land

Article

African Forest-Fringe Farmers Benefit from Modern Farming Practices despite High Environmental Impacts

Emmanuel Opoku Acheampong [1,*], Sean Sloan [1,2], Jeffrey Sayer [3] and Colin J. Macgregor [1]

1 Division of Tropical Environments and Societies, College of Science and Engineering, James Cook University, Smithfield, QLD 4878, Australia; sean.sloan@viu.ca (S.S.); colin.macgregor@jcu.edu.au (C.J.M.)
2 Department of Geography, Vancouver Island University, 900 Fifth Street, Nanaimo, BC V9R 5S5, Canada
3 Faculty of Forestry, Forest and Conservation Sciences, Forest Sciences Center, University of British Columbia, 2424 Main Mall, Vancouver, BC V6T 1Z4, Canada; jeffrey.sayer@ubc.ca
* Correspondence: emmanuel.acheampong@jcu.edu.au

Abstract: Agricultural expansion has led to a significant loss of habitat and biodiversity in Ghana and throughout West Africa and the tropics generally. Most farmers adopt both organic and inorganic inputs to boost production, with the potential to slow agricultural expansion, but with relatively little consideration of related environmental impacts. In Ghana, where high-input modern farming is rapidly overtaking traditional organic agricultural practices, we examined five stakeholder groups in regard to their perceptions of the environmental, economic, and social costs and benefits of modern, mixed-input, and traditional farming systems. The stakeholder groups included farmers adopting different agricultural practices, as well as governmental and non-governmental natural resource managers. Our findings indicate that the overall perceived costs of modern farming, attributable to large quantities of inorganic inputs, are higher than the overall perceived benefits. Farmers are, however, still motivated to practice modern farming because of perceived higher returns on investment, regardless of environmental impacts, which they tend to discount. Traditional farmers do not use inorganic inputs and instead rely on swidden 'slash-and-burn' practices, resulting in declining productivity and soil fertility over time. Since traditional farmers are ultimately forced to encroach into nearby forests to maintain productivity, the perceived environmental sustainability of such farming systems is also limited. Mixed-input farming is not significantly different from modern farming with respect to its perceived environmental and economic traits, because it incorporates agro-chemicals alongside organic practices. Stakeholders' perceptions and the apparent environmental outcomes of different farming systems suggest that reducing the use of inorganic inputs and promoting the adoption of organic inputs could minimise the negative impacts of agro-chemicals on the forest environment without necessarily compromising productivity. Campaigns to promote low-input or organic agriculture on environmental grounds in West Africa may falter if they fail to recognise farmers' relatively favourable perceptions of the environmental implications of modern farming practices.

Keywords: agricultural intensification; inputs adoption; farming practices; forest frontiers; rural Ghana; multi-criteria analysis

Citation: Acheampong, E.O.; Sloan, S.; Sayer, J.; Macgregor, C.J. African Forest-Fringe Farmers Benefit from Modern Farming Practices despite High Environmental Impacts. *Land* **2022**, *11*, 145. https://doi.org/10.3390/land11020145

Academic Editor: Antonio Raschi

Received: 3 December 2021
Accepted: 15 January 2022
Published: 18 January 2022

1. Introduction

Agriculture has altered the Earth's surface more than any other human activity. Habitat loss resulting from agricultural expansion is perhaps the greatest single threat to global biodiversity [1]. Over recent decades, the majority of new croplands have been established over tropical forests [2]. Demand for food to sustain an increasingly affluent global human population is increasingly threatening the remaining uncultivated lands with agricultural conversion [3], especially forests, giving rise to debate over the relative social and ecological virtues of agricultural intensification vs. extensification, i.e., 'land sparing' vs. 'land sharing' [4–8]. Such debate is often marked by a notable lack of appreciation of the interests and capacities of those land users and governments that would ultimately adopt such practices.

In Africa, three-quarters of the rural poor rely on agriculture for their livelihoods but they generally practice under-productive traditional farming [9–12]. This is typical in Ghana, where over 70% of rural residents are farmers [13] who widely practice swidden 'slash-and-burn' agriculture characterised by semi-subsistence production and short-term fallows that are integral to maintaining productivity. Farming practices vary, however, and each practice has a corresponding diversity of social, economic, and environmental issues such as risk aversion [14], economic profitability [15,16], and forest conversion [17]. To inform debate on the relative virtues of, and possibilities for, African agricultural development and environmental conservation, accounting for the perceptions of Ghanaian farmers and rural land managers, we scrutinised these stakeholders' perceptions regarding the benefits and costs of various farming systems.

The social, economic, and environmental dimensions of agricultural practices within agricultural peripheries abutting forests are a subject of concern because such practices significantly and disproportionately affect forest ecosystem services at regional and global scales [18,19]. A number of studies have identified various agricultural practices in Ghana as well as the factors of their adoption. For example, Kotu, et al. [20] found that farmers in northern Ghana adopt a mix of inorganic inputs (e.g., chemical fertilisers, herbicides, pesticides, improved seeds) and organic inputs and practices (e.g., intercropping, crop rotation, manure spreading) to increase production but also balance production with non-farm household income. In most of the literature, the rationale for the adoption of a given practice is mainly economic, though motivations vary along an economic spectrum defined by profit maximisation and risk aversion [21–24]. Agricultural practices also have social and environmental implications such as poverty reduction, food security, health problems, forest conservation, and water contamination, many of which extend beyond the remit of the individual landholder to the wider society [4,25]. Such social and environmental considerations may also bear on farmers' economic motivations, such as where soil conservation affects agricultural production [26] or forest conversion affects water availability [27].

Ghana has 256 forest reserves, most of which have communities within and/or at their fringes RMSC [28]. Certain farming practices, such as the use of inorganic herbicides and pesticides, have been found to negatively impact biodiversity, so they may not be appropriate within or close to reserves [29,30]. Swidden farming practices may be more appropriate, particularly given that many local farmers cannot afford inorganic inputs, but waning soil fertility impacts farm productivity while the use of fire to clear fallows threatens neighbouring farms and forests [31]. Consequently, swidden farmers may be compelled to encroach into forests to access new, fertile lands in order to supplement or replace depleted croplands in the absence of alternative soil enrichment Acheampong et al. [32]. This dynamic is particularly acute as fallows shorten under increasing demographic or commercial pressure [33], a phenomenon evident around most forest reserves in Ghana RMSC, [28]. Agricultural and forest sustainability are contingent upon balancing the full range of social, economic, and environmental dimensions of farming at forest frontiers of Ghana [34–36].

The adoption or promotion of particular agricultural practices must contend with farmers' perceptions of and attitudes towards the benefits and impacts of such practices. Some farmers are inclined to mix certain practices Acheampong et al. [37] and may correspondingly exhibit diverse attitudes. Further, non-farmer stakeholders of rural lands and resources are likely to have different perceptions regarding the social, economic, or environmental issues underlying agricultural practices. These too must be considered. The perceptions of farmers and other stakeholders may or may not align with each other, challenging efforts to promote sustainable alternatives. To help clarify this matter, we employed a multi-criteria analytical approach to profile Ghanaian farmers and other stakeholders of rural land and resource management in terms of their perceived social, economic, and environmental costs and benefits of different agricultural practices.

2. Materials and Methods

2.1. Multi-Criteria Analytical Approach to Agricultural Sustainability: A Brief Review

This study employed multi-criteria analysis (MCA) to profile perceived costs and benefits of agricultural practices according to different stakeholders of sustainable rural resources. MCA allows for the evaluation, prioritisation, and/or selection amongst alternative resolutions given conflicting perceptions, interests, and factors of resource management [38,39]. MCA employs varied techniques to process data from a number of indicators and generate an overall score indicating an 'optimal', or at least optimally compromised, decision or preference [40].

With respect to agricultural sustainability, MCA has been variously applied to elucidate social, environmental, or economic sustainability. Some researchers have used MCA to derive conceptual frameworks encompassing the values and perspectives of different stakeholders [41]. Others have used MCA to define indicators/criteria to identify practical pathways to sustainability [41,42]. A particular utility of MCA is its ability to explicitly profile the so-called triple bottom line by (optionally) affording equal importance to environmental, economic, and social aspects of sustainable decision-making [41–43].

MCAs have also been used to synthesise and assess stakeholder knowledge of land management in order to prioritise soil fertility for sustainable agriculture [44,45]. Pashaei Kamali, et al. [46] for instance used MCA to assess the validity of local expert opinions in scoring the sustainability of agricultural systems. Upon comparing the sustainability scores of local experts against published studies, Pashaei Kamali, Borges, Meuwissen, de Boer, and Oude Lansink [46] concluded that local expert opinions are a valid complement of, or potential alternative to, standard empirical knowledge. Parra-López, et al. [47] similarly deduced via MCA that local expert knowledge could inform decision-making processes where conventional empirical data are unavailable, partial, or costly.

Our study adopted MCA to profile agricultural sustainability in agricultural frontiers characterised by progressive forest conversion and/or tenuous conservation. Two attributes of MCA recommended its use to this end. First, measuring the effects of agricultural practices on society and the environment requires large quantities of empirical data on factors such as human health, poverty and food security, soil fertility, crops yields, and the costs of varied practices. Such data are usually very expensive to collect at large scales and require diverse expertise to interpret holistically. MCA is an alternative, but reliable and relatively inexpensive, means of evaluating the effects of agricultural practices on the basis of stakeholders' estimates [46,47]. Second, different stakeholders have different understandings of and concerns for various environmental and social issues related to farming. For instance, farmers are relatively interested in annual economic returns while foresters are relatively concerned with longer-term forest production. Attempting to avoid environmental degradation due to farming without economically undermining farmers requires an analytical tool capable of addressing trade-offs amongst the array of relevant stakeholders. MCA assists in reconciling conflicting attitudes amongst stakeholders, highlighting relatively promising approaches to sustainable resource management [48,49].

2.2. Methodology Overview

We synthesised perceived costs and benefits of environmental, economic, and social aspects of agricultural practices for three distinct farming systems in Ghana, these being the modern, the mixed-input, and the traditional farming systems (defined further below). Perceived costs and benefits were profiled according to appraisals by five stakeholder groups—farmers, foresters, agricultural extension officers, agro-ecological researchers, and environmental NGOs—using the V.I.S.A multi-criteria analysis model. The following sections present pertinent details.

2.2.1. Study Area and Stakeholder Groups

Our study region, the Ashanti region of Ghana, occupies about 10% of Ghana's extent and is located within longitudes 0.15° W–2.25° W and latitudes 5.54° N–7.46° N [50]. The region contains 58 of Ghana's 256 forest reserves (Figure 1). We chose this region for our study because of its high deforestation rate compared with the other regions RMSC, [28]. Along these lines, Acheampong et al. [51] finds that agricultural practices in the region have historically degraded over 70% of its original forest cover. Forest reserves have been gazetted in the Ashanti region since the 1920s, prior to which there was no official concern over sustainable forest management because forest-dependent residents were few and collected mainly Non-Timber Forest Products (NTFPs) for subsistence use [52]. Forest-fringe communities have since increased in number, resulting in increased agricultural pressure on forest lands and raising concern over effective forest conservation RMSC, [28].

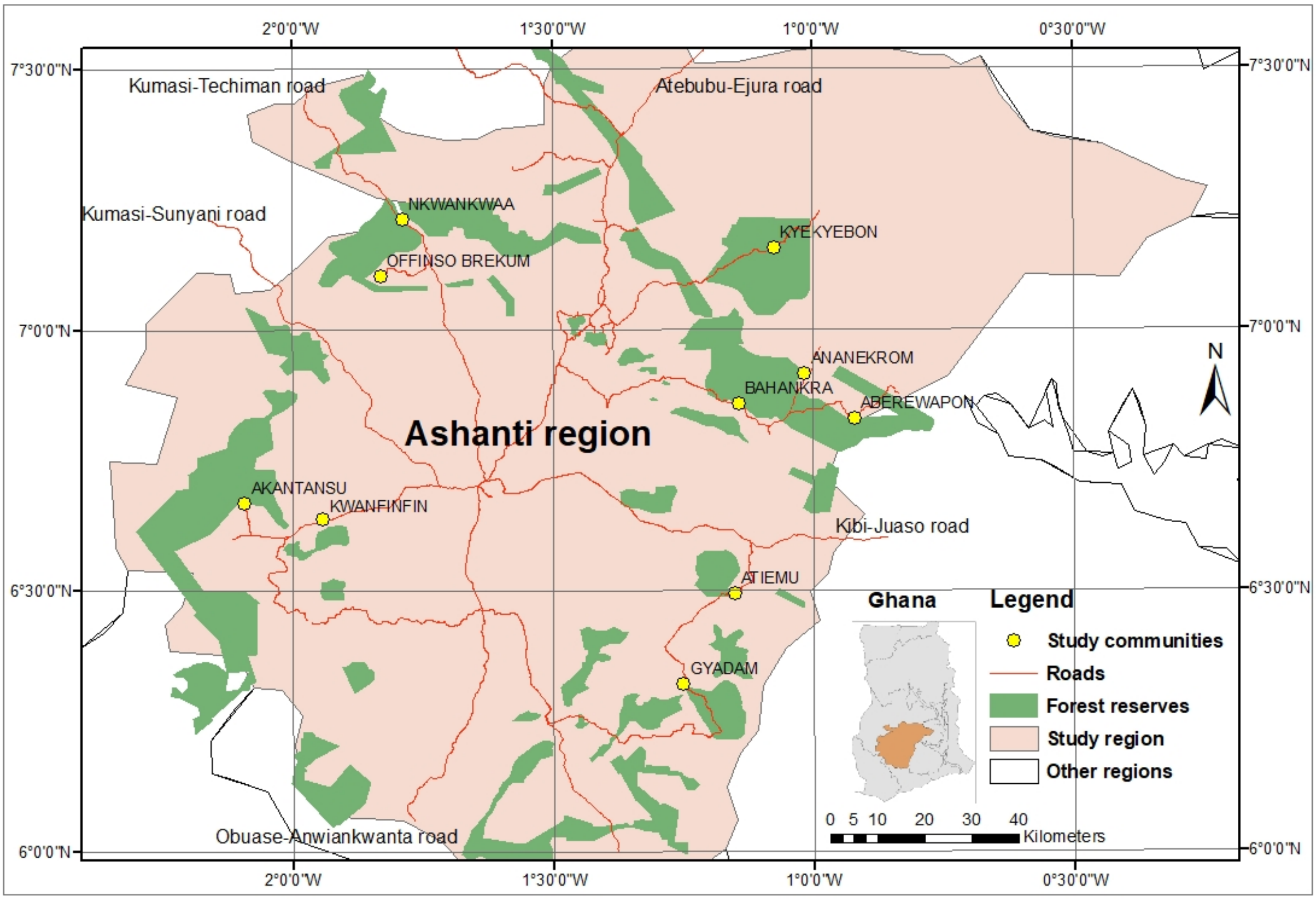

Figure 1. The Ashanti region of Ghana and its forest reserves. Source: Resource Management Support Centre (RMSC), 2016.

The five stakeholder groups for this study are farmers, foresters, agricultural extension officers, agro-ecological researchers, and environmental NGOs. These stakeholders encompass diverse actors in terms of agro-ecological priorities (production vs. conservation), presence in rural areas (local/daily vs. remote/occasional), and guidance by empirical data (low to high). Activities of these stakeholder groups have direct influences on the environment and its natural resources. For instance, the agricultural practices farmers adopt may conserve/deplete the soil or degrade/conserve adjacent forests. Foresters oversee the protection and production of forest reserves. Their activities may help prevent, control, or minimise forest degradation by farmers. Agricultural extension officers educate farmers on best practices. Together with environmental NGOs and agro-ecological researchers, agricultural extension officers educate farmers on improved agricultural technologies and practices for agricultural and environmental sustainability.

Foresters' perspectives were represented by six foresters in the positions of Assistant District Manager, Plantations Manager, and Deputy Area Manager in Ghana. Five agricultural extension officers of the Ministry of Food and Agriculture (MoFA), six agro-ecological researchers of the Council for Scientific and Industrial Research's Crops Research Institute of Ghana (CSIR-CRI), and five Directors of regional environmental NGOs, all based in the Ashanti region, were similarly interviewed as representatives of their respective sectors. These stakeholder representatives were selected based on their experience in environmental sustainability in relation to agricultural practices and forest conservation.

Regarding farmers, we interviewed one farmer from each of ten select communities adjoining forest reserves degraded by agriculture, according to regional foresters. These farmers were those identified by their communities as highly experienced in farming. The ten communities were selected from the set of 20 forest-fringe communities studied by Acheampong et al. [51]. The farmers interviewed had experience in all the three farming systems but were not practicing all at the time of the survey. Overall, 32 key participants from five stakeholder groups were surveyed.

2.2.2. Data Collection and Analysis Techniques

Acheampong et al. [37] identified six main farming practices within the forest-fringe communities of the Ashanti region. These practices are: the use of inorganic fertilisers, herbicides, and pesticides; the use of improved seeds purchased annually from agricultural supply centres; the application of organic animal manure; and annual crop rotation. We categorised these practices into three farming systems: modern, mixed-input, and traditional (Table 1). The modern system exemplifies Green Revolution technologies as practiced elsewhere globally, entailing intensive and sustained agricultural production dependent on the regular input of inorganic agro-chemicals as well as improved seeds and, by extension, a negligible role for organic fertilisers, soil management (e.g., rotations, fallows), and pest control [53,54]. In contrast, traditional farmers rely on slash-and-burn farming, characterised by very short fallows (just between harvesting and the next cropping season) and the absence of agro-chemical inputs. Traditional farmers will sell farm surpluses, but surpluses are small proportions of total farm yield, much of which is dedicated to home consumption. Mixed-input farmers are a hybrid of traditional and modern farmers. They use some inorganic inputs alongside organic manure and/or crop rotation. Mixed-input farmers' partial use of relatively costly inorganic inputs reflects their greater commercial orientation compared with traditional farmers.

Farming is the main economic activity in the study areas as well as rural Ghana. Modern and mixed-input farming are practiced in Ghana mainly to increase food production and agricultural profitability within the shortest possible time through the application of agricultural-enhancing inputs. While the rationales for these practices are economically valid, there may be some associated social and environmental implications. Traditional farming is an ancient system in Ghana and traditionally inclined farmers in the study area favour this system due to its organic and chemical-free nature [37]. This system is, however, associated with low agricultural production when continuous cropping on the same land occurs.

Table 1. Three farming systems and corresponding social, economic, and environmental issues assessed by the stakeholder groups in the Ashanti region, Ghana.

Dimension	Farming System		
	Modern	Mixed-Input	Traditional
Indicative practices, inputs	Inorganic fertilisers, herbicides, and/or pesticides; improved seeds	Organic manure (animal or plant-based), crop rotation (+inorganic inputs)	Slash-and-burn practices, brief fallows
Social issues	Health risk to farmer, societal support of use, level of difficulty in application, food health	Health risk to farmer, societal support of use, level of difficulty in application, food health	Health risk to farmer, societal support of use, food health
Economic issues	Cost of inputs, cost of labour, frequency of application, effects on crop growth, yield, output, survival, and resistance	Cost of inputs, cost of labour, frequency of application, effects on crop growth, yield, output, survival, and resistance	Cost of labour, frequency of labour use, frequency of farm maintenance, effects on crop growth, yield, output, survival, and resistance
Environmental issues	Effects on soil, water bodies, tree species, fauna, and forest	Effects on soil, water bodies, tree species, fauna, and forest	Effects on soil, tree species, fauna, and forest

Using V.I.S.A multi-criteria analysis (MCA) software (http://www.visadecisions.com/index.php) (accessed on 13 September 2019), we employed a non-econometric cost–benefit model to survey stakeholders' perspectives on the negative and positive aspects of farming practices, that is, their perceived costs and benefits (Table 1). Input data for this nominal cost–benefit model were derived from a five-point Likert-scale questionnaire administered to each stakeholder. Here, costs and benefits for a given practice do not refer to monetary costs or benefits per se, but rather to the negative or positive attributes of the practice. The qualitative, ordinal nature of the input data reflects the fact that the issues of interest (Table 1) were also often qualitative in nature, e.g., support for fertiliser use, health risks of crop rotation and manure spreading. Influenced by the user, the V.I.S.A MCA model, which is similar to other MCA models, weights costs and benefits of a farming system using the "scores for alternatives" function (S) and the "criterion weighting" function (W) as follows [46,55,56]:

$$MCA_j = \sum_{ij} W_i * S_{ij}$$

where MCA_j is the overall outcome 'resultant score' for farming system j; W_i is the weight for criterion i, where criterion i is an aspect of farming system j evaluated by a stakeholder response on the Likert scale; and S_{ij} is the score for criterion i in farming system j. The 'alternatives' in the model are the five stakeholder groups surveyed, which may offer alternative, or at least diverse, responses for a given criterion i. V.I.S.A uses a scoring system of 0 to 100, where a score of 100 for a particular criterion denotes a total agreement of the respondent with that criterion. As our Likert scale had a range of one to five, we multiplied the average scores obtained from the criteria by a scalar of 20 to yield a 0 to 100 scoring system. We then calculated the total scores for each statement/criterion for each stakeholder category and calculated the average score for each statement/criterion. The definitions for each model's criteria are presented in Tables A1–A3 for modern, mixed-input, and traditional farming systems, respectively.

The weighting function within V.I.S.A is used to indicate the relative importance that the V.I.S.A user affords to each criterion. The weighting function can also be used to explore variation in scores based on alternative prioritisations of the criteria in question. Naturally, a variation to weights will influence the outcomes of a model. For instance, a stakeholder may perceive animal manure and inorganic fertiliser as having the same benefit, but the V.I.S.A user may weight inorganic fertiliser differently from animal manure based on the particular interest or perspective of the user, e.g., price or accessibility.

Here, we initially applied equal weights to all criteria to preliminarily examine the model output based only on stakeholders' scores as reported. This approach ensured that the weighting function did not influence the resultant scores. Subsequently, we unequally weighted the criteria based on the suggestions and opinions of the stakeholders regarding sustainable agriculture, relevant literature on sustainable farming practices, and our personal experiences in the field. These unequal weights adopted a continuous scale of zero to one, where zero denotes a minimal perceived interest. This unequal-weighting function was applied to the mixed-input farming system (because it is a mix of high-input and traditional farming) and the traditional farming system to demonstrate how these systems could be strategically adjusted to achieve more sustainable farming practices while also incorporating stakeholders' perspectives.

Where possible, we collected additional data from the stakeholders regarding the scores they provided to each statement in the Likert scale questionnaire. These qualitative data were used to explain the rationale behind the stakeholders' choices of scores.

3. Results

3.1. Costs and Benefits of Modern and Mixed-Input Farming Systems

All stakeholders viewed the modern farming system as more beneficial than detrimental overall before they responded to our survey, as inferred by prior conversations. However, the equally weighted MCA model based on stakeholders' views (Table A1) reveals that the perceived overall cost of the modern farming system (0.519 out of a potential maximum of 1.0) is slightly higher than its overall benefit (0.481) (Figure 2 items a and b). Economic costs, resulting mainly from the procurement of chemical inputs, are greatest amongst all costs (Figure 2 item d). Farmers' motivations for adopting inorganic inputs within the modern farming system revolve around the economic returns from this system. Reported benefits from such economic returns are, however, only marginally higher (0.462) than the corresponding economic costs (0.429). The primary economic benefits in question include increased yields, increased resistance of crops to pests and diseases due to the use of improved seeds and pesticides, and greater farm profitability due to earlier crop maturation and more favourable marked prices.

Perceived environmental costs of modern farming (0.357) are almost double the environmental benefits (0.231) (Figure 2 items e and h). The primary environmental costs cited for the modern system include pollution of land and water bodies, chemical-infected crops, and threats to living organisms, all resulting from the use of the agro-chemicals. The environmental benefits relate to perceived soil-fertility enrichment and forest protection on the premise that forest encroachment will not occur due to the fertilisation of cultivated soils. The social costs of the modern farming system ranked lower (0.214) than either environmental or economic costs. These social costs relate to contamination that farmers and communities experience due to the application of inorganic inputs, society's general misgivings over the use of agro-chemicals, and the lack of skills for applying such chemicals appropriately.

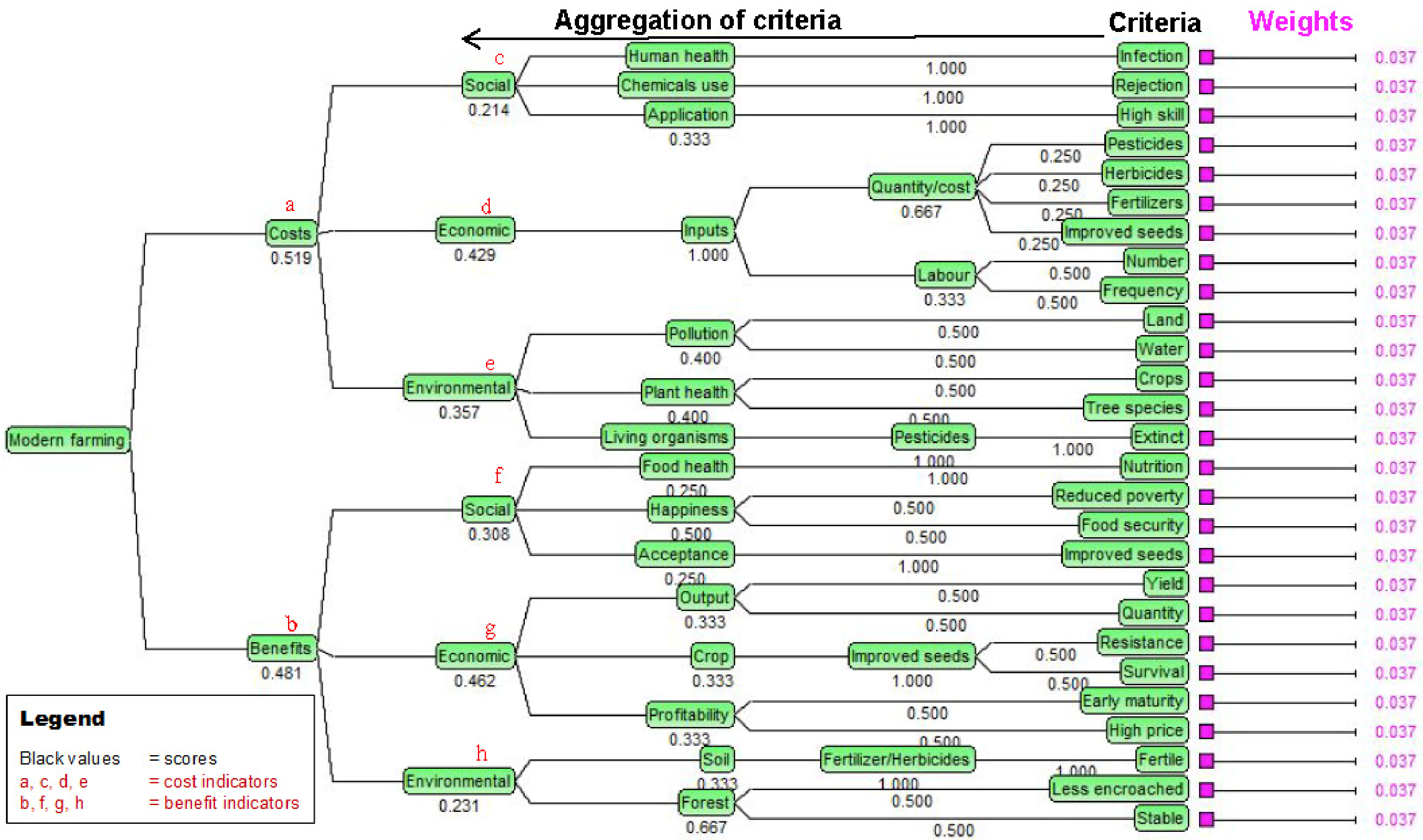

Figure 2. Relative costs and benefits of the modern farming system based on stakeholders' scores in an equally weighted MCA model.

Overall cost–benefit balances for the modern farming system differed amongst the five stakeholder groups. Inter-group differences reflected whether a given group had a low (forester and NGO) or high (farmer, extension officer, agro-ecological researcher) affinity with agriculture. Farmers, having the highest affinity, were distinguished by a uniquely favourable perception of the environmental implications of modern farming, qualifying this farming system as much more environmentally beneficial and much less costly than other stakeholders (Figure 3B). Hence, whereas farmers, agricultural extension officers, and agro-ecological researchers held the view that the benefits of modern farming outweigh its detrimental impacts, foresters and environmental NGOs held the opposite view (Figure 3A,D). While extension officers and agro-ecological researchers are in favour of modern farming overall, they still held the same opinions as foresters and environmental NGOs regarding the damaging environmental effects of inorganic inputs (Figure 3B). According to the foresters, when inorganic inputs (especially herbicides and pesticides) are used within forest reserves, the environmental damage alone is higher than the overall benefit of the modern farming system. In the words of one forester, "the use of fertilisers enriches the soil to some extent, but the use of some herbicides hardens the soil and damages flora". Another forester stated, "pesticides protect food crops from pest infestation, but they destroy more other insects needed for pollination than those that infest food crops". Such comments, as well as the marked divergence of farmers from other stakeholders with respect to perceived costs and benefits of the modern system (Figure 3B), suggest that perceived overall benefit of the modern system exceeds the overall cost only when a modern farmer may externalise costs to other lands and/or landholders. Farmers, in contrast to other stakeholders, perceive the modern farming system as more beneficial personally and for the environment. According to farmers, the use of fertilisers, pesticides, herbicides, and improved seeds makes farming not only less laborious but also more profitable. More surprisingly, and in stark contrast to other stakeholders, farmers ranked environmental benefits attributable to modern farming almost as highly as economic benefits (Figure 3B). One farmer commented, "I do not cut down trees to expand my farm. I add more of these inputs to the same land to get more produce. I am rather helping to conserve the forest". Another farmer added, "There are two ways to get more farm produce. One is to expand the farm and the other is to apply more inputs. I have decided to use the inputs rather than to encroach upon the forest". Simplifying, modern farmers believe the negative environmental effects of their practices are insignificant, in contrast to other stakeholders, since modern farmers do not need to (re)clear forest for continued cultivation.

The primary difference between the modern and the mixed-input farming systems is the latter's use of organic inputs (manure and/or mulch) and crop rotations, which alter associated costs and benefits (Figures 4 and A1). Hence, in the equally weighted MCA model, stakeholders' views of such attributes revealed the overall benefits of mixed-input farming (0.528) to be higher than the overall costs (0.472) (Figure 4 items a and b), in contrast to the modern farming system (Figure 2). This overall favourable benefit-to-cost ratio for the mixed-input farming system rests entirely on high perceived social benefits. Indeed, our equally weighted MCA model for the mixed-input farming system describes the overall economic and environmental costs (Figure 4 items d and e) as being greater than the overall economic and environmental benefits (Figure 4 items g and h), due largely to the application of inorganic inputs. Such scoring largely reflects the views of foresters and environmental NGOs, who scored the economic and environmental costs of mixed-input farming higher than the corresponding benefits due to its incorporation of inorganic inputs (Figure A1).

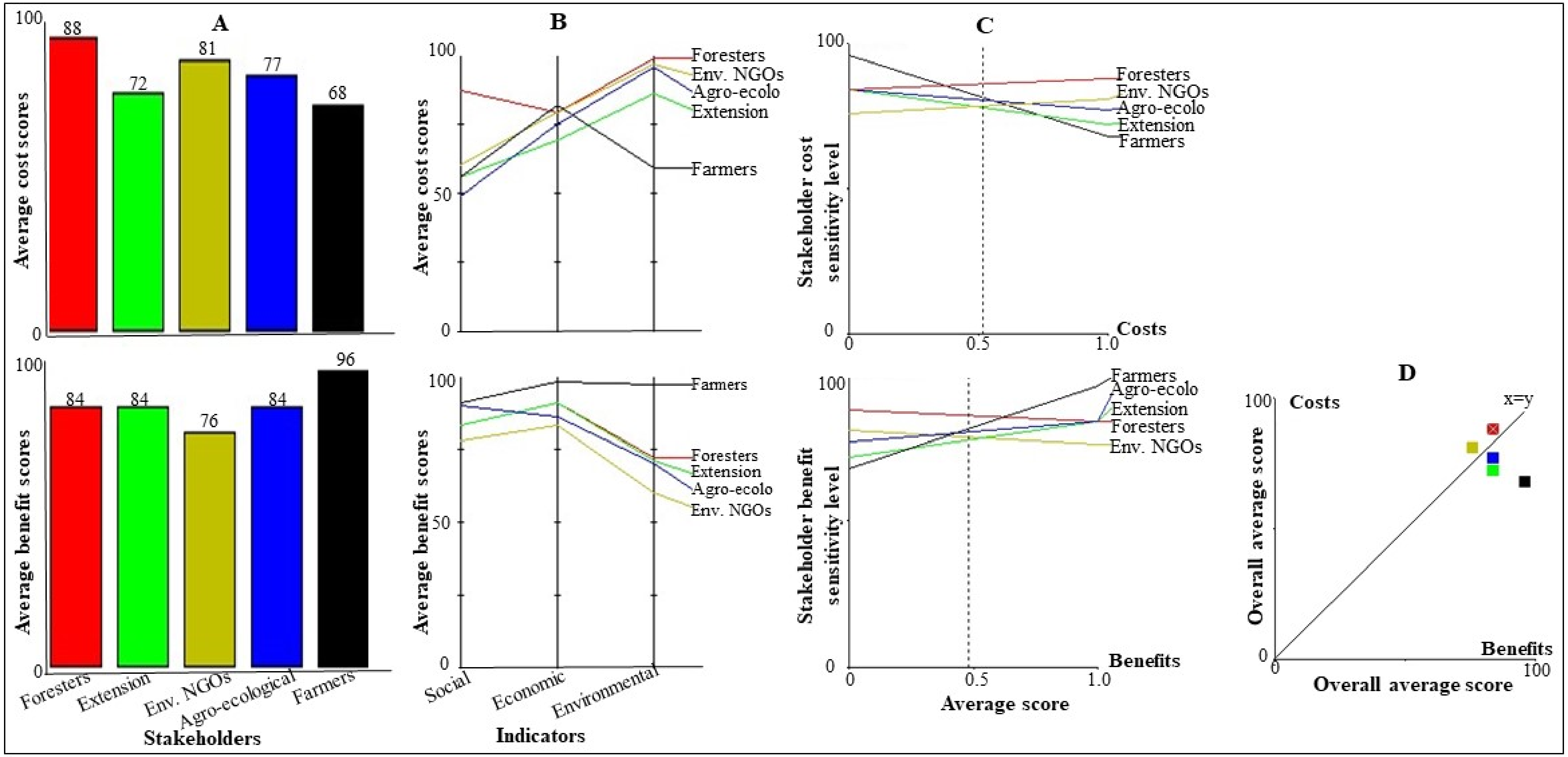

Figure 3. Stakeholder scores for costs and benefits of modern farming based on an equally weighted MCA model. (**A**) presents the overall average cost and benefit scores from each stakeholder group. (**B**) presents the sum of the scores for social, economic, and environmental costs and benefits from each stakeholder group. (**C**) presents stakeholder sensitivity levels, denoting the degree of concern of a particular stakeholder for the modern farming system. The stakeholder at a higher position on the *y*-axis in (**C**) is more sensitive to the cost or benefit of the modern farming system than a stakeholder with a lower position on the *y*-axis. (**D**) presents stakeholders' cost–benefit ratio. The colour of the points denotes the stakeholders in (**A**–**C**).

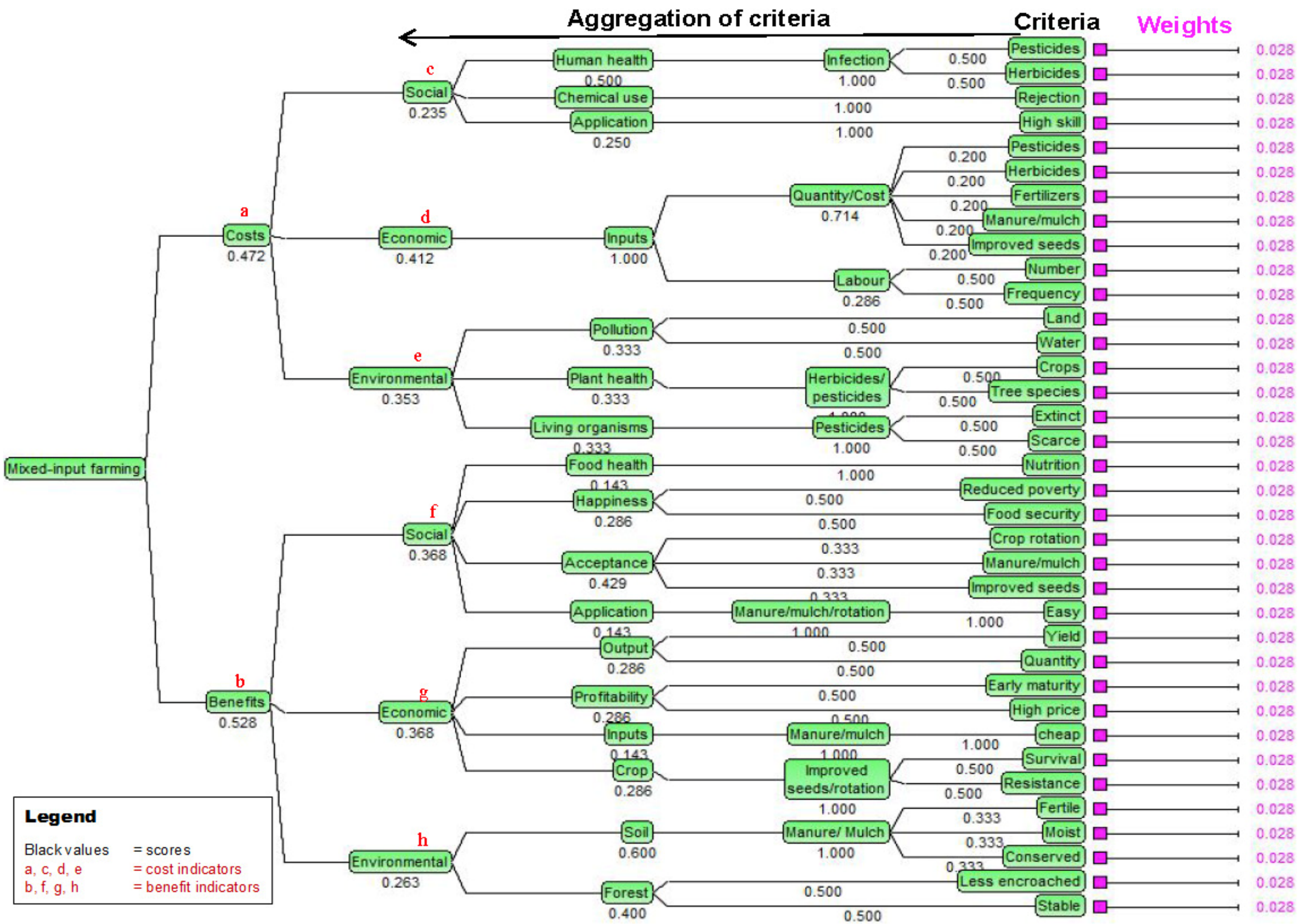

Figure 4. Relative costs and benefits of the mixed-input farming system based on stakeholders' scores in an equally weighted MCA model.

3.2. Costs and Benefits of Traditional Farming

In contrast to expectations of high favour for organic agricultural production, due to a popular tendency to conflate organic with 'sustainable' farming, stakeholders perceived the traditional farming system as more costly than beneficial overall (Figure 5 items a and b). Accordingly, amongst all stakeholder groups combined, the traditional farming system registered an overall benefit-to-cost ratio of 0.84:1 (Figure 5), lower than the 0.93:1 ratio for the modern farming system (Figure 2), and of course much lower than the 1.1:1 ratio for the mixed farming system (Figure 4). Both the equally weighted MCA model for the traditional faming system (Figure 5) and stakeholders' views on this system (Table A3) indicate that, compared with the modern farming system, the traditional system is less costly but also less productive for farmers, slightly less detrimental to the environment, and more favoured by society. Interestingly, despite its unprofitable nature, farmers and to lesser degrees foresters and agricultural extension officers ascribed traditional farming more benefit than cost overall (Figure 6A,D), in contrast to the collective view of all stakeholders noted above. This divergent position amongst farmers plus foresters and extension officers is primarily because the traditional system does not entail agro-chemicals, being costly to landholders and harmful to forests and society. Farmers' relatively unique net favour of the traditional system was analogous to their similarly unique net favour of the modern farming system (Figure 3), but less acute.

3.3. Improving the Sustainability of Agricultural Sytems within Forest Landscapes

A consideration of the relative importance of the cost and benefit criteria for a given farming system qualifies the mixed-input system as far more sustainable overall than its alternatives. The unequally weighted MCA model for the mixed-input farming system reported perceived overall benefits that far exceeded perceived overall costs, with a benefit-to-cost ratio of 5:1 (Figure 7 items a and b), compared with 1.1:1 for the equally weighted model (Figure 4). This latter ratio in turn exceeds the benefit-to-cost ratios for the modern and traditional farming systems similarly described by equally weighted MCA models (ratios 0.84–0.92:1) (Figures 2 and 5).

The unequally weighted model for the mixed-input system is suggestive of the nature of a more sustainable version of the current mixed-input farming system. The unequally weighted model affirms that strategically reducing the use of inorganic inputs and promoting the use of manure, improved seeds, and crop rotation may improve the overall sustainability of the mixed-input farming system, particularly by minimising the environmental impacts of the high inorganic input application rates associated with the modern system and avoiding the forest conversion associated with traditional systems (Figure 7). While some damage to the forest environment will still inevitably result from an improved mixed-input farming system, as perceived by the stakeholders (Figure 8B), its magnitude would be less than that entailed by the modern and mixed-input farming systems described by the equally weighted models.

Regarding the traditional farming system as described by the unequally weighted MCA model, the application of animal manure and mulch and the introduction of crop rotations increased its overall benefit-to-cost ratio to 2.83:1 (Figure 9 items a and b), being 3.4 times higher than the corresponding ratio for this system given equal weights (Figure 5 items a and b). The model indicates that reducing the frequency of burning by farmers (Figure 9 item e) in particular would lessen impacts on both farm and forest environments and, consequently, raise the environmental benefit-to-cost ratio of traditional farming from 0.79:1 (Figure 5 items e and h) to 1.19:1 (Figure 9 items e and h). Still, with the exception of farmers, the environmental costs of such improved traditional farming may not differ significantly overall from current traditional farming according to the non-farmer stakeholders (Figure 10B vs. Figure 6B).

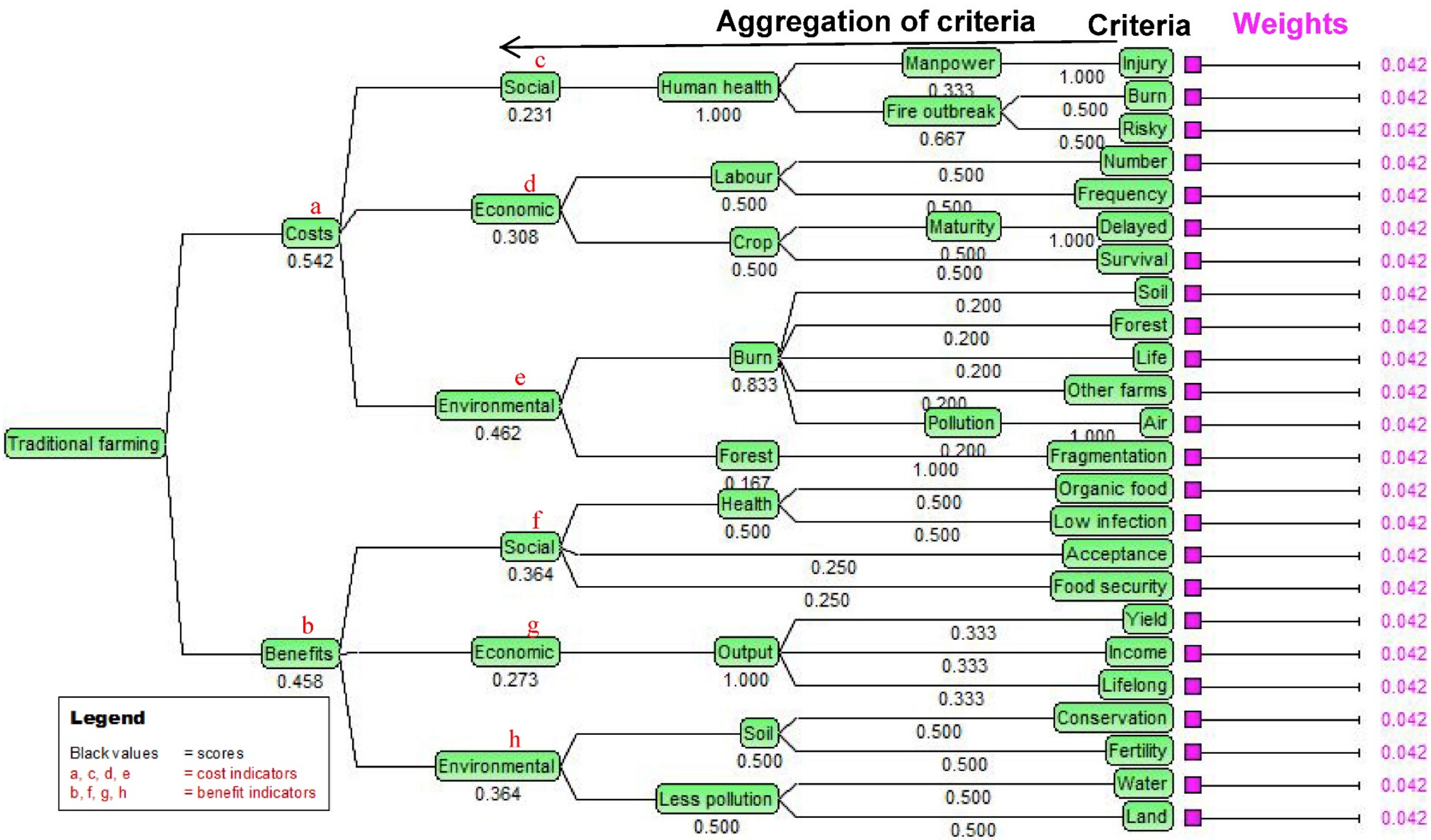

Figure 5. Relative costs and benefits of the traditional farming system based on stakeholders' scores in an equally weighted MCA model.

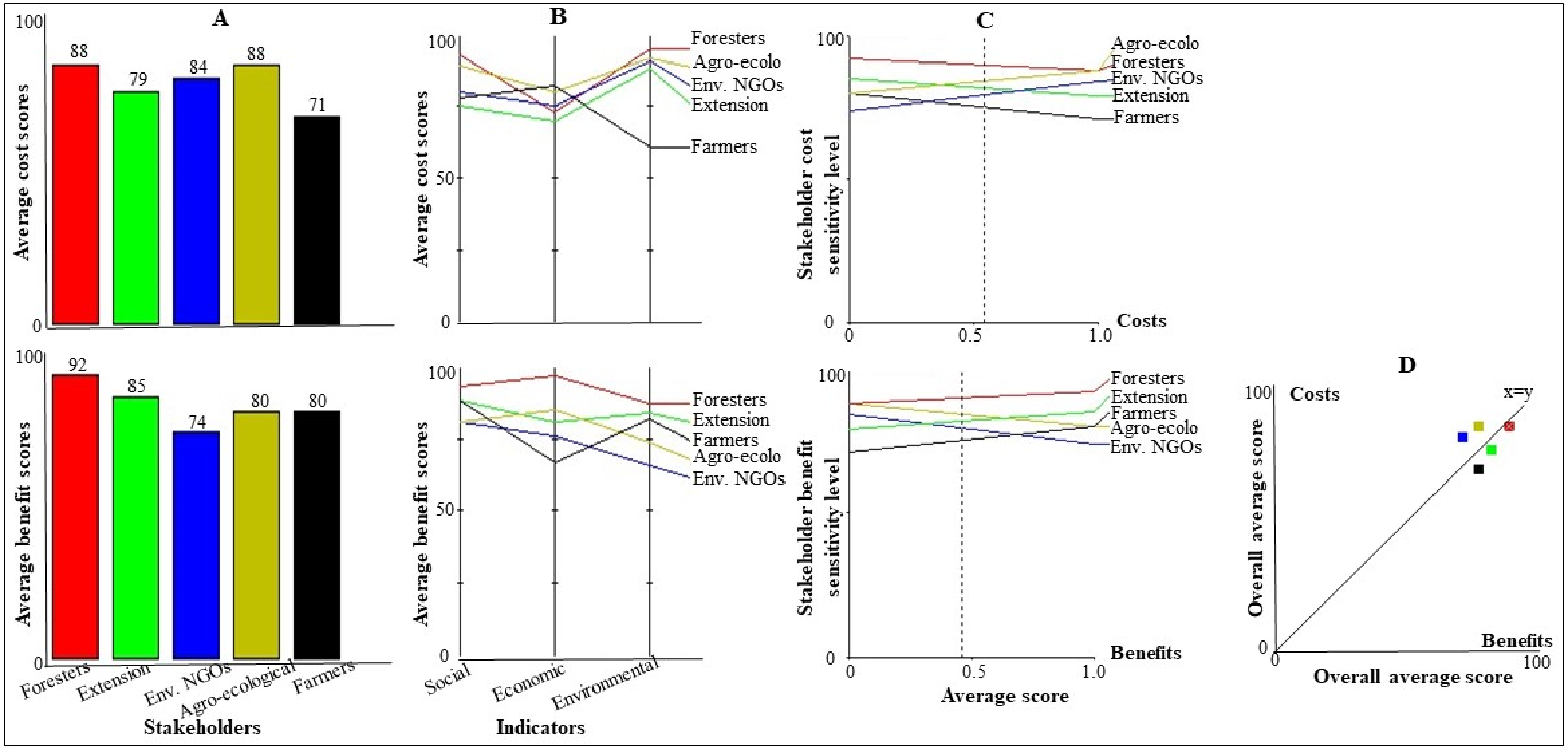

Figure 6. Stakeholder scores for costs and benefits of traditional farming based on an equally weighted MCA model. (**A**) presents the overall average cost and benefit scores from each stakeholder group. (**B**) presents the sum of the scores for social, economic, and environmental costs and benefits from each stakeholder group. (**C**) presents stakeholder sensitivity levels, denoting the degree of concern of a particular stakeholder for the traditional farming system. The stakeholder at a higher position on the *y*-axis in (**C**) is more sensitive to the cost or benefit of the traditional farming system than a stakeholder with a lower position on the *y*-axis. (**D**) presents stakeholders' cost–benefit ratio. The colour of the points denotes the stakeholders in (**A**–**C**).

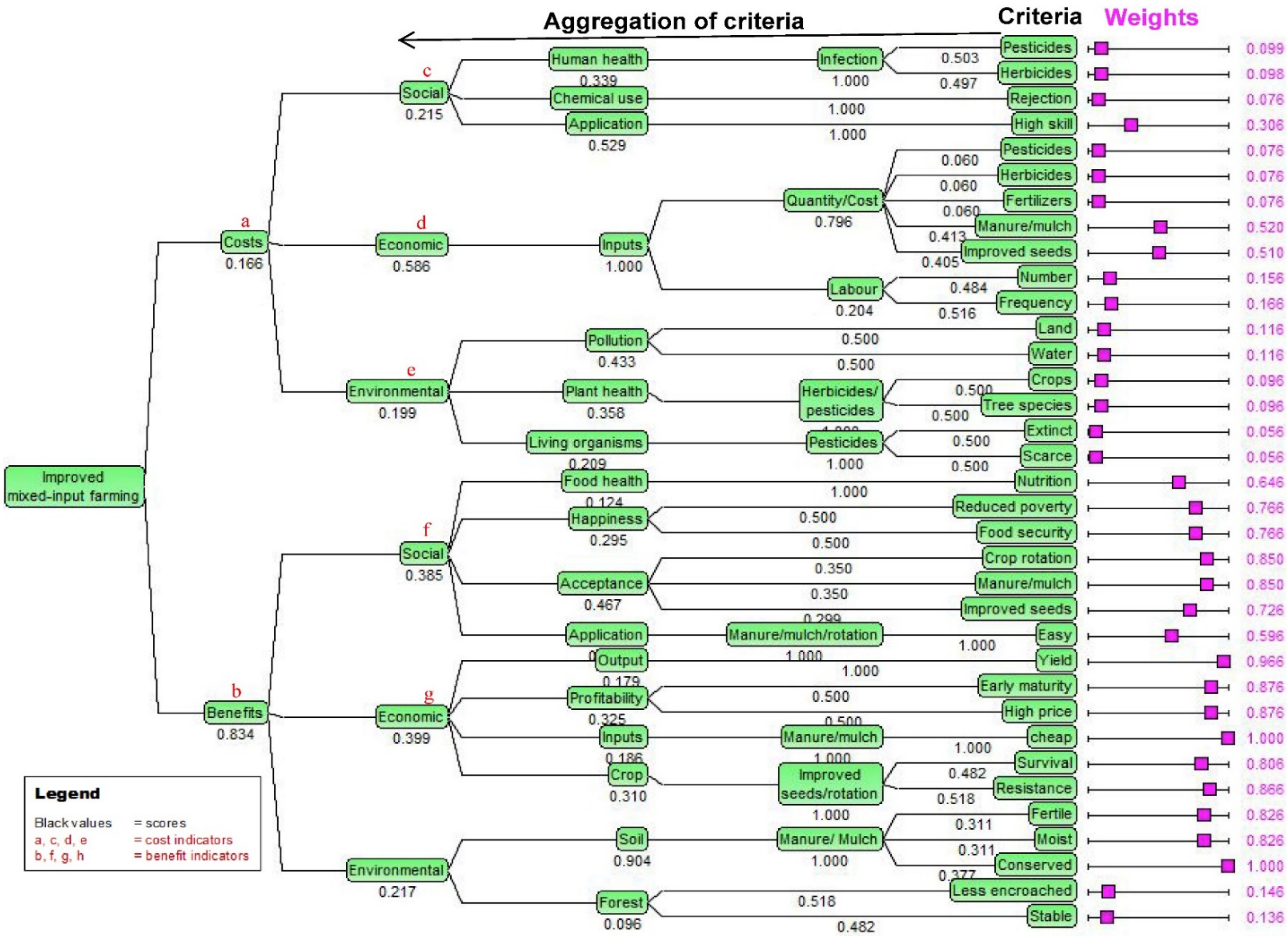

Figure 7. Relative costs and benefits of the mixed-input farming system based on weighted stakeholders' scores in an unequally weighted MCA model.

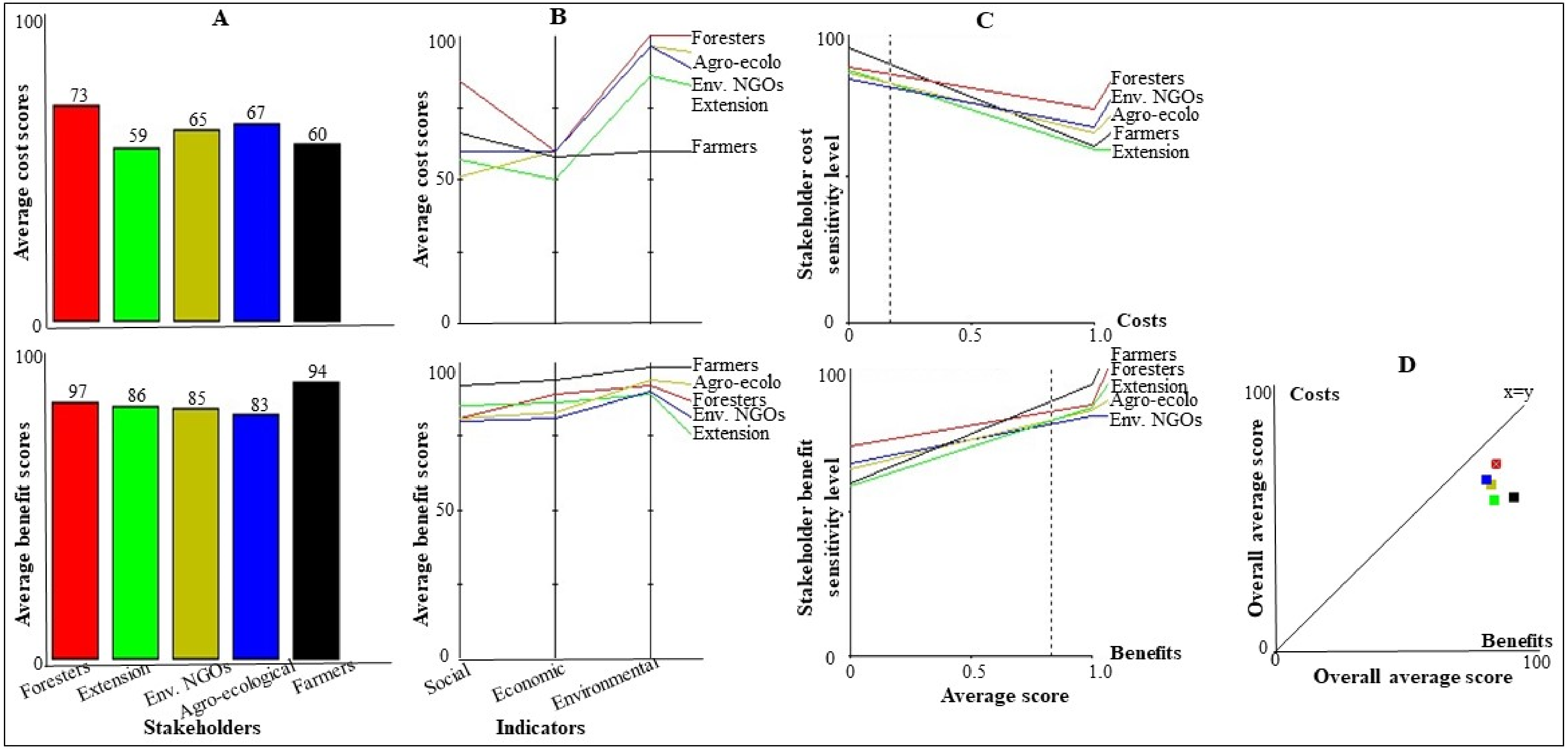

Figure 8. Stakeholder scores for costs and benefits of the mixed-input farming system based on an unequally weighted MCA model. (**A**) presents the overall average cost and benefit scores from each stakeholder group. (**B**) presents the sum of the scores for social, economic, and environmental costs and benefits from each stakeholder group. (**C**) presents stakeholder sensitivity levels, denoting the degree of concern of a particular stakeholder for the mixed-input farming system. The stakeholder at a higher position on the *y*-axis in (**C**) is more sensitive to the cost or benefit of the mixed-input farming system than a stakeholder with a lower position on the *y*-axis. (**D**) presents stakeholders' cost–benefit ratio. The colour of the points denotes the stakeholders in (**A**–**C**).

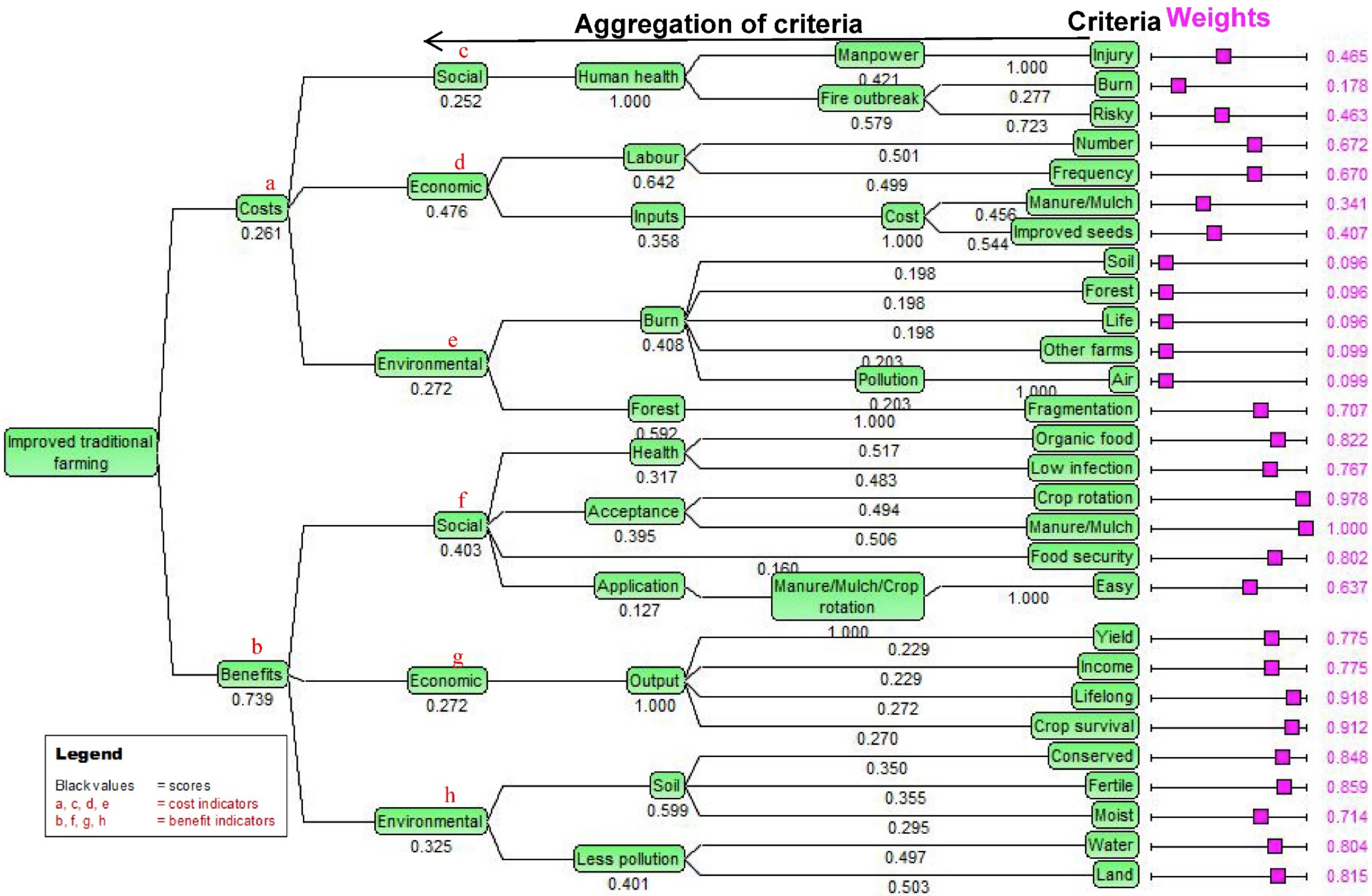

Figure 9. Relative costs and benefits of the traditional farming system based on weighted stakeholders' scores in an unequally weighted MCA model.

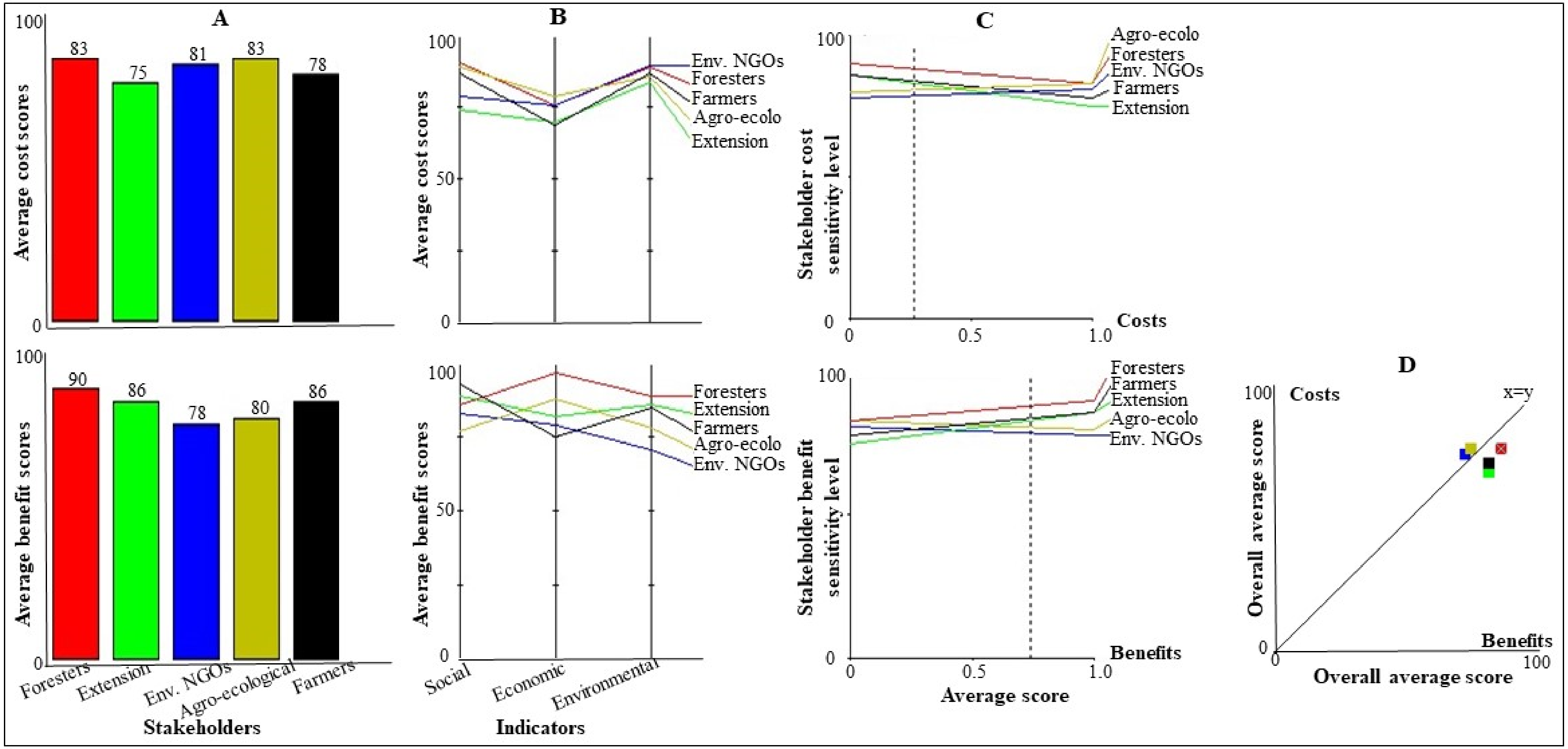

Figure 10. Stakeholder scores for costs and benefits of the traditional farming system based on an unequally weighted MCA model. (**A**) presents the overall average cost and benefit scores from each stakeholder group. (**B**) presents the sum of the scores for social, economic, and environmental costs and benefits from each stakeholder group. (**C**) presents stakeholder sensitivity levels, denoting the degree of concern of a particular stakeholder for the traditional farming system. The stakeholder at a higher position on the *y*-axis in (**C**) is more sensitive to the cost or benefit of the traditional farming system than a stakeholder with a lower position on the *y*-axis. (**D**) presents stakeholders' cost–benefit ratio. The colour of the points denotes the stakeholders in (**A**–**C**).

4. Discussion

Consultations with key stakeholders of rural lands and natural resources regarding the costs and benefits of modern, mixed-input, and traditional Ghanaian farming systems affirmed the general view that agro-chemical inputs cause more harm than benefit, at least relative to organic alternatives. Sharp discrepancies were apparent between stakeholder groups in terms of the perceived costs and benefits of individual practices and broader systems, with discrepancies seemingly reflecting the degree to which a stakeholder engages with agriculture versus conservation. Farmers able to afford agro-chemical inputs would seemingly not be willing to abandon their use on economic grounds, as evidenced by farmers' much more favourable appraisal of the economics of the modern system over the traditional system (Figures 3B and 6B) as well as their notably low appraisal of the costs of modern farming compared with other stakeholders (Figure 3B). A moderate and far more sustainable use of inorganic inputs is however possible, as shown by Jilito and Wedajo [57] and Pelletier, et al. [58] elsewhere in Africa and as indicated by the positive benefit-to-cost ratios for the Ghanaian mixed farming system. Complementing organic practices with moderate inorganic inputs would seemingly help elevate both the profitability and sustainability of farming in a conserved-forest landscape.

4.1. Improving Farm Productivity with Reduced Chemical Contamination in Forest Frontiers

Most farmers in this study rely on inorganic agricultural inputs, especially fertilisers, to improve crop yields. However, fertilisers have some negative effects, such as soil compaction, salinisation, acidification, and nutrient imbalance and a change in the composition of the soil microbiome, that could negatively affect the health and productivity of some crops [59]. Excessive fertiliser use may promote the emissions of reactive nitrogen gases harmful to human health. According to Pradhan, et al. [60], these emissions could increase by 45–73% if chemical fertilisers are solely relied on to increase production. Our model for the mixed farming system (Figure 7) suggests that the reduced use of chemical fertilisers and the increased use of organic manures can increase the profitability of farming with relatively limited environmental impacts.

Our survey revealed that most farmers that use fertilisers also apply herbicides and pesticides to control weed growth, pests, and diseases. The negative environmental impacts from the use of these chemicals have raised concerns in the literature [29,61–63]. According to the foresters and environmentalists interviewed, the use of herbicides and pesticides within and at the fringes of the forests affects the health of food crops and kills some tree species that are naturally regenerating. These chemicals do not only adversely affect Ghana's forests and biodiversity but also the health of the farmers and consumers; for instance, increased risks of child birth defects and low birth weight when pregnant women are exposed to the chemicals [30,64–68].

Promoting the use of manure for farmers in forest-fringe communities could reduce farmers' reliance on fertilisers to increase crops yields. The availability of manure in all forest-fringe communities is, however, uncertain, and farmers may have to travel long distances to purchase and/or collect manure, increasing its cost in ways not fully considered here. In addition, the capacity of manure to increase yield is lower than that of chemical fertilisers, which may matter more to mixed-input farmers than traditional farmers given the former's greater commercial orientation (i.e., concern with surplus production). Notwithstanding the clear net benefits of mixed-input systems as reported here, including economic benefits, such points highlight that the practical adoption of such systems may be challenged by seemingly mundane, but nonetheless limiting, factors not explicitly considered in this study, e.g., local year-round availability of manures, marginal economic returns, household labour commitments, (seasonal) cash poverty, risk aversion, and compatibility with cultivation seasonality. Indeed, the fact that many farmers practice the traditional system instead of the mixed-input system, which, from the farmers' perspective, is both economically and environmentally superior, suggests that such limiting factors are relevant and unaddressed.

Even still, 'low-hanging' opportunities for the improvement of Ghanaian traditional and mixed-input systems seemingly exist. Our models indicate that the stakeholders support the practice of crop rotation (Figure 7 item f and Figure 9 item f), a practice which is seemingly inexpensive and easy to implement; yet, two-thirds of the farmers in the study area grow maize as their main crop with little to no crop rotation or similar soil-enrichment practices to increase yield [37]. Smith, et al. [69] found that legume–maize rotations in Malawi produce maize yields that are higher than continuous maize cropping. Similarly, Fung, et al. [70] observed that maize–soybean intercropping systems reduce fertiliser application by 42%, cut NH_3 emissions by 45%, and produce the same quantities of maize and additional quantities of soybean when compared with maize monoculture. The practice of legume–maize and/or soy–maize rotation could therefore be beneficial both economically and with respect to food security. The practice may, however, be challenging for farmers with little or no knowledge of rotations or intercropping, again raising the issue of limiting factors and their resolution, in this case the paucity of relatively inexpensive agricultural extension in Ghana.

4.2. Applications for Rural Conservation

Multi-criteria analysis models have been applied variously to issues of land use and resource management [38,43,55,56]. Using MCA to suggest means for improved agricultural production and sustainable forest conservation is rare, however. We have demonstrated a utility of MCA as a researcher–stakeholder engagement tool to devise means of sustainably enhancing agricultural productivity in forest landscapes while accounting for diverse stakeholder perceptions. The MCA models developed here, which are based on expert opinion, indicate that sustainable agriculture, or at least comparatively sustainable agriculture, is possible at the fringes of forest reserves without necessarily compromising forest conservation. Our models also explicitly demonstrate how opinions on land use and resource management vary amongst stakeholders, even proving contrary in some cases, as highlighted by farmers' relatively favourable appraisal of environmental costs (Figures 3B and 8B). Knowledge of such contrary perspectives is crucial to the success of any promotion of sustainable agricultural practices. For instance, hypothetically, the promotion of mixed-input systems over modern systems in Ghana on the grounds that the former are more environmentally sustainable may prove unconvincing to modern farmers inclined to view their modern system as similarly environmentally benign, as illustrated here (Figure 3). Conceivably, incentives to promote mixed systems and/or restrict modern systems on environmental grounds may prove inefficient or unattractive or, potentially, aggrieve farmers.

5. Conclusions

Upon consulting stakeholders of Ghanaian agricultural and forest management, we report their overall expert opinion that the environmental, social, and economic costs of farming systems employing agro-chemical inputs generally outweigh the benefits, with important caveats. First, farmers generally dissented from this summary view, given farmers' personal economic interests in a given farming system and the fact that related environmental costs are often externalised beyond the remit of the farmer who, not incidentally, stands to gain most of the benefits. Hence, farmers were consistently less concerned about the negative environmental impacts of modern farming and viewed their environmental benefits more favourably than other stakeholders. Farmers were also inclined towards the modern system due to its greater absolute economic returns. Second, although the mixed-input farming system also entails agro-chemicals, albeit to a relatively limited degree, it was reportedly more beneficial than costly overall according to all stakeholders collectively, as well as farmers individually, unlike the modern farming system. We argue that mixed-input farming system has the potential to be a relatively sustainable system for Ghanaian forest-fringe farmers, considering its limited use of agro-chemicals alongside economic attributes similar to those of the modern farming system. Further research on limiting factors potentially impeding the wider adoption of a mixed-input system is required.

This research is limited to stakeholder opinions. Experimental research to demonstrate the environmental and economic costs and benefits of the various agricultural practices would be a significant contribution to influence decisions towards agricultural sustainability in a conserved forest landscape.

Author Contributions: Conceptualisation, E.O.A., J.S., C.J.M. and S.S.; methodology, E.O.A. and C.J.M.; validation, J.S., C.J.M. and S.S.; formal analysis, E.O.A. and S.S.; investigation, E.O.A.; resources, E.O.A.; data curation, E.O.A.; writing—original draft preparation, E.O.A.; writing—review and editing, J.S., C.J.M. and S.S.; visualisation, E.O.A., J.S., C.J.M. and S.S.; supervision, J.S., C.J.M. and S.S.; project administration, E.O.A.; funding acquisition, E.O.A. and S.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the James Cook University Postgraduate Research Scholarship (JCUPRS 2017); the Rufford Foundation (grant number 23963-B); and a Canada Research Chair (T2) from The Canadian Tri-Agency Scientific Funding Body (CRC-2020-305, 'The Human Dimensions of Sustainability and Resilience').

Data Availability Statement: Data for this research are available on request.

Acknowledgments: We thank all the participants who responded to the survey.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Cost and benefit scores stakeholders assigned to the various statements/criteria representing modern farming.

Components	Indicators	Criteria	Definition of Criteria	Stakeholders' Scores for Cost Components				
				Foresters	**Ext. Agents**	**Env. NGOs**	**Agro-Eco. Researchers**	**Farmers**
Social costs	Human health	Infection	Infection from chemicals use	93	84	92	83	53
	Societal rejection	Rejection	Rejection of chemicals use	90	36	44	27	30
	Application	High skill	High skills requirement	77	48	44	37	84
Economic costs	Inputs	Herbicides, pesticides, fertilizers, improved seeds	Quantity/cost of pesticides and herbicides	77	72	92	80	90
			Quantity/cost of fertilizers	80	88	92	83	100
			Quantity/cost of improved seeds	80	72	76	87	76
		Number	Farm labour hired	92	52	68	57	64
		Frequency	Frequency of hired labour	67	55	52	60	70
Environmental costs	Pollution	Land	Land pollution from chemicals	97	72	92	97	76
		Water	Water pollution from chemicals	100	92	100	97	76
	Plant health	Crops	Negative effects of chemicals on crops	100	100	96	100	50
		Tree species	Negative effects of chemicals on trees	100	68	96	90	46
	Living organisms	Extinct	Extinction from pesticides	100	100	100	97	47
				Stakeholders' Scores for Benefit Components				
				Foresters	**Ext. Agents**	**Env. NGOs**	**Agro-Eco. Researchers**	**Farmers**
Social benefits	Food health	Nutrition	Nutrition from improved seed	80	88	72	100	84
	Happiness	Reduced poverty, food security	Reduced poverty and increased food security	87	76	76	90	89
		Improved seeds	Society accepts improved seeds	80	92	88	80	100
Economic benefits	Output	Yield, quantity	Improved yield and increased quantity	83	92	92	90	96
	Profitability	Early maturity, high price	Early maturity with associated high price	93	88	72	77	98
	Crop survival	Survival, resistance	High survival rate and resistance	97	88	88	97	100
Environmental benefits	Soil	Fertile	Fertile soil through fertilization	90	92	92	90	98
	Forest	Less encroached, stable	Less encroachment and stable forest	63	60	44	60	96

Table A2. Cost and benefit scores stakeholders assigned to the various statements/criteria representing mixed-input farming.

Components	Indicators	Criteria	Definition of Criteria	Stakeholders' Scores for Cost Components				
				Foresters	Ext. Agents	Env. NGOs	Agro-Eco. Researchers	Farmers
Social costs	Human health	Pesticides, herbicides	Infection from chemicals use	93	84	92	83	53
	Societal rejection	Rejection	Rejection of chemicals use	90	36	44	27	30
	Application	High skill	High skills requirement	77	44	44	37	84
Economic costs	Inputs	Pesticides, herbicides, fertilizers, manure/mulch, improved seeds	Quantity/cost of pesticides and herbicides	77	72	92	80	90
			Quantity/cost of fertilizers	80	88	92	83	100
			Quantity/cost of manure	20	20	27	28	20
			Quantity/cost of improved seeds	80	72	76	87	76
		Number	Farm labour hired	92	52	60	57	64
		Frequency	Frequency of hired labour	67	44	64	57	70
Environmental costs	Pollution	Land	Land pollution from chemicals	100	72	92	97	76
		Water	Water pollution from chemicals	100	92	100	97	76
	Plant health	Crops	Negative effects of chemicals on crops	100	100	92	100	50
		Tree species	Negative effects of chemicals on trees	100	68	96	90	46
	Living organisms	Extinct	extinction from pesticides	100	100	100	97	47
				Stakeholders' Scores for Benefit Components				
				Foresters	Ext. Agents	Env. NGOs	Agro-Eco. Researchers	Farmers
Social benefits	Food health	Nutrition	Nutrition from improved seed	80	88	72	100	84
	Happiness	Reduced poverty, food security	Reduced poverty and increased food security	87	76	76	90	91
	Societal acceptance	Crop rotation, manure/mulch, improved seeds	Society accepts crop rotation, manure usage, and improved seeds	80	92	88	73	100
	Application	Easy	Easy to apply manure and crop rotation	67	80	64	70	74
Economic benefits	Output	Yield, quantity	Improved yield and increased quantity	83	88	88	90	96
	Profitability	Early maturity, high price	Early maturity with associated high price	93	88	72	77	98
	Inputs	Cheap	Manure/Mulch is cheap	77	76	80	67	75
	Crop survival	Survival, resistance	High survival rate and resistance	97	88	88	97	100
Environmental benefits	Soil	Fertile	Fertile soil through fertilizer and manure	90	92	92	93	98
		Moist, conserved	Moist and conserved soil through manure	97	92	96	100	98
	Forest	Less encroached, stable	Less encroachment and stable forest	63	60	44	60	96

Table A3. Cost and benefit scores stakeholders assigned to the various statements/criteria representing traditional farming.

Components	Indicators	Criteria	Definition of Criteria	Stakeholders' Scores for Cost Components				
				Foresters	Ext. Agents	Env. NGOs	Agro-Eco. Researchers	Farmers
Social costs	Human health	Injury	Injury from manual work	92	72	72	87	82
		Burn	Burns from fire	90	76	84	90	90
		Risky	Risk of fire outbreak	97	76	84	90	62
Economic costs	Labour	Number	Farm labour hired	90	84	88	93	78
		Frequency	Frequency of hired labour	87	80	88	87	80
	Crops	Delayed	Delayed maturity of crops	63	48	64	60	88
		Survival	Low survival of crops due to no use of chemicals	50	68	60	83	84
Environmental costs	Fire	Soil	Soil burns from frequent fire	97	92	88	90	46
		Forest	Forest burns from frequent fire	97	88	96	97	30
		Life	Animal death through fire	97	92	88	90	72
		Other farms	Fire outbreak into other farms	97	88	96	97	52
		Air	Air pollution from fire	97	88	92	100	68
	Forest	Fragmentation	Fragmentation through slash-and-burn	83	80	88	80	96
				Stakeholders' Scores for Benefit Components				
				Foresters	Ext. Agents	Env. NGOs	Agro-Eco. Researchers	Farmers
Social benefits	Food health	Organic food	Nutrition from organic food	97	92	84	83	100
		Low infection	Low infection due to no chemical use	97	92	84	83	100
	Societal acceptance	Acceptance	Society accepts organic farming	83	84	72	77	78
		Food security	Food security through increased output from good maintenance of farms	93	84	84	83	74
Economic benefits	Output	Yield, income	Increased yield and income through good maintenance	97	88	88	87	76
		Long life	Long shelf life for organic foods	97	70	60	80	50
Environmental benefits	Soil	Conservation	Soil composition not disrupted with chemicals	87	76	72	80	84
		Fertility	Natural soil fertility	87	84	72	80	86
	Less pollution	Water, land	Less water and land pollution	87	88	60	67	80

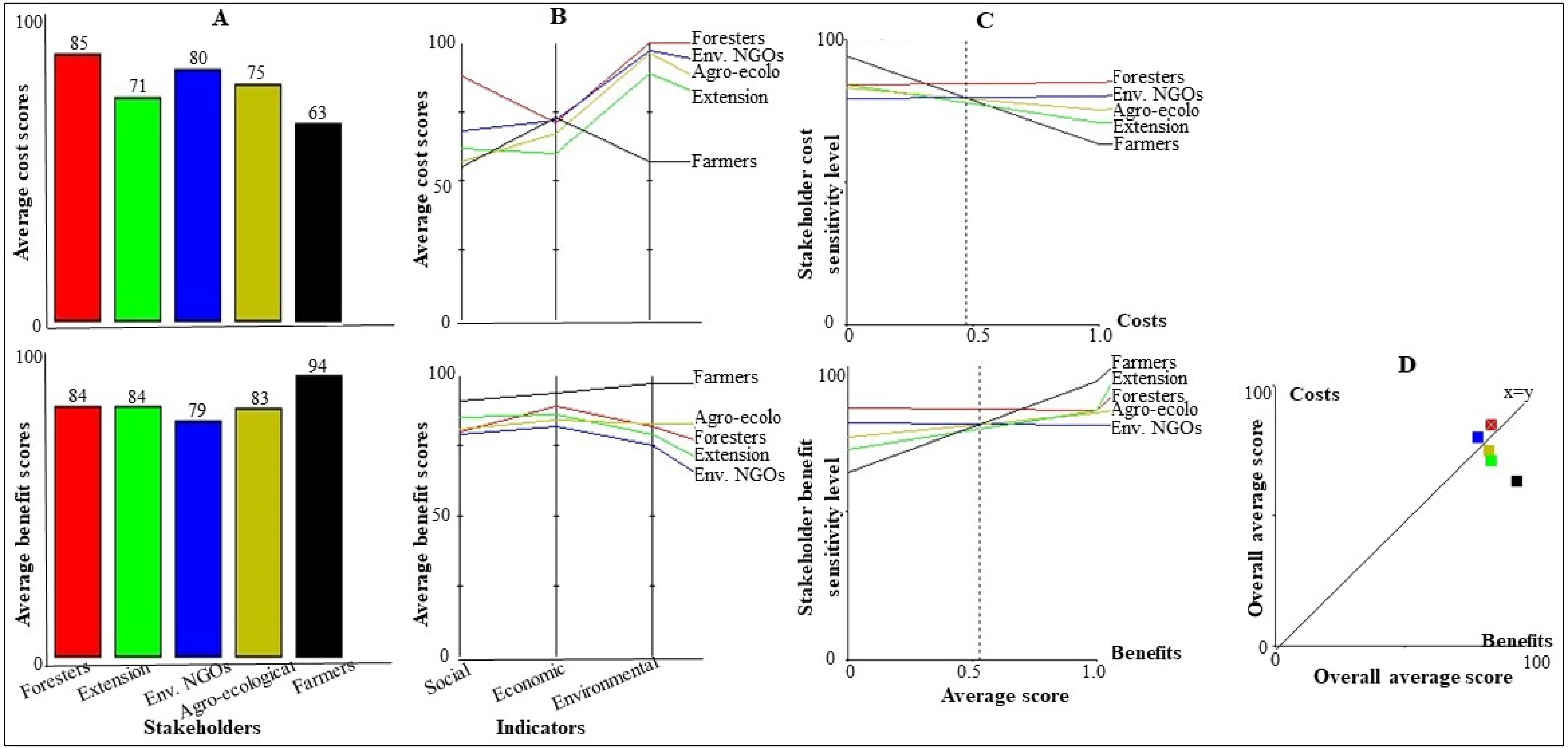

Figure A1. Stakeholder scores for costs and benefits of mixed-input farming based on an equally weighted MCA model. (**A**) presents the overall average cost and benefit scores from each stakeholder group. (**B**) presents the sum of the scores for social, economic, and environmental costs and benefits from each stakeholder group. (**C**) presents stakeholder sensitivity levels, denoting the degree of concern of a particular stakeholder for the mixed-input farming system. The stakeholder at a higher position on the *y*-axis in (**C**) is more sensitive to the cost or benefit of the mixed-input farming system than a stakeholder with a lower position on the *y*-axis. (**D**) presents stakeholders' cost–benefit ratio. The colour of the points denotes the stakeholders in (**A**–**C**).

References

1. Foley, J.A.; DeFries, R.; Asner, G.P.; Barford, C.; Bonan, G.; Carpenter, S.R.; Chapin, F.S.; Coe, M.T.; Daily, G.C.; Gibbs, H.K.; et al. Global consequences of land use. *Science* **2005**, *309*, 570–574. [CrossRef]
2. Meyfroidt, P.; Carlson, K.M.; Fagan, M.E.; Gutiérrez-Vélez, V.H.; Macedo, M.N.; Curran, L.M.; DeFries, R.S.; Dyer, G.A.; Gibbs, H.K.; Lambin, E.F.; et al. Multiple pathways of commodity crop expansion in tropical forest landscapes. *Environ. Res. Lett.* **2014**, *9*, 74012. [CrossRef]
3. FAO; IFAD; WFP. The State of Food Insecurity in the World 2015: Meeting the 2015 international hunger targets: Taking stock of uneven progress. *Adv. Nutr.* **2015**, *6*, 623–624.
4. Dicks, L.V.; Rose, D.C.; Ang, F.; Aston, S.; Birch, A.N.E.; Boatman, N.; Bowles, E.L.; Chadwick, D.; Dinsdale, A.; Durham, S.; et al. What agricultural practices are most likely to deliver "sustainable intensification" in the UK? *Food Energy Secur.* **2019**, *8*, e00148. [CrossRef]
5. Pretty, J. Intensification for redesigned and sustainable agricultural systems. *Science* **2018**, *362*, eaav0294. [CrossRef]
6. Pretty, J.; Bharucha, Z.P. Sustainable intensification in agricultural systems. *Ann. Bot.* **2014**, *114*, 1571–1596. [CrossRef]
7. Rockstrom, J.; Williams, J.; Daily, G.; Noble, A.; Matthews, N.; Gordon, L.; Wetterstrand, H.; DeClerck, F.; Shah, M.; Steduto, P.; et al. Sustainable intensification of agriculture for human prosperity and global sustainability. *Ambio* **2017**, *46*, 4–17. [CrossRef]
8. Struik, P.C.; Kuijper, T.W. Sustainable intensification in agriculture: The richer shade of green. A review. *Agron. Sustain. Dev.* **2017**, *37*, 39. [CrossRef]
9. Rudi, L.-M.; Azadi, H.; Witlox, F. Reconcilability of socio-economic development and environmental conservation in Sub-Saharan Africa. *Glob. Planet. Chang.* **2012**, *86*, 1–10. [CrossRef]
10. Ndlovu, E.; Prinsloo, B.; Roux, T.L. Impact of climate change and variability on traditional farming systems: Farmers' perceptions from south-west, semi-arid Zimbabwe. *Jàmbá J. Disaster Risk Stud.* **2020**, *12*, 1–19. [CrossRef]
11. Onyeiwu, S.; Pallant, E.; Hanlon, M. Sustainable and unsustainable agriculture in Ghana and Nigeria: 1960–2009. *WIT Trans. Ecol. Environ.* **2011**, *144*, 211. [CrossRef]
12. Raimi, A.; Adeleke, R.; Roopnarain, A. Soil fertility challenges and Biofertiliser as a viable alternative for increasing smallholder farmer crop productivity in sub-Saharan Africa. *Cogent Food Agric.* **2017**, *3*, 1400933. [CrossRef]
13. Ghana Statistical Service. *2010 Population and Housing Census: National Analytical Report*; Ghana Statistical Service: Accra, Ghana, 2013.
14. Henrich, J.; McElreath, R. Are peasants risk-averse decision makers? *Curr. Anthropol.* **2002**, *43*, 172–181. [CrossRef]
15. Mazvimavi, K.; Twomlow, S. Socioeconomic and institutional factors influencing adoption of conservation farming by vulnerable households in Zimbabwe. *Agric. Syst.* **2009**, *101*, 20–29. [CrossRef]
16. Mellon-Bedi, S.; Descheemaeker, K.; Hundie-Kotu, B.; Frimpong, S.; Groot, J.C.J. Motivational factors influencing farming practices in northern Ghana. *NJAS-Wagening. J. Life Sci.* **2020**, *92*, 100326. [CrossRef]
17. Steininger, M.K.; Tucker, C.J.; Ersts, P.; Killeen, T.J.; Villegas, Z.; Hecht, S.B. Clearance and Fragmentation of Tropical Deciduous Forest in the Tierras Bajas, Santa Cruz, Bolivia. *Conserv. Biol.* **2001**, *15*, 856–866. [CrossRef]
18. Hendershot, J.N.; Smith, J.R.; Anderson, C.B.; Letten, A.D.; Frishkoff, L.O.; Zook, J.R.; Fukami, T.; Daily, G.C. Intensive farming drives long-term shifts in avian community composition. *Nature* **2020**, *579*, 393–396. [CrossRef]
19. Randriamalala, J.R.; Hervé, D.; Letourmy, P.; Carrière, S.M. Effects of slash-and-burn practices on soil seed banks in secondary forest successions in Madagascar. *Agric. Ecosyst. Environ.* **2015**, *199*, 312–319. [CrossRef]
20. Kotu, B.H.; Alene, A.; Manyong, V.; Hoeschle-Zeledon, I.; Larbi, A. Adoption and impacts of sustainable intensification practices in Ghana. *Int. J. Agric. Sustain.* **2017**, *15*, 539–554. [CrossRef]
21. Emmanuel, D.; Owusu-Sekyere, E.; Owusu, V.; Jordaan, H. Impact of agricultural extension service on adoption of chemical fertilizer: Implications for rice productivity and development in Ghana. *NJAS-Wagening. J. Life Sci.* **2016**, *79*, 41–49. [CrossRef]
22. Tsinigo, E.; Behrman, J.R. Technological priorities in rice production among smallholder farmers in Ghana. *NJAS-Wagening. J. Life Sci.* **2017**, *83*, 47–56. [CrossRef]
23. Kassie, M.; Jaleta, M.; Shiferaw, B.; Mmbando, F.; Mekuria, M. Adoption of interrelated sustainable agricultural practices in smallholder systems: Evidence from rural Tanzania. *Technol. Forecast. Soc. Chang.* **2013**, *80*, 525–540. [CrossRef]
24. Coomes, O.T.; Grimard, F.; Potvin, C.; Sima, P. The fate of the tropical forest: Carbon or cattle? *Ecol. Econ.* **2008**, *65*, 207–212. [CrossRef]
25. Ikerd, J.E. Agriculture's search for sustainability and profitability. *J. Soil Water Conserv.* **1990**, *45*, 18–23.
26. Reij, C.; Tappan, G.; Belemvire, A. Changing land management practices and vegetation on the Central Plateau of Burkina Faso (1968–2002). *J. Arid. Environ.* **2005**, *63*, 642–659. [CrossRef]
27. Sloan, S. Tropical Forest Gain and Interactions amongst Agents of Forest Change. *Forests* **2016**, *7*, 55. [CrossRef]
28. RMSC. *Forest Reserves in Ghana*; RMSC: Ashanti Region, Ghana, 2016.
29. Norsworthy, J.K.; Ward, S.M.; Shaw, D.R.; Llewellyn, R.S.; Nichols, R.L.; Webster, T.M.; Bradley, K.W.; Frisvold, G.; Powles, S.B.; Burgos, N.R.; et al. Reducing the risks of herbicide resistance: Best management practices and recommendations. *Weed Sci.* **2012**, *60*, 31–62. [CrossRef]
30. Hayes, T.B.; Anderson, L.L.; Beasley, V.R.; de Solla, S.R.; Iguchi, T.; Ingraham, H.; Kestemont, P.; Kniewald, J.; Kniewald, Z.; Langlois, V.S.; et al. Demasculinization and feminization of male gonads by atrazine: Consistent effects across vertebrate classes. *J. Steroid Biochem. Mol. Biol.* **2011**, *127*, 64–73. [CrossRef]

31. Styger, E.; Rakotondramasy, H.M.; Pfeffer, M.J.; Fernandes, E.C.M.; Bates, D.M. Influence of slash-and-burn farming practices on fallow succession and land degradation in the rainforest region of Madagascar. *Agric. Ecosyst. Environ.* **2007**, *119*, 257–269. [CrossRef]
32. Acheampong, E.O.; Sayer, J.; Macgregor, C.J. Road improvement enhances smallholder productivity and reduces forest encroachment in Ghana. *Environ. Sci. Policy* **2018**, *85*, 64–71. [CrossRef]
33. Boserup, E. *The Conditions of Agricultural Growth: The Economics of Agrarian Change Under Population Pressure*; Earthscan Publications: London, UK, 1993.
34. Adjei-Nsiah, S. Role of pigeonpea cultivation on soil fertility and farming system sustainability in Ghana. *Int. J. Agron.* **2012**, *2012*, 702506. [CrossRef]
35. Omari, R.A.; Bellingrath-Kimura, S.; Addo, E.S.; Oikawa, Y.; Fujii, Y. 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* **2018**, *10*, 1034. [CrossRef]
36. Tambo, J.A.; Wünscher, T. Identification and prioritization of farmers' innovations in northern Ghana. *Renew. Agric. Food Syst.* **2015**, *30*, 537–549. [CrossRef]
37. Acheampong, E.O.; Sayer, J.; Macgregor, C.J.; Sloan, S. Factors influencing the adoption of agricultural practices in Ghana's forest-fringe communities. *Land* **2021**, *10*, 266. [CrossRef]
38. Alencar, L.H.; Almeida, A.T.d. A model for selecting project team members using multicriteria group decision making. *Pesqui. Oper.* **2010**, *30*, 221–236. [CrossRef]
39. Jeon, C.M.; Amekudzi, A.A.; Guensler, R.L. Evaluating plan alternatives for transportation system sustainability: Atlanta Metropolitan Region. *Int. J. Sustain. Transp.* **2010**, *4*, 227–247. [CrossRef]
40. Talukder, B.; Hipel, K.W.; vanLoon, G.W. Using multi-criteria decision analysis for assessing sustainability of agricultural systems. *Sustain. Dev.* **2018**, *26*, 781–799. [CrossRef]
41. Gibson, R.B. Sustainability assessment: Basic components of a practical approach. *Impact Assess. Proj. Apprais.* **2006**, *24*, 170–182. [CrossRef]
42. Pope, J.; Annandale, D.; Morrison-Saunders, A. Conceptualising sustainability assessment. *Environ. Impact Assess. Rev.* **2004**, *24*, 595–616. [CrossRef]
43. Convertino, M.; Baker, K.; Vogel, J.; Lu, C.; Suedel, B.; Linkov, I. Multi-criteria decision analysis to select metrics for design and monitoring of sustainable ecosystem restorations. *Ecol. Indic.* **2013**, *26*, 76–86. [CrossRef]
44. Bouma, J.; Broll, G.; Crane, T.A.; Dewitte, O.; Gardi, C.; Schulte, R.P.; Towers, W. Soil information in support of policy making and awareness raising. *Curr. Opin. Environ. Sustain.* **2012**, *4*, 552–558. [CrossRef]
45. Bampa, F.; O'Sullivan, L.; Madena, K.; Sandén, T.; Spiegel, H.; Henriksen, C.B.; Ghaley, B.B.; Jones, A.; Staes, J.; Sturel, S.; et al. Harvesting European knowledge on soil functions and land management using multi-criteria decision analysis. *Soil Use Manag.* **2019**, *35*, 6–20. [CrossRef]
46. Kamali, F.P.; Borges, J.A.R.; Meuwissen, M.P.M.; Boer, I.J.M.D.; Lansink, A.G.J.M.O. Sustainability assessment of agricultural systems: The validity of expert opinion and robustness of a multi-criteria analysis. *Agric. Syst.* **2017**, *157*, 118–128. [CrossRef]
47. Parra-López, C.; Calatrava-Requena, J.; de-Haro-Giménez, T. A multi-criteria evaluation of the environmental performances of conventional, organic and integrated olive-growing systems in the south of Spain based on experts' knowledge. *Renew. Agric. Food Syst.* **2007**, *22*, 189–203. [CrossRef]
48. Romero, C.; Rehman, T. *Multiple Criteria Analysis for Agricultural Decisions*, 2nd ed.; Elsevier: Amsterdam, The Netherlands, 2003.
49. Alary, V.; Gousseff, M.; Nidumolu, U.B. Comparison of multi-criteria decision models to approach the trade-off between environmental sustainability and economical viability—A case of nitrogen balance in dairy farming systems in Reunion Island. *J. Agric. Sci.* **2008**, *146*, 389–402. [CrossRef]
50. Ghana Statistical Service. *2010 Population and Housing Census: Regional Analytical Report, Ashanti Region*; Ghana Statistical Service: Accra, Ghana, 2013.
51. Acheampong, E.O.; Macgregor, C.J.; Sloan, S.; Sayer, J. Deforestation is driven by agricultural expansion in Ghana's forest reserves. *Sci. Afr.* **2019**, *5*, e00146. [CrossRef]
52. Kotey, E.N.A.; Francois, J.; Owusu, J.G.K.; Yeboah, R.; Amanor, K.S.; Antwi, L. *Falling into Place. Policy That Works for Forests and People Series No. 4*; International Institute for Environment and Development: London, UK, 1998.
53. Burton, R.J.F. Seeing through the 'good farmer's' eyes: Towards developing an understanding of the social symbolic value of 'productivist' behaviour. *Sociol. Rural.* **2004**, *44*, 195–215. [CrossRef]
54. Lowe, P.; Murdoch, J.; Marsden, T.; Munton, R.; Flynn, A. Regulating the new rural spaces: The uneven development of land. *J. Rural. Stud.* **1993**, *9*, 205–222. [CrossRef]
55. Hongoh, V.; Hoen, A.G.; Aenishaenslin, C.; Waaub, J.-P.; Bélanger, D.; Michel, P.; The Lyme-MCDA Consortium. Spatially explicit multi-criteria decision analysis for managing vector-borne diseases. *Int. J. Health Geogr.* **2011**, *10*, 70. [CrossRef]
56. Linares, P.; Romero, C. A multiple criteria decision making approach for electricity planning in Spain: Economic versus environmental objectives. *J. Oper. Res. Soc.* **2000**, *51*, 736–743. [CrossRef]
57. Jilito, M.F.; Wedajo, D.Y. Trends and challenges in improved agricultural inputs use by smallholder farmers in Ethiopia: A review. *Turk. J. Agric. Food Sci. Technol.* **2020**, *8*, 2286–2292. [CrossRef]

58. Pelletier, J.; Ngoma, H.; Mason, N.M.; Barrett, C.B. Does smallholder maize intensification reduce deforestation? Evidence from Zambia. *Glob. Environ. Chang.* **2020**, *63*, 102127. [CrossRef]
59. Huang, X.; Liu, L.; Wen, T.; Zhu, R.; Zhang, J.; Cai, Z. Illumina MiSeq investigations on the changes of microbial community in the Fusarium oxysporum f.sp. cubense infected soil during and after reductive soil disinfestation. *Microbiol. Res.* **2015**, *181*, 33–42. [CrossRef]
60. Pradhan, P.; Fischer, G.; van Velthuizen, H.; Reusser, D.E.; Kropp, J.P. Closing yield gaps: How sustainable can we be? *PLoS ONE* **2015**, *10*, e0129487. [CrossRef]
61. Arias-Estévez, M.; López-Periago, E.; Martínez-Carballo, E.; Simal-Gándara, J.; Mejuto, J.-C.; García-Río, L. The mobility and degradation of pesticides in soils and the pollution of groundwater resources. *Agric. Ecosyst. Environ.* **2008**, *123*, 247–260. [CrossRef]
62. Athukorala, W.; Wilson, C.; Robinson, T. Determinants of health costs due to farmers' exposure to pesticides: An empirical analysis. *J. Agric. Econ.* **2012**, *63*, 158–174. [CrossRef]
63. Kabir, M.H.; Rainis, R. Adoption and intensity of integrated pest management (IPM) vegetable farming in Bangladesh: An approach to sustainable agricultural development. *Environ. Dev. Sustain.* **2015**, *17*, 1413–1429. [CrossRef]
64. Bie, H.M.A.D.; Oostrom, K.J.; Waal, H.A.D.-V.D. Brain development, intelligence and cognitive outcome in children born small for gestational age. *Horm. Res. Paediatr.* **2010**, *73*, 6–14. [CrossRef] [PubMed]
65. Haraux, E.; Tourneux, P.; Kouakam, C.; Stephan-Blanchard, E.; Boudailliez, B.; Leke, A.; Klein, C.; Chardon, K. Isolated hypospadias: The impact of prenatal exposure to pesticides, as determined by meconium analysis. *Environ. Int.* **2018**, *119*, 20–25. [CrossRef]
66. Bruner-Tran, K.L.; Osteen, K.G. Developmental exposure to TCDD reduces fertility and negatively affects pregnancy outcomes across multiple generations. *Reprod. Toxicol.* **2011**, *31*, 344–350. [CrossRef] [PubMed]
67. Wickerham, E.L.; Lozoff, B.; Shao, J.; Kaciroti, N.; Xia, Y.; Meeker, J.D. Reduced birth weight in relation to pesticide mixtures detected in cord blood of full-term infants. *Environ. Int.* **2012**, *47*, 80–85. [CrossRef] [PubMed]
68. Skevas, T.; Stefanou, S.E.; Lansink, A.G.J.M.O. Do farmers internalise environmental spillovers of pesticides in production? *J. Agric. Econ.* **2013**, *64*, 624–640. [CrossRef]
69. Smith, A.; Snapp, S.; Dimes, J.; Gwenambira, C.; Chikowo, R. Doubled-up legume rotations improve soil fertility and maintain productivity under variable conditions in maize-based cropping systems in Malawi. *Agric. Syst.* **2016**, *145*, 139–149. [CrossRef]
70. Fung, K.M.; Tai, A.P.K.; Yong, T.; Liu, X.; Lam, H.-M. Co-benefits of intercropping as a sustainable farming method for safeguarding both food security and air quality. *Environ. Res. Lett.* **2019**, *14*, 44011. [CrossRef]