over the reported productivity indices under de facto farmer practice, but 47.6% to 56.1% below the established maize productivity potential [4–4.4.5 t ha^{-1}; 6,8]. The increase in sole maize yields may be associated with the researcher-designed farmer-managed (RDFM) type of research trials used, in which researchers establish the plot layout and closely supervise farm operations. The latter observed good agronomic practices including improved planting density i.e., 44,444 plants ha^{-1} versus the reported farmer's average planting density of 20,000 plants ha^{-1} [8]. According to [51], the results of RDFM trials present farmer productivity potential in contrast with that commonly attained.

However, as noted in earlier empirical studies [5,27], grain yields of maize in the unfertilized sole system are expected to decline over time following the continual uptake of soil nutrients by plants upon harvesting without the amendment of soil fertility.

In addition to increasing grain yields of maize, Gliricidia supply firewood to supplement household cooking energy. In our study, an average of 1.81 t ha^{-1} of firewood was produced in the Gliricidia-Maize system from 2016 to 2020.

4.2. Benefit Cost Analysis Results

The results in Table 2 show the variable profitability indicators among the Gliricidia-Maize and the sole maize systems. Aggregated over the 20-year cycle, the NPV of the Gliricidia-Maize system was 1.8 times that of the unfertilized sole maize system. In relative economic terms, the returns to investment (BCR) followed a similar pattern, and ranged from 4.27 (Gliricidia-Maize) to 3.59 (unfertilized sole maize). Moreover, the Gliricidia-Maize system exhibited a higher IRR (90%) than that of the unfertilized sole maize system (58%). Average net returns to labour per person day ranged from 9038 Tsh ha^{-1} (unfertilized sole maize) to 13,323.89 Ts ha^{-1} (Gliricidia-Maize), which is between 1.8 and 2.7 times the opportunity cost of labour in the study site.

Table 2. The financial profitability of a 20-year cycle of the Gliricidia-Maize and unfertilized sole maize systems.

System	NPV (Tsh ha^{-1})	BCR	IRR (%)	Returns to Labour (Tsh ha^{-1} d^{-1})
Maize-Gliricidia	19,238,798.43	4.27	90	13,323.89
Sole maize	10,934,669.90	3.59	58	9038.00

These results suggest that the intercropping of maize with Gliricidia is more profitable than the unfertilized sole maize system. The relative higher profit of the Gliricidia-Maize system may be associated with two main factors. The first factor is the proportionate increase in crop and tree yields and, revenue as Gliricidia ages [27]. The second factor is the decreasing trend in the cost of inputs including labour and tree seedlings. The present value (PV) of the cost of year 1 is 13.31 times that of year 20. Likewise, earlier studies by [12,19,22] noted the higher cost of production during the first year compared to subsequent years due to additional costs of nursery establishment and transplanting of Gliricidia seedlings. Over time, the cost incurred in maintaining Gliricidia trees only includes the cost of labour for the pruning of Gliricidia, which involves the removal of leaves from branches to establish wood stakes and the application of leaves to the soil as green manure. In year 20, the average revenue of the Gliricidia-Maize system is 156% over that of the unfertilized sole maize system with only a 6% increase in the cost of production. According to [51], the low profitability of the continuous sole cropping systems favours the adoption of the agroforestry-based technologies.

Likewise, studies in Eastern Zambia by [12] reported higher values of profitability indicators in the agroforestry-based systems ranging from US$233 to US$327 ha^{-1} (NPV) and 2.77–3.13 (BCR) in contrast with NPV and BCR of US$130 and 2.01, respectively, exhibited by the unfertilized sole maize system. However, these results show that the impact of Gliricidia-Maize intercropping on NPV at Dodoma is lower than that found in Eastern Zambia with only 5 years of analysis. This is most likely due to climatic variation between the two sites, i.e., average seasonal rainfall of 1000 mm in Eastern Zambia versus 634 mm at Kongwa, Dodoma. The amount of rainfall determines the tree density, decomposition of pruning materials, and consequently, yields and revenue of the Gliricidia-Maize system [5,27]. Like NPV, the impact of Gliricidia-Maize intercropping on BCR is higher in Eastern Zambia than Dodoma sites (54% versus 39% increase of BCR).

4.3. Sensitivity Analysis

Table 3 shows the NPV and BCR of the Gliricidia-Maize system are more sensitive to the decrease in output than the increase in input prices. The 30% decrease in the former decreased NPV by 38%, from Tsh 19,238,798.43 to Tsh 11,779,186.49 ha^{-1}. In contrast, NPV declined by 8.8% following an equivalent percentage increase in input prices.

Table 3. Sensitivity analysis of Sole Maize and Gliricidia-Maize systems.

	Profitability Indicators		**Absolute Difference**	
	NPV (Tsh ha^{-1})	**BCR**	**NPV (Tsh ha^{-1})**	**BCR**
Gliricidia-Maize system				
30% increase in input prices	17,550,826.02	3.28	1,688,000	0.99
30% decrease in output prices	11,779,186.49	2.99	7,459,612	1.28
Sole maize system				
30% increase in input prices	9,721,596.48	2.76	1,213,073	0.83
30% decrease in output prices	6,441,195.51	2.51	4,493,474	1.08

Similarly, BCR declined by 30% and 23.2% with the equivalent percentage decrease and increase in output and input prices, respectively. This trend most likely reflects the increased number and quantity of outputs over time in agroforestry systems, giving low values of NPV and BCR upon discounting. In year 1, the maize grain yield was the only output in the Gliricidia-Maize system. From year 2 onwards, Gliricidia trees are pruned to produce firewood and foliage biomass as additional products in this system, leading to the increase in quantity of outputs over time. The latter is either incorporated into the soil as the green manure (as in this study) or used as feed for livestock. Similarly, [22] observed the high sensitivity of profitability performance indicators to changes in output prices in agroforestry systems, and they recommend the choice of tree species that produce sufficient output(s) such as biomass in the early years of agroforestry projects.

Despite the higher costs of agroforestry establishment, the increase in input prices affected more disproportionally the unfertilized sole maize than the Gliricidia-Maize system (11.1% in contrast to 8.8% decrease in NPV). This contrast might be due to the elimination of tree-related costs such as nursery establishment after the first year of agroforestry establishment. Additionally, the benefits accrued overtime in the Gliricidia-Maize system offset the initial investment costs.

5. Conclusions and Recommendations

This paper presents a new approach of integrating a biophysical model with an economic analysis of an agroforestry-based system. This integrated assessment enhances the quantification of benefits of agricultural technologies including agroforestry that improves decision making for policy makers, development practitioners and farmers.

We estimated the profitability of the Gliricidia-Maize system in relation to the unfertilized sole maize system to inform scaling up and farmer adoption. Benefit cost analysis showed the net worth of the Gliricidia-Maize system is 75.9% higher than that of the unfertilized sole maize system.

Sensitivity analysis results indicated that the profitability of the Gliricidia-Maize system is more sensitive to changes in output than input prices. Despite higher initial costs of agroforestry establishment, the increase in input prices affects more disproportionally the unfertilized sole maize than the Gliricidia-Maize system in absolute profitability terms.

These results suggest that Gliricidia-Maize intercropping technology can be promoted to improve soil fertility and food security and, to mitigate negative effects of climate change as it also improves the income of smallholder and subsistent farmers.

Therefore, this paper recommends the scaling up of Gliricidia-Maize intercropping technology among other farmers in the dryland areas of Dodoma region, Tanzania. Higher initial investment costs could deter farmers to adopt the technology, but sensitivity analysis results suggest this cost is offset with time when additional outputs (firewood and foliage biomass) from agroforestry are produced and factored in to the profitability assessment. Development practitioners need to disseminate this information to farmers, and policy makers to make informed decisions to support technology scaling in dryland areas.

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References

1. Sanchez, P.A. Soil fertility and hunger in Africa. *Science* **2002**, *295*, 2019–2020. [CrossRef] [PubMed]
2. Vanlauwe, B.; Giller, K.E. Popular myths around soil fertility management in sub-Saharan Africa. *Agric. Ecosyst. Environ.* **2006**, *116*, 34–46. [CrossRef]
3. Coulibaly, J.Y.; Mango, J.; Swamila, M.; Tall, A.; Kaur, H.; Hansen, J. *What Climate Services Do Farmers and Pastoralists Need in Tanzania? CCAFS Working Paper*; CCAFS: Copenhagen, Denmark, 2015.
4. Swamila, M.; Philip, D.; Akyoo, A.M.; Sieber, S.; Bekunda, M.; Kimaro, A.A. Gliricidia agroforestry technology adoption potential in selected dryland areas of Dodoma region, Tanzania. *Agriculture* **2020**, *10*, 306. [CrossRef]
5. Akinnifesi, F.K.; Makumba, W.; Sileshi, G.; Ajayi, O.C.; Mweta, D. Synergistic effect of inorganic N and P fertilizers and organic inputs from Gliricidia sepium on productivity of intercropped maize in Southern Malawi. *Plant Soil* **2007**, *294*, 203–217.
6. Kimaro, A.A.; Weldesemayat, S.G.; Mpanda, M.; Swai, E.; Kayeye, H.; Nyoka, B.I.; Majule, A.E.; Perfect, J.; Kundhlande, G. Evidence-Based Scaling-Up of Evergreen Agriculture for Increasing Crop Productivity, Fodder Supply and, Resilience of the Maize-Mixed and Agro-Pastoral Farming Systems in Tanzania and Malawi. In Project Reports, Studies and Working Papers. 2012. Available online: https://cgspace.cgiar.org/bitstream/handle/10568/69125/ar_esa_evergreen.pdf?sequence=1 (accessed on 10 May 2018).
7. Mwinuka, L.; Mutabazi, K.D.; Graef, F.; Sieber, S.; Makindara, J.; Kimaro, A.; Uckert, G. Simulated willingness of farmers to adopt fertilizer micro-dosing and rainwater harvesting technologies in semi-arid and sub-humid farming systems in Tanzania. *Food Secur.* **2017**, *9*, 1237–1253. [CrossRef]
8. Kadigi, I.L.; Richardson, J.W.; Mutabazi, K.D.; Philip, D.; Mourice, S.K.; Mbungu, W.; Bizimana, J.C.; Sieber, S. The effect of nitrogen-fertilizer and optimal plant population on the profitability of maize plots in the Wami River sub-basin, Tanzania: A bio-economic simulation approach. *Agric. Syst.* **2020**, *185*, 102948. [CrossRef] [PubMed]
9. Waithaka, M.; Nelson, G.C.; Thomas, T.S.; Kyotalimye, M. (Eds.) *East African Agriculture and Climate Change: A Comprehensive Analysis*; International Food Policy Research Institute (IFPRI): Washington, DC, USA, 2013. [CrossRef]
10. URT—The United Republic of Tanzania. Ministry of Agriculture, Food Security, and Cooperatives: Agriculture Climate Resilience Plan 2014–2019. 2014. Available online: http://extwprlegs1.fao.org/docs/pdf/tan152483.pdf (accessed on 10 April 2021).
11. Bucagu, C.; Turinzwenayo, F.; Ndoli, A.; Nabahungu, N.L.; Mukuralinda, A.; Smethurst, P. Determining and managing maize yield gaps in Rwanda. *Food Secur.* **2020**, *12*, 1269–1282. [CrossRef]
12. Ajayi, O.C.; Akinnifesi, F.K.; Sileshi, G.; Kanjipite, W. Labour inputs and financial profitability of conventional and agroforestry-based soil fertility management practices in Zambia. *Agrekon* **2009**, *48*, 276–292. [CrossRef]
13. Turinawe, A.; Drake, L.; Mugisha, J. Adoption intensity of soil and water conservation technologies: A case of South Western Uganda. *Environ. Dev. Sustain.* **2015**, *17*, 711–730. [CrossRef]
14. Mwinuka, L.; Mutabazi, K.D.; Makindara, J.; Sieber, S. Reckoning the risks and rewards of fertilizer micro-dosing in a sub-humid farming system inTanzania. *Afr. J. Sci. Technol. Innov. Dev.* **2016**, *8*, 497–508. [CrossRef] [PubMed]
15. Renwick, L.L.; Kimaro, A.A.; Hafner, J.M.; Rosenstock, T.S.; Gaudin, A. Maize-pigeonpea intercropping outperforms monocultures under drought. *Front. Sustain. Food Syst.* **2020**, *4*, 253. [CrossRef]
16. World Bank. Fertilizer Kilograms per Hectare. 2014. Available online: https:$\backslash$data.worldbank.org/indicator/AG.CON.FERT.ZS (accessed on 12 September 2020).
17. Tumbo, S.D.; Mutabazi, K.D.; Mourice, S.K.; Msongaleli, B.M.; Wambura, F.J.; Mzirai, O.B.; Kadigi, I.L.; Kahimba, F.C.; Mlonganile, P.; Ngongolo, H.K.; et al. Assessment of climate change impacts and adaptation in agriculture: The case study of the wami river sub-basin, Tanzania. In *Climate Variability and Change in Africa*; Springer: Cham, Switzerland, 2020; pp. 115–136.
18. Graef, F.; Schneider, I.; Fasse, A.; Germer, J.U.; Gevorgyan, E.; Haule, F.; Hoffmann, H.; Kahimba, F.C.; Kashaga, L.; Kissoly, L.; et al. Natural resource management and crop production strategies to improve regional food systems in Tanzania. *Outlook Agric.* **2015**, *44*, 159–167. [CrossRef]
19. Swinkels, R.A.; Franzel, S.; Shepherd, K.D.; Ohlsson, E.; Ndufa, J.K. The economics of short rotation improved fallows: Evidence from areas of high population density in western Kenya. *Agric. Syst.* **1997**, *55*, 99–121. [CrossRef]
20. Ayuk, E.T.; Duguma, B.; Kengue, J.; Mollet, M.; Tiki-Manga, T.; Zenkeng, P. Uses, management and economic potential of Irvingia gabonensis in the humid lowlands of Cameroon. *For. Ecol. Manag.* **1999**, *113*, 1–9. [CrossRef]
21. Wambugu, C.; Franzel, S.; Tuwei, P.; Karanja, G. Scaling up the use of fodder shrubs in central Kenya. *Dev. Pract.* **2001**, *11*, 487–494. [CrossRef]
22. Ramadhani, T.; Otsyina, R.; Franzel, S. Improving household incomes and reducing deforestation using rotational woodlots in Tabora district, Tanzania. *Agric. Ecosyst. Environ.* **2002**, *89*, 229–239. [CrossRef]
23. Franzel, S.; Wambugu, C.; Tuwei, P.K. *The Adoption and Dissemination of Fodder Shrubs in Central Kenya*; ODI: London, UK, 2003.

24. Horne, P.; Stür, W.W. *Developing Agricultural Solutions with Smallholder Farmers: How to Get Started with Participatory Approaches*; ACIAR: Canberra, Australia, 2003.
25. Shelton, H.M.; Franzel, S.; Peters, M. Adoption of tropical legume technology around the world: Analysis of success. In *Grassland: A Global Resource*; McGilloway, D.A., Ed.; Wageningen Academic Publishers: Wageningen, The Netherlands, 2005; pp. 149–166.
26. Akinnifesi, F.K.; Makumba, W.; Kwesiga, F.R. Sustainable maize production using gliricidia/maize intercropping in southern Malawi. *Exp. Agric.* **2006**, *42*, 441–457. [CrossRef]
27. Makumba, W.; Janssen, B.; Oenema, O.; Akinnifesi, F.K.; Mweta, D.; Kwesiga, F. The long-term effects of a gliricidia–maize intercropping system in Southern Malawi, on gliricidia and maize yields, and soil properties. *Agric. Ecosyst. Environ.* **2006**, *116*, 85–92. [CrossRef]
28. Ajayi, A.T.; Buhari, L.O. Methods of conflict resolution in African traditional society. *Afr. Res. Rev.* **2014**, *8*, 138–157. [CrossRef]
29. Smethurst, P.J.; Huth, N.I.; Masikati, P.; Sileshi, G.W.; Akinnifesi, F.K.; Wilson, J.; Sinclair, F. Accurate crop yield predictions from modelling tree-crop interactions in gliricidia-maize agroforestry. *Agric. Syst.* **2017**, *155*, 70–77. [CrossRef]
30. Sileshi, G.; Mafongoya, P.L.; Kwesiga, F.; Nkunika, P. Termite damage to maize grown in agroforestry systems, traditional fallows and monoculture on nitrogen-limited soils in eastern Zambia. *Agric. For. Entomol.* **2005**, *7*, 61–69. [CrossRef]
31. Sileshi, G.; Mafongoya, P.L. Long-term effects of improved legume fallows on soil invertebrate macrofauna and maize yield in eastern Zambia. *Agric. Ecosyst. Environ.* **2006**, *115*, 69–78. [CrossRef]
32. Chikusie-Chirwa, P.W. Water and Nitrogen Dynamics in Gliricidia Sepium/Pigeonpea/Maize Systems in Southern Malawi. Ph.D. Thesis, University of Nottingham, Nottingham, UK, 2002.
33. Kwesiga, F.; Akinnifesi, F.K.; Mafongoya, P.L.; McDermott, M.H.; Agumya, A. Agroforestry research and development in southern Africa during the 1990s: Review and challenges ahead. *Agrofor. Syst.* **2003**, *59*, 173–186. [CrossRef]
34. Phiri, E.; Verplancke, H.; Kwesiga, F.; Mafongoya, P. Water balance and maize yield following improved sesbania fallow in eastern Zambia. *Agrofor. Syst.* **2003**, *59*, 197–205. [CrossRef]
35. Akinnifesi, F.K.; Sileshi, G.; Ajayi, O.C.; Chirwa, P.W.; Kwesiga, F.R.; Harawa, R. Contributions of agroforestry research and development to livelihood of smallholder farmers in Southern Africa: 2. Fruit, medicinal, fuelwood and fodder tree systems. *Agric. J.* **2008**, *3*, 76–88.
36. Mafongoya, P.L.; Kuntashula, E.; Sileshi, G. Managing soil fertility and nutrient cycles through fertilizer trees in southern Africa. In *Chapter 19 Biological Approaches to Sustainable Soil Systems*; Uphoff, N., Ball, A.S., Fernes, E., Herren, H., Husson, O., Liang, M., Palm, C., Pretty, J., Sanchez, P., Sanginga, N., Eds.; Taylor & Francis: New York, NY, USA, 2006; pp. 273–289.
37. Sileshi, G.W.; Akinnifesi, F.K.; Ajayi, O.C.; Muys, B. Integration of legume trees in maize-based cropping systems improves rainfall use efficiency and crop yield stability. *Agric. Water Manag.* **2011**, *98*, 1364–1372. [CrossRef]
38. Makumba, W.; Akinnifesi, F.K.; Janssen, B.; Oenema, O. Long-term impact of a gliricidia-maize intercropping system on carbon sequestration in southern Malawi. *Agric. Ecosyst. Environ.* **2007**, *118*, 237–243. [CrossRef]
39. Kaonga, M.L.; Bayliss-Smith, T.P. Carbon pools in tree biomass and the soil in improved fallows in eastern Zambia. *Agrofor. Syst.* **2009**, *76*, 37–51. [CrossRef]
40. Kimaro, A.A.; Jonas, E.; Swai, E.; Rubanza, C.; Martha, S.; Ganga Rao, N.V.P.R.; Okori, P. Gliricidia-Based Doubled Up Legume for Improving Crop Production and Agroecosystem Resilience in Kongwa and Kiteto Districts, Dokumen 2017. Available online: https://dokumen.tips/science/gliricidia-based-doubled-uplegume-for-improving-crops-production-and-agroecosystem.html (accessed on 13 December 2019).
41. Van Noordwijk, M.; Lusiana, B. WaNuLCAS, a model of water, nutrient and light capture in agroforestry systems. In *Agroforestry for Sustainable Land-Use Fundamental Research and Modelling with Emphasis on Temperate and Mediterranean Applications*; Springer: Dordrecht, The Netherlands, 1999; pp. 217–242.
42. Keating, B.; Carberry, P.; Thomas, S.; Clark, J. Chapter 2: Eco-efficient agriculture and climate change: Conceptual foundations and frameworks. In *Eco-Efficiency: From Vision to Reality (Issues in Tropical Agriculture Series)*; Hershey, C.H., Neate, P., Eds.; Centro Internacional de Agricultura Tropical (CIAT): Cali, CO, USA, 2013; pp. 19–28, (CIAT Publication No. 381); ISBN 978-958-694-118-1.
43. Adesina, A.A.; Mbila, D.; Nkamleu, G.B.; Endamana, D. Econometric analysis of the determinants of adoption of alley farming by farmers in the forest zone of southwest Cameroon. *Agric. Ecosyst. Environ.* **2020**, *80*, 255–265. [CrossRef]
44. Haggblade, S.; Tembo, G.; Donovan, C. Household level financial incentives to adoption of conservation agricultural technologies in Africa. *AgEcon Search* **2004**. [CrossRef]
45. Monjardino, M.; Philp, J.N.M.; Kuehne, G.; Phimphachanhvongsod, V.; Sihathep, V.; Denton, M.D. Quantifying the value of adopting a post-rice legume crop to intensify mixed smallholder farms in Southeast Asia. *Agric. Syst.* **2020**, *177*, 102690. [CrossRef]
46. McDonald, C.K.; MacLeod, N.D.; Lisson, S.; Corfield, J.P. The Integrated Analysis Tool (Iat)–A model for the evaluation of crop-livestock and socio-economic interventions in smallholder farming systems. *Agric. Syst.* **2019**, *176*, 102659. [CrossRef]
47. Ajayi, O.C.; Akinnifesi, F.K.; Sileshi, G.; Chakeredza, S. Adoption of renewable soil fertility replenishment technologies in the southern African region: Lessons learnt and the way forward. In *Natural Resources Forum*; Blackwell Publishing Ltd.: Oxford, UK, 2007; Volume 31, pp. 306–317.
48. Coe, R.; Sinclair, F.; Barrios, E. Scaling up agroforestry requires research 'in'rather than 'for' development. *Curr. Opin. Environ. Sustain.* **2014**, *6*, 73–77. [CrossRef]
49. Sullivan, G.M.; Susan, M.H.; Jefferson, M.F. (Eds.) Financial and Economic Analyses of Agroforestry Systems. In Proceedings of the A Workshop Held in Honolulu, Honolulu, HI, USA, July 1991; Nitrogen Fixing Tree Association: Paia, IL, USA, 1992.

50. Akyeampong, E.; Duguma, B.; Heineman, A.M.; Kamara, C.S.; Kiepe, P.; Kwesiga, F.; Ong, C.K.; Otieno, H.J.; Rao, M.R. A synthesis of ICRAF's research on alley cropping. In *Alley Farming Research and Development*; Kang, B.T., Osiname, A.O., Larbi, A., Eds.; IITA: Ibadan, Nigeria, 1995; pp. 40–51.
51. Franzel, S. Financial analysis of agroforestry practices. In *Valuing Agroforestry Systems*; Springer: Dordrecht, The Netherlands, 2004; pp. 9–37.
52. Thompson, H.E.; Berrang-Ford, L.; Ford, J.D. Climate change and food security in sub-Saharan Africa: A systematic literature review. *Sustainability* **2010**, *2*, 2719–2733. [CrossRef]
53. White, J.W.; Hoogenboom, G.; Kimball, B.A.; Wall, G.W. Methodologies for simulating impacts of climate change on crop production. *Field Crop. Res.* **2011**, *124*, 357–368. [CrossRef]
54. Kahimba, F.C.; Sife, A.S.; Maliondo, S.M.S.; Mpeta, E.J.; Olson, J. Climate change and food security in Tanzania: Analysis of current knowledge and research gaps. *Tanzan. J. Agric. Sci.* **2015**, *14*, 21–33.
55. Rosenzweig, C.; Jones, J.; Antle, J.; Hatfield, J. Protocols for AgMIP Regional Integrated Assessments, Version 6.0. 2015. Available online: http://www.agmip.org/wp-content/uploads/2015/09/AgMIP-RIA-Protocols-V6sm.pdf (accessed on 30 June 2020).
56. Lisson, S.; MacLeod, N.; McDonald, C.; Corfield, J.; Pengelly, B.; Wirajaswadi, L.; Rahman, R.; Bahar, S.; Padjung, R.; Razak, N.; et al. participatory, farming systems approach to improving Bali cattle production in the smallholder crop–livestock systems of Eastern Indonesia. *Agric. Syst.* **2010**, *103*, 486–497. [CrossRef]
57. Thornton, P.K.; Herrero, M. Integrated crop–livestock simulation models for scenario analysis and impact assessment. *Agric. Syst.* **2001**, *70*, 581–602. [CrossRef]
58. Herrero, M.; González-Estrada, E.; Thornton, P.K.; Quirós, C.; Waithaka, M.M.; Ruiz, R.; Hoogenboom, G. IMPACT: Generic household-level databases and diagnostics tools for integrated crop-livestock systems analysis. *Agric. Syst.* **2007**, *92*, 240–265. [CrossRef]
59. Shalander, K.; Sravya, M.; Pramanik, S.; DakshinaMurthy, K.; Balaji Naik, B.; Samuel, J.; Prestwich, D.; Whitbread, A. Potential for enhancing farmer income in semi-arid Telangana: A multi-model systems approach. *Agric. Econ. Res. Rev.* **2017**, *30*, 300.
60. Feder, G.; Just, R.E.; Zilberman, D. Adoption of agricultural innovations in developing countries: A survey. *Econ. Dev. Cult. Chang.* **1985**, *33*, 255–298. [CrossRef]
61. Rogers, E.M. *Diffusion of Innovations*; Free Press: New York, NY, USA, 2003; p. 551.
62. Kuehne, G.; Llewellyn, R.; Pannell, D.; Ouzman, J.; Wilkinson, R.; Dolling, P. *ADOPT: The Adoption and Diffusion Outcome Prediction Tool—Smallholder Beta Version (Beta Version, June 2013)*; Computer software; CSIRO: Canberra, Australia, 2020.
63. Pfister, F.; Bader, H.P.; Scheidegger, R.; Baccini, P. Dynamic modelling of resource management for farming systems. *Agric. Syst.* **2005**, *86*, 1–28. [CrossRef]
64. Shideed, K.H.; El Mourid, M. Adoption and impact assessment of improved technologies in crop and livestock production systems in the WANA region. In *The Development of Integrated Crop/Livestock Production in Low Rainfall Areas of Mashreq and Maghreb Regions (Mashreq/Maghreb Project)*; ICARDA: Aleppo, Syria, 2005.
65. Shemsanga, C.; Muzuka, A.N.N.; Martz, L.W.; Komakech, H.C.; Omambia, A.N. Statistics in climate variability, dry spells, and implications for local livelihoods in semiarid regions of Tanzania: The way forward. In *Handbook of 715 Climate Change Mitigation and Adaptation*, 2nd ed.; Chen, W.Y., Suzuki, T., Lackner, M., Eds.; Springer: Berlin, Germany, 2016; pp. 801–848. [CrossRef]
66. Holzworth, D.; Huth, N.I.; Fainges, J.; Brown, H.; Zurcher, E.; Cichota, R.; Verral, S.; Herrmann, N.I.; Zheng, B.; Snow, V. APSIM Next Generation: Overcoming challenges in modernising a farming systems model. *Environ. Model. Softw.* **2018**, *103*, 43–51. [CrossRef]
67. Yang, J.M.; Yang, J.Y.; Liu, S.; Hoogenboom, G. An evaluation of the statistical methods for testing the performance of crop models with observed data. *Agric. Syst.* **2014**, *127*, 81–89. [CrossRef]
68. Senkondo, E.M.M.; Msangi, A.S.K.; Xavery, P.; Lazaro, E.A.; Hatibu, N. Profitability of rainwater harvesting for agricultural production in selected semi-arid areas of Tanzania. *J. Appl. Irrig. Sci.* **2004**, *39*, 65–81.
69. Gittinger, J.P. *Economic Analysis of Agricultural Projects*, 2nd ed.; John Hopkins University Press: Baltimore, MD, USA, 1982.
70. Kunze, D. Economic assessment of water harvesting techniques: A demonstration of various methods. *Q. J. Int. Agric.* **2000**, *39*, 69–91.