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Northern Ghana Land Use Ecosystem Service and Economic Valuation Study

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Ghana Agriculture and Natural Resource Management Project

Northern Ghana Land Use Ecosystem Service and Economic Valuation Study

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EXECUTIVE SUMMARY

Mounting pressure from population growth, natural resource shortages, development demands, and an increasingly erratic climate has left communities in northern Ghana to face significant challenges in balancing short-and long-term food security and financial needs. Produced under the USAID AgNRM project, *The Northern Ghana Land Use Ecosystem Service and Economic Valuation Study* is an assessment of the economic and environmental implications of land uses as well as changes in land use. By offering a scientifically credible and holistic assessment of the value of common land uses in northern Ghana, it may serve as a useful resource for land users and decision makers looking to engage in sustainable, balanced land use planning.

Northern Ghana Land Use Ecosystem Service and Economic Valuation Study is the product of a series of analyses of the ecosystem services and values associated with ten common land uses in Northern Ghana. These analyses include a quantification of the greenhouse gas impacts; the application of models to simulate rates of erosion; aquifer recharge; nutrient and sediment runoff; an economic analysis of net present value; and a qualitative assessment of the climate resilience and biodiversity associated with selected land uses.

Among the results, the study clearly shows the importance of natural forests and land uses with trees and vegetation for regulating water supply and greenhouse gas emissions, enhancing climate resilience, and providing biodiversity benefits. The analyses also highlight how economically undervalued natural forests are, given the economic value of goods and services they provide. Results also point to the potentially significant environmental and economic benefits associated with climate-smart agricultural practices.

To more effectively convey the results of this study to communities and broad audiences, two accompanying products have been developed: the *Eco Game* and the *Visual Land Use Planning Guide*. Informed by the *Northern Ghana Land Use Ecosystem Service and Economic Valuation Study*, they employ a highly user-oriented, interactive approach that distills the results and clearly present the impact of land uses and land use changes in northern Ghana. The *Eco Game* is an interactive multi-player game in which users or players attempt to build a sustainable community by selecting land uses that provide for community needs and are resilient to shocks and natural disasters. The *Visual Land Use Planning Guide* uses graphics rather than text to communicate the impact of land use changes. Designed as a flip chart, each type of land use change and associated economic and environmental impacts is presented on a single laminated page using graphics. A more detailed explanation of this communication approach is offered in the Communicating Impacts of Land Use Transitions section of this report.

By translating the complex analyses and results of this report into a highly visual, intuitive format, communities may be better engaged and empowered to adopt land use practices and planning that improve overall sustainability in terms of both economic and environmental outcomes.

INTRODUCTION

Mounting pressure from population growth, natural resource shortages, development demands, and an increasingly erratic climate has left communities in northern Ghana facing significant challenges with regard balancing their short-and long-term needs. Decisions made by land users, such as farmers, fuelwood collectors, and shea butter producers, have a sizeable impact on the landscape, and over time, extraction of natural resources and unsustainable land use practices have led to the degradation of vitally important ecosystem services in northern Ghana. This has a devastating impact on livelihoods, and on health and security, disproportionately affecting the most vulnerable.

Under the USAID AgNRM project, the *Northern Ghana Land Use Ecosystem Service and Economic Valuation Study*, (herein referred to simply as the *Land Use Impact Study*) has been developed as a resource for land stewards to develop a more holistic understanding of the short and long-term consequences of land uses and changes in land use. Developed through a series of scientific analyses, water modeling, and economic analyses, it offers a credible and valuable assessment of the impacts of land uses in northern Ghana. By accounting for both financial and environmental impacts, the *Land Use Impact Study* offers land stewards a more complete evaluation, allowing for more balanced, informed land use planning.

The Northern Ghana Land Use Ecosystem Service and Economic Valuation Study offers clear and compelling information about the financial and environmental implications of land use and land use changes to help communities improve environmental stewardship and enhance resilience.

The process of developing the *Land Use Impact Study* was stakeholder driven, involving consultations with local experts and relevant stakeholders to ensure both that key assumptions and variables appropriately reflected local conditions and practices, and that the analysis would be pertinent and useful to communities. Data collection included field research, consultations, and literature reviews. The analyses themselves were completed by expert economists, greenhouse gas accounting specialists, and hydrological modelers. The resulting assessment is a scientifically robust, geographically specific evaluation of the water and climate impacts, as well as the net present value (NPV) for each of those ten land uses. Furthermore, an expert qualitative assessment of the relative values each land use has for biodiversity and climate resilience has been included to further support holistic decision-making.

The Land Use Impact Study serves as the basis for an accompanying set of products to support land use planning. To improve the accessibility of the study’s results to broad audiences, these products attempt to translate and distil the results using a highly user-focused communication approach. The *Eco Game* is an interactive multi-player game in which users or players attempt to build a sustainable community by selecting land uses that provide for community needs and are resilient to shocks and natural disasters. The *Visual Land Use Planning Guide* uses graphics rather than text to communicate the impact of land use changes. Designed as a flip chart, each type of land use change and associated economic and environmental impacts are presented on a single laminated page using graphics. A more detailed explanation of this communication approach is offered in the Communicating Impacts of Land Use Transitions section of this report.

Overview of the Land Use Impact Study for Northern Ghana

The Land Use Impact Study is the result of separate analyses examining the economic value and ecosystem services associated with a set of land uses that reflect the Northern Ghanaian landscape. The land uses were selected through a process of in-country consultations and literature review of practices in Northern Ghana, and are depicted in Figure 1. Details on the assumptions for each scenario are provided in Annex 1.

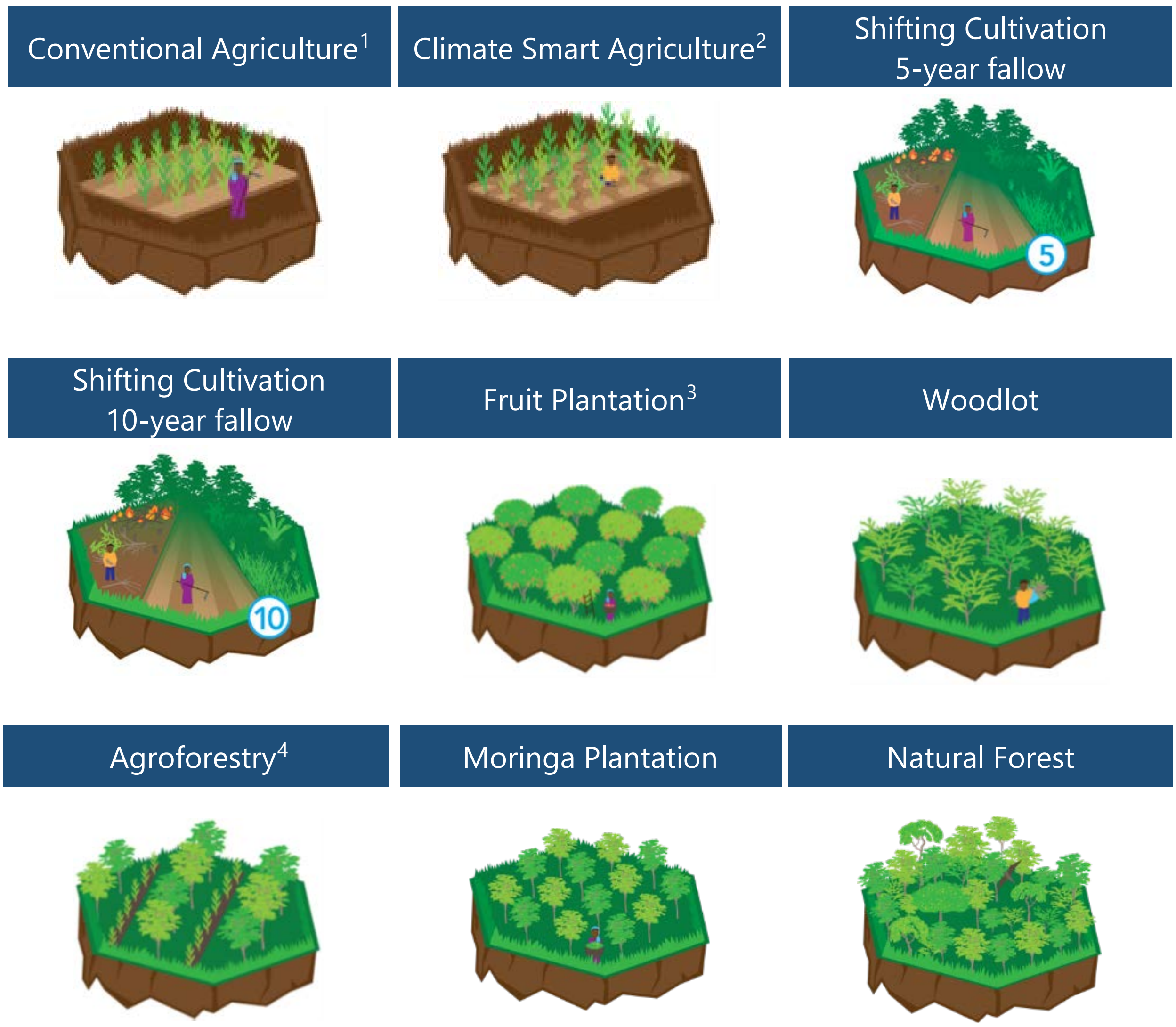


Figure 1: Land uses included in the analysis (bare land not depicted)

The analyses of the economic value and ecosystem services associated with each land use were

[1] Maize cultivation, application of synthetic fertilizers, full tillage
[2] Manure fertilization, reduced tillage using a ripper, soil moisture conservation and fertilization through mulching, and stone ridging for soil conservation and reduction of water runoff
[3] Mango and cashew
[4] Cashew and corn intercropping

developed through a set of scientific and economic methods and approaches that applied information sourced from field data collection, literature review, and stakeholder consultation. In addition to quantifying the economic and ecosystem service values of each individual land use, the impact of transitioning between land uses was also quantified to support those responsible for making land use decisions in weighing environmental and financial implications.

The analyses are grouped into two broad categories: 1) Economic, and 2) Ecosystem Services, which is subdivided into a set of subcategories, including hydrological, climate and biodiversity (see Figure 2).

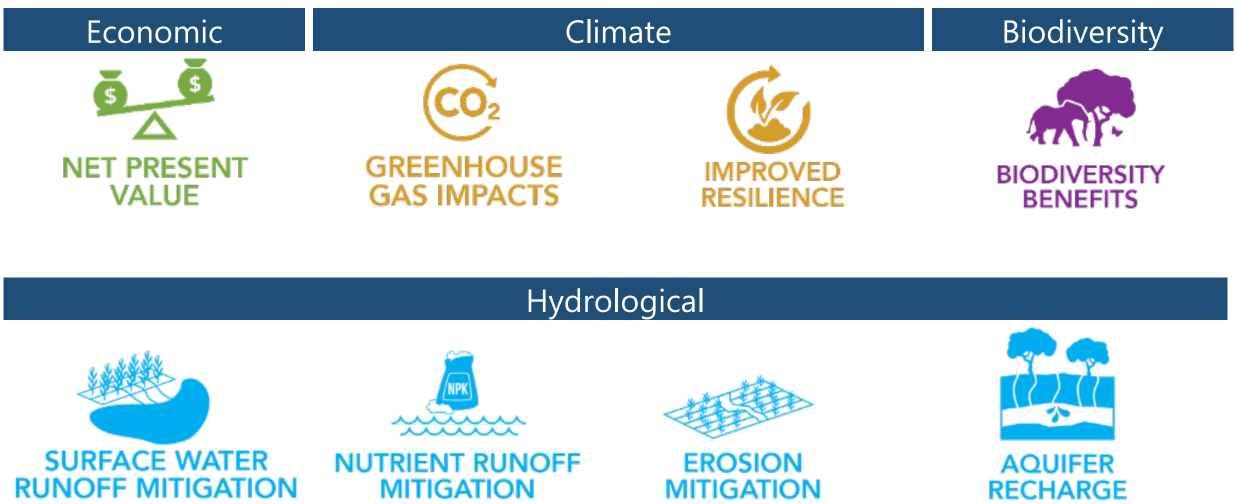


Figure 2**: Indicators used to** assess the value of economic and ecosystem services

The Land Use Impact Study will summarize the results of the analyses described below, but will not articulate of the dynamics behind the transitions. Rather, it will take the form of a flip chart, with full pages dedicated to specific transitions, using graphics, and icons to clearly communicate impacts of land use changes. More details on this are provided in the Communicating Impacts of Land Use Transitions section of this report.

ANALYSES

Economic Value of Land Uses

Economic factors are almost always among the most important drivers of land use decisions and are essential to consider in balanced and realistic land use management and planning. The economic assessment of land uses included in the Land Use Impact Study was conducted by natural resource economists, who quantified the 'net present value' (NPV) for each land use as well as the costs and/or benefits associated with transitioning from one land use to another. The net present value includes an inflation adjustment for economic gains made in the future.

The NPV represents the revenue from each land use minus the costs, providing a holistic assessment of the net income that land use would provide. For example, in the case of annual crops, costs are expended at the beginning of the season for planting, fertilizing, etc. and labor and/or equipment are employed for harvesting and getting the product to market. The NPV of that land use is the benefits of the sale of the crops minus the costs of the activities (factoring in necessary discounts for the interest rate).

Estimated changes in land value (NPV) from converting from one use include any land clearing costs and stump removal (usually by burning), as well as any benefits that arise from land clearing, such as selling fuelwood[5]. The effect of the change on land value was quantified as follows:

CHANGE = NEW LAND VALUE − ORIGINAL LAND VALUE + CONVERSION COSTS

Full details on the economic analysis are available in (Sohngen et al. 2017).

Ecosystem Services Provided by Land Uses

The Millennium Ecosystem Assessment defines ecosystem services as the provisioning (e.g. water resources), regulating (e.g. climate regulation, water quality), cultural (e.g. aesthetic), and supporting (e.g. soil formation) benefits that people obtain from ecosystems (Millennium Ecosystem Assessment, 2005). Ecosystem services are components of the environment like clean water, air, and soil that form the foundation of food production, timber and non-timber resources, nutrient cycling, water availability, and control of the global climate.

[5] For the purposes of this analysis we have not assumed higher value uses of wood, such as lumber or log export markets, and have assumed that all wood is used for fuelwood. This may undervalue the natural forest option, given that some natural forests may contain valuable species.

The ecosystem services included in this assessment were identified through research and a stakeholder consultation process.[6] Representatives from the Forestry Commission, Environmental Protection Agency, the Water Resources Commission, the Wildlife Division, the Ghana Water Company, Traditional Authorities in the Red and White Volta Basin (including representatives from CREMAs), and representatives from NGOs and universities in Ghana were all engaged in the selection process. The result was the identification of the following most highly valued ecosystem services for the region:

- Natural resource products such as shea and moringa;
- Water quality and availability;
- Fuelwood/charcoal;
- Vegetation cover to control soil erosion and soil fertility;
- The role of greenhouse gases on climate regulation.

Based on the results of the consultation and the availability of data, methods, and resources to carry out the analysis of ecosystem services, the following analyses were undertaken.

Payment for Ecosystem Services

While natural ecosystems provide highly valuable services, these functions are most often provided free of charge. As such, they are frequently taken for granted and undervalued. One way to recognize the real significance of these essential services is to assign monetary value to them. Payment for ecosystem services (PES) schemes provide a market mechanism that incentivizes practices that protect ecosystem services by assigning a monetary value to carbon, water, etc.

PES schemes are built upon carefully identified and defined ecosystem services that are reliably measured and monitored. Ghana has an emerging REDD+ program that, once operational, will serve to incentivize policies and interventions that avoid deforestation and degradation through results-based payments for emission reductions. However, there are currently no PES schemes in northern Ghana that directly engage stakeholders at the community level by offering results-based payments for interventions that preserve ecosystem services.

Therefore, this study offers a credible exploration of the value of ecosystem services in northern Ghana, serving as a first step in identifying and quantifying relevant ecosystem services in the region. By measuring the impact that different land use decisions have on key ecosystem services, it could provide a basis to identify the tangible benefits that could be of value to potential buyers in a PES scheme.

Water Impacts

Water is at the heart of critical ecosystem services throughout the world, and northern Ghana is no exception. During the wet season, the region is often subject to severe flooding that damages houses and roads, removes fertile topsoil from farmers' fields, and puts lives at risk. The dry season

[6] For more information on the background research see: Grais A.M. et al. 2016. Ecosystem Valuation in Northern Ghana Background Report. USAID Agriculture and Natural Resource Management Program

brings the opposite problem, when drought causes crops to fail and leaves communities with insufficient freshwater sources. Natural ecosystems play an important role not only in providing freshwater, but also in improving the quality of rainfall as it filters through vegetation, regulating flow, lessening the impact of floods, and preventing soil from eroding off fields. This provision and regulation can be referred to as water-based ecosystem services.

Water-based ecosystem services were evaluated through four main indicators. For each land-use transition, the Soil and Water Assessment Tool (SWAT) was employed to quantify the impacts on the following ecosystem services (more details on methods can be found in Annex 2).

Surface water runoff mitigation refers to the ability of a land use to slow down rainfall that reaches the surface and travels on, or "runs off" the surface into streams, rivers or other water bodies. When water takes a longer time to run off and reach streams and rivers, floods tend to be less intense and occur longer after a rainstorm, allowing for more warning to be given to nearby communities. Slowing surface runoff also gives water the time necessary to seep into groundwater aquifers. Land uses with more surface vegetation such as grasses, leaves, sticks, and shrubs create more obstacles for water, thus slowing its flow.

Nutrient runoff mitigation refers to the ability of a land use to prevent nutrients such as nitrogen and phosphorous from reaching streams, rivers, and other water bodies. Nutrients can come from the natural soil, fertilizer, manure, pesticides or other sources, and are often transported by water runoff.

High rates of nutrient runoff can pollute bodies of water and lead to algae blooms. A rapid increase in algae can deplete available oxygen in these bodies of water, harming fish populations and ecosystems. This can have direct, negative consequences for communities and cities that depend on these for drinking water, and can also have financial implications for industries, such as fisheries and beverage companies that rely on healthy waterways

Erosion mitigation refers to the ability of a land use to prevent soil from being transported off the land. When rainstorms occur, water running across the land surface carries soil with it, transporting it elsewhere and is often ultimately deposited in waterways. The rate of erosion is affected by the type and state of the soil, the topography, and the intensity and frequency of precipitation -- soils that are more disturbed and that have less protective vegetation are more vulnerable to erosion.

High rates of erosion can lead to a loss of productive topsoil in agricultural areas, as well as destabilized soils that cause landslides. Increases in sediment deposited in streams and waterways can cause problems for aquatic species by reducing water quality and aquatic habitat. High sediment loads in water bodies can also negatively impact important infrastructure (irrigation and dams), and disrupt irrigated agriculture, imposing higher operating costs for hydroelectric facilities and water treatment plants.

Aquifer recharge is the process by which the water table or aquifer is replenished with water. It is an important component of the water cycle: precipitation delivers water from the atmosphere, which then either flows into rivers or streams, is absorbed by vegetation, evaporates back into the atmosphere, or seeps into the aquifer. The rate at which aquifers are recharged depends on complex relationships between precipitation, evaporation, land use, soil characteristics and topography. Slowing surface runoff through maintaining ground vegetation can help to increase rates of aquifer recharge by giving water time to infiltrate the soil.

Aquifers, accessed by wells, are important sources of drinking water and irrigation to communities in northern Ghana, especially during the dry season. In northern Ghana, the average annual total rainfall is 800 to 1,200 mm, and only a small fraction of that reaches local aquifers given the high rates of evapotranspiration associated with the tropical climate. As the analysis for this study revealed, where land is forested, as much as 30% of rainfall can infiltrate, the soil to reach aquifers but on bare land this decreases to less than 1%. Given per capita water needs for cooking, drinking, cleaning, as well as agriculture and industry, this difference in terms of 'recovery' of rainfall is highly important. Furthermore, as the impacts of climate change intensify, rainfall is likely to become more erratic, amplifying the importance of maintaining a steady source of freshwater stored in aquifers.

Climate Regulation and Resilience

Land use management practices and changes in land use result in greenhouse gas (GHG) emissions. When carbon stored in vegetation is released into the atmosphere as carbon dioxide or when vegetation is burned releasing methane and nitrous oxide, these emissions contribute to atmospheric greenhouse gas levels, driving climate change. In addition, when forests are cleared, their capacity for additional carbon sequestration is lost or reduced. Converting land to agriculture can further contribute to climate change, as soil disturbance from tilling and fertilizer use are also sources of emissions. Conversely, planting trees leads to the gradual removal of carbon dioxide from the atmosphere.

Climate change is already being felt in northern Ghana. The region has experienced pronounced droughts, a shift of the onset of the rainy season from April to May, and an increase in dry spells during the rainy season (Hulme, 2001; Laux et al. 2008). This trend is predicted to become increasingly pronounced, impacting harvests and escalating food insecurity (Laube et al. 2012; Van de Giesen et al. 2010).

Climate-based ecosystem services for each land use and land use transition were evaluated for their overall GHG impacts, reflecting both carbon dioxide (CO_2) emissions and sequestration associated with the land use. In this analysis, GHG impacts were estimated by quantifying the amount of carbon contained in each land use, as well as any additional emissions associated with soil management, fertilizer use, and soil emissions. That information was used to construct emission factors (t CO_2e ha^{-1} yr^{-1}) for each land use transition, representing the net increase or decrease of GHG emissions resulting from converting one land use to another over the course of twenty years after transition[7].

Africa is among the most vulnerable regions in the world to the impacts of climate change, and Ghana is no exception. The country's dependence on rain-fed agriculture, combined with the increased risks for natural disasters such as drought and flooding associated with climate change mean that there is a need to adopt land use and management practices that are resilient to these shocks (Asafu-Adjaye 2013).

Features of climate-resilient land use practices include tolerance to environmental shocks and long-term climate variability, as well as agricultural systems that are more productive and use inputs such as water and fertilizer more efficiently (Holmgren, 2012). Capacity for improving or sustaining the provision of vital ecosystem services is another important feature of climate resilience (FAO 2013) as it can lower long-term vulnerability to environmental shocks and stressors.

For this analysis, the relative level of climate resilience each land use reflects was determined based on a qualitative assessment of its capacity to withstand shocks and risks associated with the impacts of climate change in northern Ghana, including drought, flooding, and temperature increases.

Biodiversity

The health and viability of human populations is intrinsically tied to the web of living organisms and natural resources they exist within. Other living organisms perform essential functions needed to maintain all components necessary for human survival, including food and clean water. Plants and animals are not only sources of food, but perform essential functions that build and maintain soil fertility, pollinate food crops, provide medicine and material for clothing and shelter, and serve important cultural, spiritual, and emotional functions.

Each land use offers a unique array of potential habitats and food sources for flora and fauna. Some land uses are inherently more conducive to the survival of a larger variety of flora and fauna than others, depending on levels of heterogeneity and how close the land use is to the 'natural

[7] This timeframe was selected to accurately reflect the potential CO_2 sequestration that tree crops or treed ecosystems offer, gradually sequestering biomass as trees grow. In addition, soil disturbances that accompany land use change result in emissions from soil that happen gradually over the course of 20 years post-transition, and thus this timeframe most accurately captures the total GHG impact the land use change has.

state' (Fahrig et al. 2010).

For this analysis, a qualitative assessment was made to determine what land uses offer a higher level of biodiversity and the associated benefits based on expert opinion and published literature. More details on the assessment of biodiversity benefits associated with each land use are available in Annex 2.

RESULTS AND DISCUSSION

This study brought together a set of independent analyses that examined the economic and environmental impacts of land uses and land use change, and the findings clearly illuminate the importance of balancing financial goals with ecological sustainability. The results are presented below, starting with the economic and ecosystem service values of each land use, followed by the impact of switching from one land use to another.

Land Use Values

The table below shows the estimated economic and ecosystem service values associated with each land use. Values are color coded to reflect overall positive (green), moderate (grey), and negative (red) value.

Table 1: Quantified ecosystem services and economic value of assessed land uses

Estimated Ecosystem Services and Economic Value	**Bare Land**	**Conventional Agriculture**	**CSA[8] with Manure**	**CSA - Ripper**	**CSA – Mulching**	**CSA – Stone Ridging**	**SC[9] 5- year fallow**	**SC 10 -year fallow**	**Agroforestry**	**Moringa**	**Fruit Plantation**	**Fuel wood Plantation**	**Natural Forest**
Sediment (erosion) (tons/ha/year)	40	14	13	14	1	2	5	2	0.8	0.8	0.8	0.2	0.02
Surface Runoff (mm)	523	308	307	308	269	218	145	119	213	213	213	103	93
Nutrient Runoff (tons/ha/year)	0.86	0.18	0.54	0.18	0.15	0.11	0.03	0.02	0.04	0.04	0.04	0.02	0.01
Aquifer Recharge (mm/ha/year)	10	62	65	62	91	135	261	298	88	88	88	279	313
GHG Emissions/ Sequestration ($t\ CO_2\ ha^{-1}\ yr^{-1}$)	1	2	7	2	2	2	2	2	-5	-17	2	-7	-1
Biodiversity Value	Low	Low	Low	Low	Low	Low	Medium	Medium	Medium	Low	Medium	Low	High
Climate Resilience	Low	Low	Medium	Medium	Medium	Medium	Medium	Medium	High	High	Medium	High	High
NPV (GH¢/ha)	0	6,550	7,890	4930	6600	ID†	4,910	3,770	4,050	3,260	2,680	1,890	6,630

†Insufficient data

Unsurprisingly, the natural forest offers the highest ecosystem service values, generally followed by the other land uses with trees (fuelwood, fruit plantations, moringa, agroforestry). While natural forests offer the highest benefits in terms of water ecosystem services, their rate of GHG

[8] Climate Smart Agriculture
[9] Shifting Cultivation

sequestration rate is somewhat lower than some of the other land uses such as moringa and agroforestry which specifically incorporate fast growing tree species. The GHG sequestration of moringa was found to be particularly high, though published studies and literature on the climate impacts of this fast-growing, drought-resistant tree are very limited[10].

Forests also have a relatively high NPV due to the estimated revenue from sustainable fuelwood collection (5 m^3 ha^{-1} yr^{-1} without the need for purchasing inputs or significant labor) and shea. It should be noted that the estimation of forest NPV did not include potential additional revenue from (or costs associated with) other non-timber forest products such as medicine or bush meat, and thus the presented NPV likely undervalues forest to some degree.

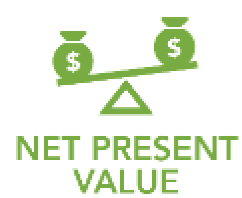
The other land uses that were found to have the highest economic returns were conventional agriculture, CSA-Manure, and CSA-Mulching. It should be noted, however, that there was limited data on the specific costs of the CSA practices assessed in this study, and thus many of the assumptions and results from (Ng'ang'a et al. 2017) were applied[11]. That said, stone ridging or comparable CSA interventions were not examined in that study, and due to insufficient data on the economic variables associated with stone ridging, an estimate of the NPV is not available for that practice.

Impact of Land Use Changes

A series of transition matrices were developed to present the impacts of transitioning between land uses assessed through this study: bare land, conventional agriculture, climate smart agriculture (CSA) manure, CSA ripper, CSA mulching, CSA stone ridging, agroforestry, 5-year fallow cycle shifting cultivation, 10-year fallow cycle shifting cultivation, moringa plantations, cashew plantations, mango plantations, woodlots, and natural forest (Tables 2-7).

Economic Impacts

Estimated changes in land value (NPV) when converting from one use to another are presented in Table 2 below. The analysis of NPV was developed using field data as well as other best available resources for determining management practices, labor implications, cost of inputs, and market prices. For more information, see Sohngen, B., Haruna, B., Smoot, J., 2017. Economic Analysis of Alternative Land Uses in Ghana. Prepared by Sylvan Acres Limited Liability Company for Winrock International.



Colors indicate the magnitude of changes in NPV: red cells represent a negative change in value and green cells represent an increase in value. Color saturation indicates the magnitude of economic impact, with the darkest green representing an increase in value of greater than 7,000

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[10] Almost all sources cite a single study conducted in Japan (Villafuerte et al. 2009).

[11] Specifically, from the 'minimum tillage' and 'improved nutrient management' practices examined by Ng'ang'a S.K et al 2017.

GH¢, the medium green color represents an increase in value between 3,000 and 7,000 GH¢, and the lightest green representing an increase in value of less than 3,000 GH¢. The darkest red represents a loss in value of greater than 7,000 GH¢, the medium red color represents a decrease in value between 3,000 and 7,000 GH¢, and the lightest green representing a decrease in value of less than 3,000 GH¢.

Land uses in the first column are the pre-transition land use, and those in the top row are land uses converted to.

Table 2: Estimated economic impacts (changes in NPV) of land use transitions

TO / FROM	Bare land	Conventional Agriculture	CSA Manure	Min till/Nut Mgmt. crop (mulching)	Min Till crop (Ripper)	5-year fallow	10-year fallow	Agroforestry	Moringa Plantation	Mango Plantation	Cashew Plantation	Fuelwood Plantation	Natural Forest
Bare land		6550	7883	6600	4933	4907	3766	4045	3255	482	4875	2887	6629
Conventional Agriculture	-6550		1333	50	-1617	-1643	-2784	-2505	-3295	-6068	-1675	-3663	79
CSA Manure	-7883	-1333		-1283	-2950	-2977	-4117	-3838	-4628	-7402	-3009	-4996	-1254
Min Till/Nut Mgmt. crop (Mulching)	-6600	-50	1283		-1667	-1693	-2834	-2555	-3345	-6118	-1725	-3713	29
Min Till crop (Ripper)	-4933	1617	2950	1667		-27	-1167	-888	-1678	-4452	-59	-2046	1696
5-year fallow	-4907	1643	2977	1693	27		-1141	-862	-1652	-4425	-32	-2019	1723
10-year fallow	-3766	2784	4117	2834	1167	1141		279	-511	-3284	1109	-878	2863
Agroforestry	-4083	2467	3800	2517	850	824	-317		-828	-3601	792	-1195	2546
Moringa Plantation	2407	8957	10290	9007	7340	7314	6173	6452		2889	7282	5294	9036
Mango Plantation	-767	5783	7117	5833	4167	4140	2999	3278	2488		4108	2121	5863
Cashew Plantation	-4913	1637	2971	1687	21	-6	-1147	-868	-1658	-4431		-2025	1717
Fuelwood Plantation	632	7182	8516	7232	5566	5539	4398	4677	3887	1114	5507		7262
Nat. Forest	3190	9740	11074	9790	8124	8097	6956	7235	6445	3672	8065	6078	

This analysis highlights the economic gains associated with clearing forests or tree crops, largely due to the assumption that cleared trees could be sold for fuelwood. Nevertheless, there are apparent economic gains in transitioning permanent agriculture to natural forest, though successful re-establishment of natural forests, especially those including productive shea, require a substantial amount of time as shea can take 15-20 years to bear fruit (Place et al. 2016).

Conversion to mango plantations overall appears to have negative economic impacts, largely due to the higher use of fertilizers and herbicides associated with mango cultivation. Furthermore, given the already generally arid conditions in northern Ghana, this land use may be an unsustainable choice given its relatively high water demands and increasingly erratic weather conditions.

Water Impacts

The SWAT modeling produced estimates of water-related ecosystem services based on climate, topography, soil type, land cover, and management practices. Results were produced in units appropriate to the assessed ecosystem service, whereby nutrient runoff and sediment yield impacts were measured in tons per hectare (t/ha) and surface runoff and groundwater recharge was measured in millimeters (mm). Given the varying units of measurement and a lack of research on the real impacts of these changes in water ecosystem services in the northern Ghanaian landscape (e.g. the amount of sedimentation per hectare needed to cause detrimental siltation in waterways), results have been simplified into the percentage change in the provision of ecosystem services resulting from the land use change. These results are presented in Tables 3 through 6 below.

Colors convey the type and magnitude of change: red cells represent a negative impact and green cells represent a positive impact, with color saturation demonstrating relative intensity. The darkest red color conveys the greatest negative change (i.e. increases in nutrient runoff, surface runoff, sediment load, or decrease in groundwater recharge) whereby dark red indicates an increase of more than 80%, medium red indicates between 20 and 80%, and light red indicates an increase of less than 20%. The darkest green color conveys the greatest positive change (i.e. decreased nutrient runoff, surface runoff, sediment load, or increase in groundwater recharge). The darkest green indicates a decrease of more than 80%, the less dark green is for decreases between 20 and 80%, and light green indicates a decrease of less than 20%.

Land uses in the first column are the pre-transition land use, and those in the top row are post-transition land uses.

Table 3: Estimated changes in nutrient runoff (%)

FROM \ TO	Bare land	Conventional Agriculture	CSA Manure	CSA Mulching	CSA Ripper	CSA Stone Ridging	Shifting Cultivation - 5-year fallow	Shifting Cultivation - 10-year fallow	Agroforestry	Moringa Plantation	Mango Plantation	Cashew Plantation	Fuelwood Plantation	Natural Forest
Bare land		-79	-37	-82	-79	-87	-96	-98	-95	-95	-95	-95	-98	-99
Conventional Agriculture	370		196	-15	0	-41	-81	-89	-77	-77	-77	-77	-91	-95
CSA Manure	59	-66		-71	-66	-80	-94	-96	-92	-92	-92	-92	-97	-98
CSA Mulching	456	18	250		18	-30	-77	-87	-73	-73	-73	-73	-90	-94
CSA Ripper	369	0	196	-16		-41	-81	-89	-77	-77	-77	-77	-92	-95
CSA Stone Ridging	692	69	399	43	69		-68	-82	-61	-61	-61	-61	-86	-92
Shifting Cultivation - 5 year fallow	2362	424	1451	343	425	211		-44	21	21	21	21	-55	-76
Shifting Cultivation - 10-year fallow	4311	839	2679	694	840	457	79		116	116	116	116	-20	-56
Agroforestry	1939	334	1184	267	335	157	-17	-54		0	0	0	-63	-80
Moringa Plantation	1939	334	1184	267	335	157	-17	-54	0		0	0	-63	-80
Mango Plantation	1939	334	1184	267	335	157	-17	-54	0	0		0	-63	-80
Cashew Plantation	1939	334	1184	267	335	157	-17	-54	0	0	0		-63	-80
Fuelwood Plantation	5425	1076	3381	894	1078	597	124	25	171	171	171	171		-45
Natural Forest	9960	2042	6238	1710	2045	1170	309	128	393	393	393	393	82	

Not surprisingly, the most negative changes in **nutrient runoff** were seen in converting to land uses with less vegetation, as well as those that introduced synthetic or organic fertilizers.

Surface Runoff

SURFACE WATER RUNOFF MITIGATION

Table 4: Estimate change in the rate of surface runoff (%)

FROM \ TO	Bare land	Conventional Agriculture	CSA Manure	CSA Mulching	CSA Ripper	CSA Stone Ridging	Shifting Cultivation - 5-year fallow	Shifting Cultivation - 10-year fallow	Agroforestry	Moringa Plantation	Mango Plantation	Cashew Plantation	Fuelwood Plantation	Natural Forest
Bare land		-41	-41	-48	-41	-58	-72	-77	-59	-59	-59	-59	-80	-82
Conventional Agriculture	70		0	-13	0	-29	-53	-61	-31	-31	-31	-31	-67	-70
CSA Manure	70	0		-12	0	-29	-53	-61	-31	-31	-31	-31	-67	-70
CSA Mulching	94	14	14		14	-19	-46	-56	-21	-21	-21	-21	-62	-66
CSA Ripper	70	0	0	-13		-29	-53	-61	-31	-31	-31	-31	-67	-70
CSA Stone Ridging	140	42	41	24	42		-34	-45	-2	-2	-2	-2	-53	-57
Shifting Cultivation - 5-year fallow	261	113	113	86	113	50		-18	47	47	47	47	-29	-36
Shifting Cultivation - 10-year fallow	338	158	158	126	158	82	21		78	78	78	78	-14	-22
Agroforestry	146	45	45	27	45	2	-32	-44		0	0	0	-52	-56
Moringa Plantation	146	45	45	27	45	2	-32	-44	0		0	0	-52	-56
Mango Plantation	146	45	45	27	45	2	-32	-44	0	0		0	-52	-56
Cashew Plantation	146	45	45	27	45	2	-32	-44	0	0	0		-52	-56
Fuelwood Plantation	410	201	200	163	201	112	41	16	107	107	107	107		-10
Natural Forest	465	233	232	191	233	135	56	29	130	130	130	130	11	

The role established trees has in mitigating **surface water runoff** is very clear, with the exception of converting shifting cultivation to some types of tree plantations. This can likely be explained by the composition of vegetation in these land uses – the shrubby, dense vegetation close to the soil typical of lands left fallow in a shifting cultivation cycle is likely more effective at mitigating surface runoff than the heavily-managed tree plantations that are often cleared of ground vegetation.

Sediment Yield

Table 5: Estimated changes in rates of sediment yield (%)

FROM \ TO	Bare land	Conventional Agriculture	CSA Manure	CSA Mulching	CSA Ripper	CSA Stone Ridging	Shifting Cultivation - 5-year fallow	Shifting Cultivation - 10-year fallow	Agroforestry	Moringa Plantation	Mango Plantation	Cashew Plantation	Fuelwood Plantation	Natural Forest
Bare land		-64	-68	-97	-64	-95	-87	-95	-98	-98	-98	-98	-100	-100
Conventional Agriculture	176		-13	-93	-1	-86	-65	-87	-94	-94	-94	-94	-99	-100
CSA Manure	217	15		-92	14	-83	-60	-86	-93	-93	-93	-93	-98	-100
CSA Mulching	3632	1253	1078		1245	96	370	71	-23	-23	-23	-23	-81	-98
CSA Ripper	178	1	-12	-93		-85	-65	-87	-94	-94	-94	-94	-99	-100
CSA Stone Ridging	1807	591	502	-49	587		140	-13	-61	-61	-61	-61	-91	-99
Shifting Cultivation - 5-year fallow	694	188	151	-79	186	-58		-64	-84	-84	-84	-84	-96	-100
Shifting Cultivation - 10-year fallow	2087	693	590	-41	688	15	175		-55	-55	-55	-55	-89	-99
Agroforestry	4737	1653	1427	30	1643	154	509	121		0	0	0	-76	-97
Moringa Plantation	4737	1653	1427	30	1643	154	509	121	0		0	0	-76	-97
Mango Plantation	4737	1653	1427	30	1643	154	509	121	0	0		0	-76	-97
Cashew Plantation	4737	1653	1427	30	1643	154	509	121	0	0	0		-76	-97
Fuelwood Plantation	20059	7207	6264	440	7164	957	2439	822	317	317	317	317		-88
Natural Forest	169918	61526	53571	4456	61166	8817	21313	7675	3415	3415	3415	3415	743	

The impact of land use change on **sediment yield** (i.e. erosion) is closely related to the amount of soil disturbance involved in the land uses. The positive impact of CSA practices on this ecosystem services is clear, with the positive impact of mulching and stone ridging particularly evident, as they provide good ground cover that protects the soil from being quickly dislodged by rainfall.

Groundwater Recharge

Table 6: Estimated changes in rates of groundwater recharge (%)

TO / FROM	Bare land	Conventional Agriculture	CSA Manure	CSA Mulching	CSA Ripper	CSA Stone Ridging	Shifting Cultivation - 5-year fallow	Shifting Cultivation - 10-year fallow	Agroforestry	Moringa Plantation	Mango Plantation	Cashew Plantation	Fuelwood Plantation	Natural Forest
Bare land		527	552	819	527	1259	2528	2892	789	789	789	789	2709	3044
Conventional Agriculture	-84		4	47	0	117	319	377	42	42	42	42	348	401
CSA Manure	-85	-4		41	-4	108	303	359	36	36	36	36	331	382
CSA Mulching	-89	-32	-29		-32	48	186	226	-3	-3	-3	-3	206	242
CSA Ripper	-84	0	4	46		117	319	377	42	42	42	42	348	401
CSA Stone Ridging	-93	-54	-52	-32	-54		93	120	-35	-35	-35	-35	107	131
Shifting Cultivation - 5-year fallow	-96	-76	-75	-65	-76	-48		14	-66	-66	-66	-66	7	20
Shifting Cultivation - 10-year fallow	-97	-79	-78	-69	-79	-55	-12		-70	-70	-70	-70	-6	5
Agroforestry	-89	-29	-27	3	-29	53	196	237		0	0	0	216	254
Moringa Plantation	-89	-29	-27	3	-29	53	196	237	0		0	0	216	254
Mango Plantation	-89	-29	-27	3	-29	53	196	237	0	0		0	216	254
Cashew Plantation	-89	-29	-27	3	-29	53	196	237	0	0	0		216	254
Fuelwood Plantation	-96	-78	-77	-67	-78	-52	-6	6	-68	-68	-68	-68		12
Natural Forest	-97	-80	-79	-71	-80	-57	-16	-5	-72	-72	-72	-72	-11	

The impacts of transitioning to most tree plantations was detrimental in terms of **groundwater recharge** due to their relatively high water demands. This analysis also demonstrated the positive effects of CSA practices that trap and slow down water on the land, whereby stone ridging and mulching improved groundwater recharge as compared to tree plantations.

The most striking result across all water-based ecosystem service analyses is the vital role that natural forests play in recharging groundwater, mitigating sediment and nutrient runoff, and slowing the flow of surface water. Converting land uses with trees to land uses without trees consistently has negative effects on water-based ecosystem services, most dramatically seen in converting natural forests. Not surprisingly, the lack of vegetation on bare land makes this land use the most detrimental to water-based ecosystem services, followed by conventional agriculture.

Greenhouse Gas Emissions

Estimated greenhouse gas emissions over 20 years after the initial land use conversion are presented in Table 7 below. Land uses in the first column are the pre-transition land use, and those in the top row are post-transition land uses. Estimates include emissions associated with the initial clearing of the land use as well as subsequent emissions or removals associated with the new land use.

Colors indicate the estimated magnitude of CO_2 emissions or sequestration by land use: red cells represent emissions, green cells show sequestration, with color saturation indicating the relative intensity of impact. The darkest green represents sequestration over 150 t CO_2 ha^{-1}, the medium green color represents CO_2 sequestration of between 31 to 150 t CO_2e ha^{-1}, and the lightest green represents CO_2 sequestration of less than 30 t CO_2e ha^{-1}. The darkest red represents emissions over 150 t CO_2 ha^{-1}, the medium red color represents CO_2 emissions between 31 to 150 t CO_2e ha^{-1}, and the lightest red represents CO_2 emissions of less than 30 t CO_2e ha^{-1}.

Land uses in the first column are the pre-transition land use, and those in the top row are land uses converted to.

Table 7: Estimated cumulative greenhouse gas impacts 20 years post-conversion

FROM \ TO	Bare land	Conventional Agriculture	CSA Manure	CSA Mulching	CSA Ripper	CSA Stone Ridging	Shifting Cultivation - 5-year fallow	Shifting Cultivation - 10-year fallow	Agroforestry - Intercropping	Moringa Plantation	Mango Plantation	Cashew Plantation	Fuelwood Plantation	Natural Forest
Bare land		20	1	-111	-111	-111	14	13	-253	-493	-10	-202	-278	-165
Conventional Agriculture	-20		98	-14	-14	-14	-6	-7	-156	-392	87	-105	-180	-67
CSA Manure	-118	-98		-112	-112	-112	-104	-106	-254	-494	-11	-203	-279	-166
CSA Mulching	-6	14	112		0	0	8	7	-142	-382	101	-91	-166	-53
CSA Smart Ripper	-6	14	112	0		0	8	7	-142	-382	101	-91	-166	-53
CSA Stone Ridging	-6	14	112	0	0		8	7	-142	-382	101	-91	-166	-53
Shifting Cultivation - 5-year fallow	-14	6	10	-8	-8	8		-2	-150	-390	-1	-193	-175	-62
Shifting Cultivation - 10-year fallow	-13	7	12	-7	-7	-7	2		-148	-389	1	-98	-173	-60
Agroforestry - Intercropping	290	310	408	296	296	296	304	302		-86	397	205	130	242
Moringa Plantation	645	649	747	635	635	635	643	642	493		736	544	469	581
Mango Plantation	70	46	144	32	32	32	40	39	-109	-350		-59	-134	-21
Cashew Plantation	264	240	338	226	226	226	234	232	84	-156	327		59	153
Fuelwood Plantation	187	206	305	193	193	193	201	199	51	-189	241	49		139
Natural Forest	137	157	255	143	143	143	151	150	1	-239	244	52	-23	

This matrix clearly shows the benefit land uses with trees offer in terms of greenhouse gases sequestration. Overall, conversions from land uses without trees to those with trees resulted in significant CO_2 sequestration, and vice-versa. The only exception is establishing mango plantations, as the relatively high emissions from fertilizer application (see Annex 1 for a list of assumptions about fertilizer use) outweigh potential sequestration from the growth of mango trees.

The greatest positive CO_2 impacts come from establishing moringa and fuelwood plantations, followed by agroforestry systems, cashew plantations, and natural forests. This is reflective of the reality that intensively managed productive plantations typically have higher sequestration rates than natural forests do, particularly in dry climates where natural forest growth is relatively slow.

Land use transitions that most consistently resulted in emissions were transitions to conventional agriculture or climate-smart agriculture applying manure. These land uses have low carbon stocks and relatively high emissions from fertilizer use. Reductions in tillage and inputs associated with the other climate-smart agriculture practices assessed resulted in a reduction in emissions compared to conventional agricultural practices.

COMMUNICATING THE IMPACT OF LAND USE TRANSITIONS

To enhance the accessibility of the *Land Use Impact Study*, an approach employing graphics rather than text was developed to clearly convey the economic and environmental impacts of land use changes to broad audiences. This approach is applied in the accompanying *Visual Land Use Planning Guide* product, but is also presented here.

For every economic or environmental indicator assessed in this study (e.g., erosion mitigation) the impacts of land use change were categorized into one of seven categories corresponding to the relative magnitude of impact a land use change has. There are three positive categories, three negative categories, and one neutral category (when a land use change has been deemed to have no impact on an indicator). This classification system was translated into a graphic format using a dial (shown in Figure 3). The color on the dial the arrow points to communicates the magnitude of impact.

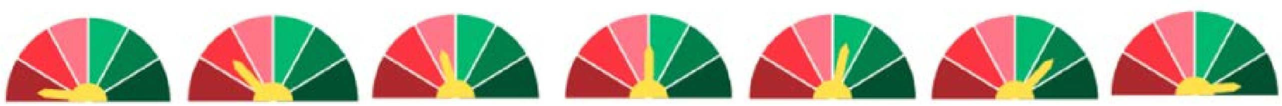


Figure 3: Land use impact dials

The red colors on the left of the dial convey a negative impact and the three green colors on the right convey a positive impact. Color saturation specifies the relative magnitude of the impact. For example, where the assessment revealed the impact of a land use change has the greatest negative impacts, a dial will be presented with the biodiversity icon showing the dial's arrow pointing to the dark red color.

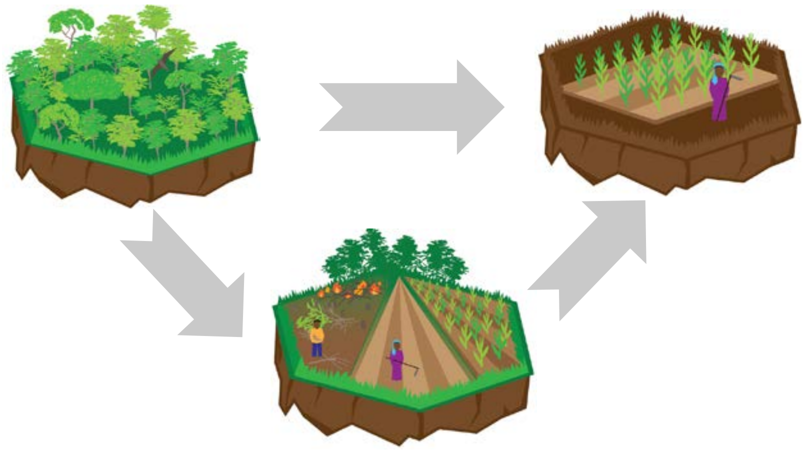
For the **economic impacts**, the greatest magnitude of change (dial pointing to the deep green or deep red) conveys a change in NPV than 7,000 Ghanaian cedis (GH¢). Moderate impacts are deemed to be a change in NPV between 7,000 GH¢ and 3,000 GH¢, and minor impacts are deemed to be a change less than 3,000 GH¢. Numbers have been rounded to the nearest 100.

For the **water ecosystem service indicators**, the greatest magnitude of impact reflects change greater than 80, the moderate impacts are deemed to be a change between 80 and 20, and minor impacts are deemed to be a change less than 20.

Greenhouse gas impacts are presented as the total emissions or sequestration over 20 years post land use change. The greatest magnitude of impact reflects emissions or carbon dioxide removals of over 150 t CO_2e ha^{-1}, moderate impacts are emissions or removals between 31 to 150 t CO_2e ha^{-1}, and minor impacts are emissions or removals less than 30 t CO_2e ha^{-1}. Numbers have been rounded to the nearest 10.

Changes associated with **climate resilience and biodiversity** were assessed qualitatively (see Annex 2), and the magnitude of change is also represented by the position of the arrow on the dial.

Forest Clearing for Agriculture



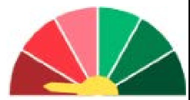
Agricultural expansion, triggered by population growth and development pressures, has been identified as the primary driver of deforestation across Ghana[12]. This has a high cost on the vital ecosystem services that many communities rely upon to sustain their livelihoods. Under this scenario, the impact of converting forest to productive agricultural land is examined. The two agricultural production systems assessed include:

1. **Conventional agriculture**: land dedicated to the production of maize, soybeans, rice, groundnuts, sorghum, yams, and other staples of the northern Ghanaian diet. The results of the analysis presented below reflect the most dominant practices in northern Ghana: maize production supported by the application of synthetic fertilizers.

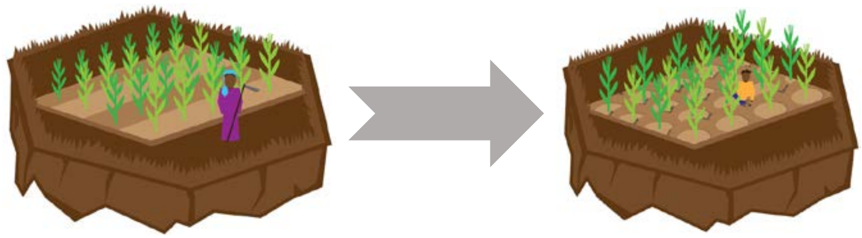
2. **Shifting cultivation**: a traditional form of agricultural production whereby land is temporarily cleared for crop cultivation for one or two years, and then left fallow. Soil nutrients and vegetation are restored during fallow periods and the clearing process, which involves burning forest residues, further fertilizes soil. As such, this process maintains soil fertility without the need for added fertilizer.

   Often, the same piece of land will be subject to cultivation over several cycles, and as Ghana's population has grown, lands that were formally fallow for long periods are cultivated more often or turning into permanent agricultural fields. As such, the analysis includes two shifting cultivation scenarios: 2-years of cultivation and 5-years of fallow and 2-years of cultivation and 10-years of fallow.

[12] Ghana National REDD+ Strategy, 2015. Available at: https://www.forestcarbonpartnership.org/sites/fcp/files/2016/Sep/Ghana27s20National20REDD2B20Strategy20Dec20 2015.pdf

	Economics	Water				Climate		Biodiversity
	Net Present Value (GH¢)	Erosion	Aquifer Recharge	Surface Water Runoff	Nutrient Runoff	Greenhouse Gas (t CO_2 ha)	Improved Resilience	
Conversion to convention al agriculture	9,700 	61,530 	-80 	230 	2,040 	157 		
Conversion to shifting cultivation 5-year fallow	8,100 	21,310 	-16 	60 	310 	151 		
Conversion to shifting cultivation 10-year fallow	7,000 	7,680 	-5 	30 	130 	150 		

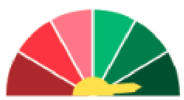
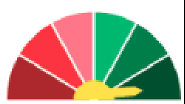
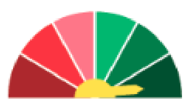
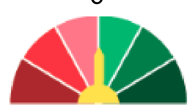
Transitioning from Conventional to Climate-Smart Agriculture



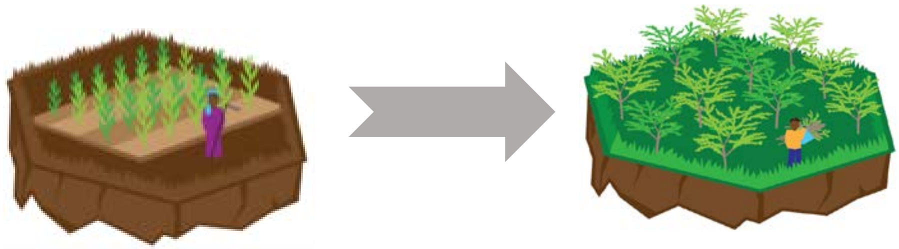
Conventional agriculture practices that involve significant soil disturbance through tilling and the application of agrochemicals can have negative impacts on soil, water quality, and greenhouse gas emissions. These practices also increase vulnerability to climate change because they often do not use resources like water in the most efficient, effective way.

Certain interventions can increase this resiliency, broadly termed climate-smart agriculture (CSA) practices. CSA techniques integrate technology and management practices to lower soil disturbance and conserve limited natural resources to allow farmers to better withstand environmental shocks associated with climate change such as drought and flooding. This scenario explores the impact of implementing a series of CSA practices, including:

- Using a ripper for tillage: The ripper aerates compacted soil for planting, but limits soil disturbance as compared to traditional full tillage of the soil. The application of the ripper can therefore lead to lower rates of erosion, nutrient and surface water runoff, and greenhouse gas emissions.
- Mulch application: Mulching is a technique whereby topsoil is covered in plant material and residues to retain soil moisture, increase nutrients, and inhibit weed growth. Benefits of this practice include increases in soil fertility and therefore yield, less erosion, nutrient and surface runoff, as well as lower water demand.
- Building stone contours/ridges: This practice can support water and soil conservation by introducing a physical barrier to inhibit erosion and nutrient and surface runoff.
- Applying organic (manure) fertilizer: Manure application can improve soil fertility, thereby increasing yields and productivity. Where marginal lands can be restored through soil fertility improvement, it can relieve agricultural expansion pressure elsewhere and contribute to food security.

	Economics	Water				Climate		Biodiversity
	Net Present Value (GH¢)	Erosion	Aquifer Recharge	Surface Water Runoff	Nutrient Runoff	Greenhouse Gases (t CO_2 ha)	Improved Resilience	
Ripper (reduced tillage)	1,600 	-1 	0 	0 	0 	-14 		No change assumed.
Mulching	100 	-90 	50 	-10 	-15 	-14 		No change assumed.
Stone ridging	No data available.	-90 	120 	-30 	-40 	-14 		No change assumed.
Manure	100 	-10 	4 	0 	200 	98 		No change assumed.

Woodlot Establishment



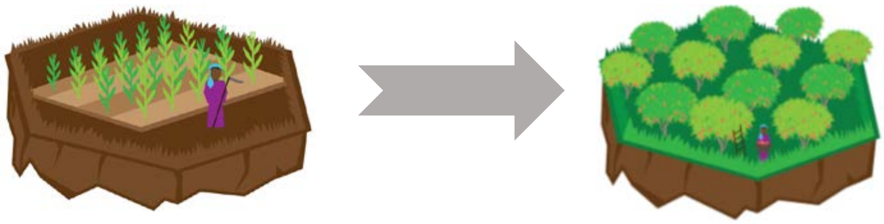
As the main source of energy for most inhabitants of northern Ghana, fuelwood and charcoal are in high demand. This has led to fuelwood collection functioning as a primary driver of deforestation and degradation in northern Ghana[13]. The unsustainable extraction of this resource from forests and other treed ecosystems has consequently led to the degradation of ecosystem services.

The establishment of woodlots or tree plantations may offer a viable, more sustainable solution for meeting energy needs. This type of land use not only has the potential to prevent degradation of natural forests associated with fuelwood harvesting, but also can add tree cover, improve ecosystem services, and provide a source of income for communities. This scenario quantifies the impacts of establishing woodlots by examining the economic and environmental implications of land use conversion from conventional agriculture to woodlots or tree plantations.

[13] Ghana National REDD+ Strategy, 2015. Available at: https://www.forestcarbonpartnership.org/sites/fcp/files/2016/Sep/Ghana27s20National20REDD2B20Strategy20Dec20 2015.pdf

Economics	Water				Climate		Biodiversity
Net Present Value (GH¢)	Erosion	Aquifer Recharge	Surface Water Runoff	Nutrient Runoff	Greenhouse Gas ($t\ CO_2\ ha$)	Improved Resilience	
-3,700 	-100 	350 	-70 	-90 	-180 		

Tree Crop Establishment



Establishing ecologically appropriate tree crops can result in substantial economic and environmental benefits. While initial costs are often higher than other agricultural crops, over time, tree crops can render substantial economic returns as well as additional ecosystem services that improve the overall profitability and environmental integrity of a land use. Under this scenario, the impact of transitioning from conventional agriculture to a set of different tree crops is explored, including agroforestry intercropping, cashew plantations, mango plantations, and moringa plantations.

	Economics	Water				Climate		Biodiversity
	Net Present Value (GH¢)	Erosion	Aquifer Recharge	Surface Water Runoff	Nutrient Runoff	Greenhouse Gas Impacts t CO_2 ha	Improved Resilience	
Agro-forestry	-2,500 	-90 	25 	-30 	-0.1 	-262 		
Moringa plantation	 -3,300	-90 	25 	-30 	-0.1 	-392 		
Mango plantation	-6,000 	-90 	-25 	-30 	-0.1 	87 		
Cashew plantation	-1,700 	-90 	-25 	-30 	-0.1 	-105 		

CONCLUSIONS

The outcomes of the analyses conducted for the Land Use Impact Study demonstrate the distinct economic and environmental costs and benefits that each land use is associated with. Understanding both the short and long-term impacts of those realities can allow CREMAs and other land stewards to best provide for the needs of their communities.

Overall, the analyses undertaken underscore the environmental and economic benefits of CSA practices with significant positive impacts on erosion and aquifer recharge as well as economic gains for mulching and manure application. When compared to traditional, 'conventional' agricultural practices, the capacity of CSA to not only improve ecosystem services, but also to better withstand the shocks and stresses of climate change such as drought and rain variability, should make a compelling argument for the integration of CSA practices.

Similarly, in comparison to conventional agriculture, the tree crops assessed also represent a significant improvement in the provision of ecosystem services. High establishment, input, and labor costs associated with most of the tree crops make the economic argument less strong, yet their more climate resilient profile overall and capacity to improve hydrological ecosystem services should not be overlooked.

The analysis also revealed the high value of natural forests, both economically and for the provision of essential ecosystem services. This land use offered the highest values for most of the ecosystem services, underlining the importance of maintaining these ecosystems. The fuelwood they provide, as well as revenue from the collection of shea nuts demonstrates the true economic value of this commonly undervalued land use.

The potential impact these analyses have rests firmly in how effectively they are communicated to those responsible for making land use decisions in northern Ghana. This highly accessible approach for conveying the results through Land Use Impact Study was developed to clearly communicate results in a universally understandable way. By employing graphics and intuitive messaging, the Land Use Impact Study can serve as a useful and meaningful resource for decision makers in communities across northern Ghana and beyond to engage in land use management and planning that considers both environmental and economic impacts, enabling them to thrive in the short and long-term.

ANNEX 1 – ASSUMPTIONS

Permanent Agriculture, Conventional

Maize cultivation, full tillage, 119 kg/ha of NPK fertilizer[14], no irrigation.

Permanent Agriculture, Manure

Maize cultivation, reduced tillage, 1 ton/ha of wet chicken manure (equivalent to 250 kg/ha when converted to dry weight)[15].

Climate Smart Agriculture: mulching, ripper (conservative tillage), stone ridging

Maize cultivation, reduced tillage, no fertilizer.

Agroforestry

Mango or cashew intercropping under 30-year rotation, no tillage, no fertilizer, no irrigation.

Shifting Cultivation – 5-year fallow

Two years of cultivation, followed by 5 years of fallow. Maize cultivation, full tillage, no fertilizer application, or irrigation.

Shifting Cultivation – 10-year fallow

Two years of cultivation, followed by 10 years of fallow. Maize cultivation, full tillage, no fertilizer application, or irrigation.

Moringa Plantation

30-year rotation[16], 217 trees per hectare[17], no tillage, no fertilizer, no irrigation.

Mango Plantation

253 trees/ha under a 50-year rotation, no tillage, 7.5 kg NPK/tree and 3 kg manure/tree, no irrigation (~900 L/month).

Cashew Plantation

60-year rotation, no tillage, fertilized with 7 kg Sulfate Ammonia/ha in addition to 10 kg TSP/ha, no irrigation.

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[14] *Amanor-Boadu, et al. 2015. Agricultural Production Survey for the Northern Regions of Ghana: 2013-2014 Results. USAID Ghana.*

[15] *MacCarthy, D. et al. 2017. Using CERES-Maize and ENSO as Decision Support Tools to Evaluate Climate-Sensitive Farm Management Practices for Maize Production in the Northern Regions of Ghana. Frontiers in Plant Science, B 31.*

[16] *Villafuerte LR, Villafurte-Abonal L (2009) Data taken from the Forestry Agency of Japan in Moringa. Malunggay Phillippines, Apples of Gold Publishing, Singapore, P 240.*

[17] Moringa Tree Fund http://sustainableinvestingchallenge.org/wp-content/uploads/2013/03/Moringa-Tree-Fund-Prospectus.pdf

Fuelwood plantation

Acacia and Cassia woodlots at a 5-year rotation, no tillage, no fertilizer[18], no irrigation.

[18] *Vordzogbe, V. et al. 2015. Woodlot Agroforestry in the lower Volta Basin Ghana: Contribution of Tree Species Admixture to Aboveground Carbon. West African Journal of Applied Ecology. Vol. 23(1).*

ANNEX 2 – METHODS

Estimation of economic value

The economic analysis conducted included both an assessment of the net present value (NPV) of each land use, as well as an assessment of any additional costs and/or benefits associated with shifting from one land use to another. Information to derive estimates of these costs and benefits, including common practices, labor costs, yields, market prices, and the cost of inputs were collected through field data collection as well as literature review.

The NPV represents the present value of the discounted cash flows and considers:

1. The opportunity costs of labor for owners when we estimate of the costs of production, using the appropriate wage rate for the individual doing the work.
2. Production costs
3. Yield and associated economic benefits with the land use

To estimate the costs or benefits associated from switching land uses, land-clearing costs, or land preparation costs for each conversion type were also quantified.

A full description of methods and inputs for the economic analysis is offered in Sohngen, B., Haruna, B., Smoot, J., 2017. Economic Analysis of Alternative Land Uses in Ghana. Prepared by Sylvan Acres Limited Liability Company for Winrock International.

Estimation of water-based ecosystem service indicators

The water-based ecosystem services included in the Land Use Impact Study are:

- Surface runoff
- Sediment yield
- Nutrient runoff
- Groundwater recharge

All four of these indicators were estimated using the Soil and Water Assessment Tool (SWAT), a physically based hydrological model run in a Geographical Information System (GIS) using the ArcSWAT tool. SWAT uses spatial inputs for land cover, soil type, elevation/slope and weather patterns to simulate all aspects of the water cycle for a given area of interest. For this study, several small watersheds that drain into the Black Volta River were grouped and used for SWAT simulation. These watersheds contain three CREMAs: Dorimon, Wechiau and Zukpiri and in total contain an area of 2,517 km^2.

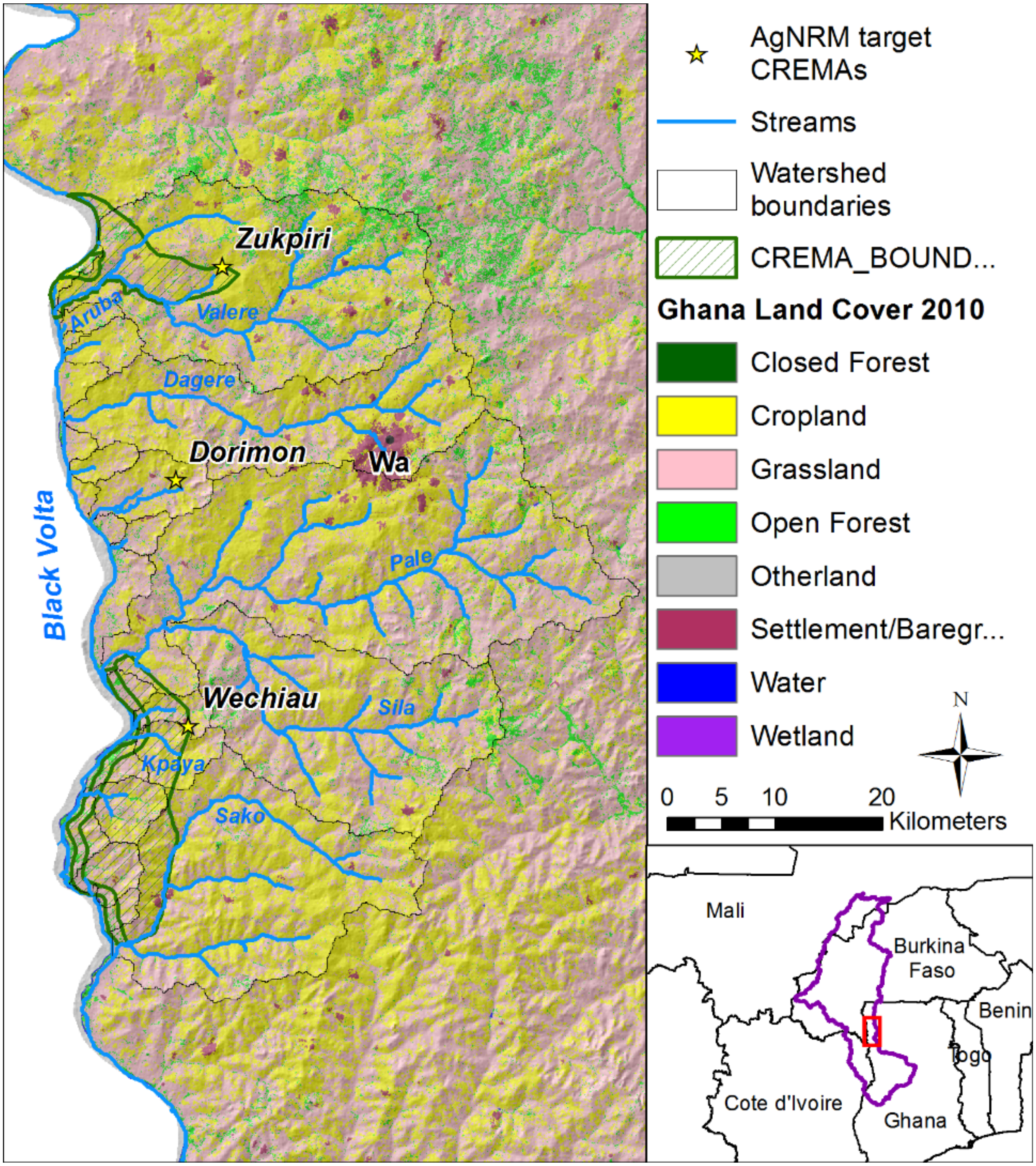

Figure 1: Group watershed area used for SWAT analysis with associated land cover/land use

Spatial inputs into the model included:

- Digital elevation model (DEM) from the global STRM product with a resolution of 90m
- Soil type map from the global FAO soils layer
- Land cover/land use map created by Ghana's Forestry Commission for 2010 at a 30m resolution

Using the ArcSWAT interface and GIS tools, the DEM was used to derive the stream network of the watersheds and checked against aerial photos from Google Earth for accuracy. The DEM was also used to derive slope. The land cover/land use map included the categories forest, grassland, settlement, cropland, wetland, other land and water. Within the entire group watershed of interest, areas were classified by their unique combination of slope, soil type and land cover to create hydrological response units (HRUs). Since these three factors are the main land-based drivers of hydrological response, it is assumed that two areas within the group watershed that belong to the same HRU will have a similar hydrological response (and therefore similar values for the four water-based ecosystem service indicators).

Once initial HRUs were established, management practices were applied in ArcSWAT. Default management parameters from the land cover/land use map were altered to best represent the Land Use Impact Study land uses (Table 8). Major parameters that were altered included the default land cover type, the fertilizer regime applied, the crop schedule, the Soil Conservation Service curve number (which drives surface runoff in SWAT) and the Universal Soil Loss Equation (USLE) P value (which drives sediment erosion in SWAT).

Table 8: SWAT management parameters applied to each ESDST land use

Land use	ArcSWAT land cover default	Fertilizer applied	Crop schedule	Curve number	USLE P value	Sources
Natural forest	Mixed forest	None	None	73	1	Default values in ArcSWAT
Woodlot	Oak	None	Harvest every five years	73	1	Expert opinion Yaw Atuahene
Fruit tree plantations (cashew, mango and agroforestry	Cashew	Sulfate ammonia (7 kg) and TSP (10 kg)	None	77	1	Expert opinion, FAO[19]
Conventional agriculture	Generic agriculture: row crops	15-15-15 (119 kg)	Generic spring-tillage (5/20), plant (6/1), fertilize (6/2 and 7/1), harvest (9/15)	85	0.8	Amanor-Boadu, et al. (2015), MESTI (2015)
CSA, manure	Generic agriculture: row crops	Layer-fresh manure (1000 kg)	Same as conventional agriculture	85	0.8	MacCarthy et al. (2017)

[19] http://teca.fao.org/sites/default/files/technology_files/GIZ-ACi_GH_Flipchart_Cashew_Establishment_2011.pdf

CSA, mulching	Generic agriculture: row crops	Same as conventional agriculture	No till, plant (6/1), fertilize (6/2 and 7/1), harvest (9/15)	82	0.07	Arnold et al. (2012), MESTI (2015)
CSA, ripper tillage	Generic agriculture: row crops	Same as conventional agriculture	Till with ripper (5/20), plant (6/1), fertilize (6/2 and 7/1), harvest (9/15)	85	0.8	Arnold et al. (2012)
CSA, ridging	Generic agriculture: row crops	Same as conventional agriculture	Same as conventional agriculture	78	0.17	Arnold et al. (2012), MESTI (2015)
Conventional agriculture, five-year fallow cycle	Mix of generic agriculture: row crops and brush rangeland	None	Seven-year cycle: same as conventional agriculture for first two years. Then brush range planted and left unmanaged for five years.	Agriculture: 85 Range: 74	1	Arnold et al. (2012)
Conventional agriculture, ten-year fallow cycle	Mix of generic agriculture: row crops and brush rangeland	None	12-year cycle: same as conventional agriculture for first two years. Then brush range planted and left unmanaged for ten years.	Agriculture: 85 Range: 74	Agriculture: 0.8 Range: 1	

After the land and management parameters were set, weather inputs were added to ArcSWAT. Data from the Ghana Meteorological Agency's Dorimon weather station were used for temperature and rainfall for the period 1980-2013. The SWAT model was then run for the same period multiple times over the entire group watershed to assess the impact of the Land Use Impact Study on the different water-based ecosystem service indicators. The annual averages of select SWAT outputs over the 33-year period were averaged across all HRUs with the same land use to arrive at final values for each of the four water-based ecosystem service indicators (Table 9).

Table 9: Output SWAT parameters used to assess water-based ecosystem service indicators

Land use	SWAT output parameter	Unit	SWAT Description (Arnold et a l. 2012)
Surface runoff	SURQ_GEN	mm H_2O	Surface runoff generated in HRU during time step
Sediment yield	SYLD	Metric tons ha^{-1}	Sediment from the HRU that is transported into the main channel during the time step.
Nutrient runoff	NSURQ	kg N ha^{-1}	Nitrate transported with surface runoff into the stream during the time step.
Groundwater recharge	GW_RCHG	mm H_2O	Recharge entering aquifers during time step.

Estimation of greenhouse gas emissions

Greenhouse gasses were estimated by applying the IPCC Stock-Change approach. Post-land use change carbon stocks are subtracted from pre-land use change carbon stocks to estimate the total greenhouse gas impact of the change in land use (see table 10 for carbon stocks applied). In addition, changes in soil carbon stocks and fertilizer use was included in the estimate. In accordance with IPCC guidance, soil emissions are assumed to occur over 20 years. Furthermore, where land use is converted to tree crops or natural forest, CO_2 sequestration occurs gradually over time. As such, GHG **impacts presented reflect the total net emissions or sequestration over 20 years.**

Annual greenhouse gas impacts from land use change were calculated as follows:

$$EF_{LUC(x)} = ((C_{bio.pre} - C_{bio.post} + \Delta SOC) - E_{fertilizer\ pre} + E_{fertilizer\ post}$$

Where:

$EF_{LUC(x)}$	Emission factor for year land use change x, t $CO_2e\ ha^{-1}\ yr^{-1}$
$C_{bio.pre}$	Pre-land use change carbon stocks[20], t $CO_2e\ ha^{-1}$
$C_{bio.post}$	Post-land use change carbon stocks[21], t $CO_2e\ ha^{-1}$
ΔSOC	Change in soil carbon stocks in year t following deforestation, t C ha^{-1} (equation given in the 'Changes in Soil Carbon Stocks' section below.)
$E_{fertilizer\ pre}$	Emissions from fertilizer applied pre-land use change
$E_{fertilizer\ post}$	Emissions from fertilizer applied post-land use change

[20] For tree crops, shifting cultivation, and natural forest: 'Annual Sequestration' column from table 5 '
For bare land, conventional agriculture and climate-smart agriculture: pre-deforestation C stocks were assumed to be zero.

[21] 'Annual Sequestration' column from table 10 (post-deforestation C stocks assumed to be zero for bare land, conventional agriculture, and climate-smart agriculture).

For transitions from tree crops or natural forest to all other land uses, an additional EF was developed to account for emissions associated with the initial loss of tree biomass occurring in the first year post-conversion:

$$EF_{LUC(tX)y1} = ((C_{bio.pre} - C_{bio.post} + \Delta SOC) - E_{fertilizer\ pre} + E_{fertilizer\ post}$$

Where:

$EF_{LUC(tX)y1}$	Emission factor for year land use change tree crop x or natural forest in year 1, t CO_2e ha^{-1} yr^{-1}
$C_{bio.pre}$	Pre-land use change carbon stocks[22], t CO_2e ha^{-1}
$C_{bio.post}$	Post-land use change carbon stocks[23], t CO_2e ha^{-1}
ΔSOC	Change in soil carbon stocks in year t following deforestation, t C ha^{-1} (equation given in the 'Changes in Soil Carbon Stocks' section below.)
$E_{fertilizer\ pre}$	Emissions from fertilizer applied pre-land use change

For estimates of 20-year total GHG emissions, as presented in the document, the following approaches were taken:

- Transitions between annual crops or shifting cultivation to all other land uses: Annual emissions (i.e., $EF_{LUC(x)}$) were multiplied by 20.
- Transitions from tree crops or natural forest to all other land uses: Emissions associated with initial clearing of tree crops (first year post-transition) were integrated into the estimate of 20-year total emissions according to the following formula:

$$EF_{LUC(tX,y20)} = EF_{LUC(x,y1)} + (EF_{LUC(x)} * 19)$$

Where:

$E_{LUC(tX,y20)}$	Emissions land use change tree crop x or natural forest in yr 20 t CO_2e ha^{-1}
$EF_{LUC(tX,y1)}$	Emission factor for land use change tree crop x or natural forest in yr 1 t CO_2e ha^{-1}
$EF_{LUC(tX)}$	Emission factor for land use change tree crop x or natural forest t CO_2e ha^{-1}

[22] Standing stocks from table 10

[23] 'Annual Sequestration' column from table 5 (post-deforestation C stocks assumed to be zero for bare land, conventional agriculture, and climate-smart agriculture).

Table 10: Carbon stocks and annual carbon sequestration rate for land uses included in this study

Land Use	Standing stocks ($t\ CO_2\ ha^{-1}$)	Source	Annual Sequestration ($t\ CO_2\ ha^{-1}\ yr^{-1}$)	Source	Pools
Conventional Agriculture	Annual net C stocks and sequestration of zero (whatever C sequestered through crop growth is ultimately released post-harvest).				
CSA- Manure					
CSA- Mulching					
CSA- Ripper					
CSA- Stone Ridging					
Agroforestry	160*		5.32 (30-year rotation length)		Trees
Shifting Cultivation – 5 year fallow	3*	Adu-Bredu et al. 2008.	0.46*	Adu-Bredu et al. 2008.	Trees, herbaceous, litter
Shifting Cultivation – 10 year fallow	6*	Adu-Bredu et al. 2008.	0.54*	Adu-Bredu et al. 2008.	Trees, herbaceous, litter
Plantations - Moringa	260*	Villafuerte LR, Villafurte-Abonal L (2009)	17.33* (30-year rotation length)	Villafuerte LR, Villafurte-Abonal L (2009)	Trees
Plantations – Mango	136*	Trees of Hope Plan Vivo Project	2.72* (50-year rotation)	Trees of Hope Plan Vivo Project	Trees
Plantations – Cashew	69*	Miombo Community Land Use and Carbon Project Plan Vivo document	2.29* (60-year rotation)	Miombo Community Land Use and Carbon Project Plan Vivo document	Trees
Fuel wood plantation	33*	Vordzogbe, V. et al. 2015	6.55*	Vordzogbe, V. et al. 2015	Trees
Natural Forest	90	Adu-Bredu et al. 2008.	0.9	IPCC Good Practice Guidance for LULUCF 2003.	Trees, herbaceous, litter

** Long-term average stocks, or the average carbon stock of the land use over several rotations. This is derived by dividing the total standing stocks as given by literature in half.*
Tree biomass includes above and belowground biomass

Changes in soil carbon stocks

Changes in soil carbon stocks are related to the post deforestation land use and were estimated using the IPCC 2006 guidelines whereby changes in soil carbon stocks are based on the use of soil factors that account for how the soil is tilled, the method of management, and inputs in the post deforestation land use. The following formula represents a modified version of equation 2.25 in the IPCC guidelines, whereby soil emissions from both pre-and post-land use change are calculated and then subtracted from each other to estimate net soil emissions from the change in land use:

$$\Delta SOC = (C_{soil\_pre} * F_{LU} * F_{MG} * F_I) - (C_{soil\_post} * F_{LU} * F_{MG} * F_I)$$

Where:

ΔSOC	Soil carbon emitted, t C ha^{-1}
C_{soil}	Carbon stock in soil organic matter pool (to 30 cm), t C ha^{-1}. This was assumed to be 146.6 t CO_2 ha^{-1} across all land uses based on an average soil carbon across Northern, Upper East, and Upper West regions of Ghana, as found in the Harmonized World Soil Database[24].
F_{LU}	Stock change factor for land-use systems for a particular land-use, dimensionless (IPCC 2006 Table 5.5)
F_{MG}	Stock change factor for management regime, dimensionless (IPCC 2006 Table 5.5)
F_I	Stock change factor for input of organic matter, dimensionless (IPCC 2006 Table 5.5)

The change in soil carbon stocks is assumed to occur over a 20-year time period, but for simplicity in accounting emissions are considered to be committed and to occur at the time of conversion.

Emissions from fertilizer use

Emissions from fertilizer use were estimated by combining information on fertilizer type and application rate with emission factors associated with the fertilizer type.

Emissions from synthetic fertilizer use were estimated by applying emission factors contained in Christeensen et al. 2014, which include emissions from both fertilizer production and application.

For emissions from manure, the estimate was based on Section 11.2 of IPCC guidelines for estimating direct emissions from application, indirect emissions from application, emissions from atmospheric deposition of volatized N, and emissions from fertilizer production. This is described in the following formula:

[24] http://webarchive.iiasa.ac.at/Research/LUC/External-World-soil-database/HTML/

$$E_{SF} = \frac{A \times Fert \times N \times (EF_{app} + EF_{prod})}{1000}$$

Where:

E_{SF}	Emissions from synthetic fertilizer use, t CO_2e yr^{-1}
E_{AM}	Emissions from animal manure use, t CO_2e yr^{-1}
A	Area, hectares, ha
Fert	Amount of fertilizer applied, kg ha^{-1} yr^{-1}.
N	Percentage of the fertilizer type made up of nitrogen, (from table below)
EF_{app}	Emission factor for the application of the fertilizer type, kg CO_2e / kg N (from table 11)
EF_{prod}	Emission factor for the production of the fertilizer type, kg CO_2e / kg N (from table 11)

Table 11: N and EFprod CO_2 (Derived from The Agronomy Guide 2015-2016. Penn State College of Agricultural Sciences and Echochem Solutions for manure and poultry litter) and EFapp CO_2 (calculated based on IPCC Tier 1 Approach – see section below)

Fertilizer	$N_{fertilizer\ type}$	EF_{prod} (kg CO_2-e/kg N)	EF_{app} (kg CO_2-e/kg N)
Manure, dry (treated)	0.0195	0	6.673
Manure, wet (fresh)	0.7	0	6.673
Poultry litter, dry (treated)	4.5	0	6.673
Poultry litter, wet (fresh)	0.9	0	6.673

Fertilizer application emissions

Fertilizer application emissions were estimated using an IPCC Tier 1 approach based on Section 11.2 of the 2006 IPCC Guidelines:

*Direct emissions (t CO_2e) = annual application kg N yr^{-1} *0.01 * 1.5714 * 298*

*Leaching/runoff emissions = annual application kg N yr^{-1} * 0.3 * 0.0075 * 1.5714 * 298*

Volatilization and deposition emissions for synthetic fertilizer = annual application kg N yr^{-1} 0.1 * 0.01*1.5714 * 298*

Volatilization and deposition emissions for organic fertilizer = annual application kg N yr^{-1} 0.2 * 0.01*1.5714 * 298*

Where:

- 0.01 is the default for the emission factor for direct emissions and for emission from atmospheric deposition of N on soils and water surfaces
- 1.5714 is the ratio for conversion of N_2O-N to N_2O
- 298 is the global warming potential of nitrous oxide (for conversion of N_2O emissions to CO_2-equivalent emissions
- 0.0075 is the emission factor for leaching/runoff

- 0.3 is the fraction of N losses by leaching/runoff for regions where runoff exceeds the soil water holding capacity
- 0.1 is the default fraction of synthetic fertilizer that volatilizes and 0.2 is the default fraction of organic fertilizer that volatizes

Results from the equations above were combined to derive a fertilizer application emission factor for both synthetic and organic fertilizer.

Fertilizer type, application rate, and emissions are summarized in the table below.

Table 12: Fertilizer emissions for agricultural systems included in the study

Land Use	Fertilizer type	Amount applied (kg ha^{-1})	Source	Emissions (t CO_2 e ha^{-1} yr^{-1})
Conventional Agriculture	NPK	118.75	Amanor-Boadu, et al. 2015.	0.19
CSA- Manure	Poultry manure	250 (dry)	MacCarthy, D. et al. 2017.	7.51
CSA- Mulching	None			
CSA- Ripper	None			
CSA- Stone Ridging	None			
Agroforestry	None			
Shifting Cultivation	None			
Plantations - Moringa	None			
Plantations – Mango	Farm Yard Manure	1893.8*	Mango fruit farming information guide	8.9
	NPK	757.5*	Mango fruit farming information guide	1.2
Plantations – Cashew	Sulphate of Ammonia	7	Good Practices for the Establishment of a New Cashew Farm	0.02
	Triple Superphosphate	10	Good Practices for the Establishment of a New Cashew Farm	0.0
Fuelwood plantation	None			

*Based on an assumed density of 252.5 trees per hectare

Estimation of land use resilience to effects of climate change

To determine the level of resilience to the impacts of climate change for each land use type, a qualitative assessment was made based on expert opinion and published literature (Asafu-Adjaye 2013, FAO 2013). Results are presented in the table below.

Table 13: Climate resilience per land use

Land Use	Capacity to withstand economic and environmental shocks
Conventional Agriculture	Low
CSA- Manure	Medium
CSA- Mulching	Medium
CSA- Ripper	Medium
CSA- Stone Ridging	Medium
Shifting Cultivation	Medium
Agroforestry	High
Plantations –Moringa	High
Plantations – Mango, Cashew	Low
Fuelwood plantation	High
Natural forest	High

Estimation of biodiversity benefits

To determine the biodiversity value or benefit associated with each land use type, a qualitative assessment was made based on expert opinion and published literature (Newbold et al. 2014, (Pertecto et al. 2008, Fahrig et al. 2010).

Table 14: Biodiversity benefits per land use

Land Use	Biodiversity
Conventional Agriculture	Low
CSA- Manure	Low
CSA- Mulching	Low
CSA- Ripper	Low
CSA- Stone Ridging	Low
Agroforestry	Medium
Shifting Cultivation	Medium
Plantations – Mango, Cashew, and Moringa	Medium
Fuelwood plantation	Low
Natural forest	High

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