Environmental and Economic Impacts of Land-Use Change in *Imperata* Areas: A Bioeconomic Modelling Approach

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Abstract: This paper assessed the biophysical and economic consequences of land-use change from *Imperata* grasslands to continuous maize cropping and tree-based farming systems in Claveria, Northern Mindanao, Philippines. The long-term productivity and sustainability of upland farms under the three land-uses (*Imperata*, maize and *Gmelina*) were determined through a bioeconomic modeling approach using Soil Changes Under Agroforestry (SCUAF) model linked to a cost-benefit spreadsheet. Changes in soil carbon and soil erosion as well as carbon sequestration potential were examined.

Simulation results have shown that the *Gmelina* system appears to be superior compared with the other systems studied since it had the least cumulative soil loss and highest organic C retained in the soil-plant system. The *Gmelina* plantation system obtained a higher level of farm productivity, highest private financial profitability and social benefits from carbon sequestration. The social benefits of carbon sequestration for *Gmelina* system can strongly justify for government intervention that would encourage farmers to transform marginal *Imperata* areas into a productive and sustainable *Gmelina* plantation system.

Keywords: *Imperata grasslands, land-use, bioeconomic modeling, carbon sequestrtation, SCUAF, Gmelina arborea, agroforestry*

1. INTRODUCTION

Grasslands in the Philippines serve as intermediate zones wherein a portion is being transformed into permanent croplands or plantations while new areas are being converted as forest areas are being cleared (Garrity et al., 1995). *Imperata cylindrica* is the dominant species in these grasslands and it maintains a continuous dominance over competing plant species in frequently burned areas due to its climax nature. *Imperata* grasslands generally represent degraded, acidic, low organic matter and areas susceptible to erosion.

However, conversion of these grasslands into upland crop farms planted to maize, upland rice and cassava is proliferating at a fast rate. This is triggered by the interacting factors of rapidly increasing population, system of landholding, difficulty in finding a job and declining area of arable land per farmer in the lowlands.

In the Philippines, fast growing multipurpose tree species (MPTS) were introduced as a revegetating and rehabilitating agent to stabilize the condition of the area and ensure a more sustainable and higher crop productivity (Gellor and Austral, 1996). Fast growing species such as *Gmelina arborea*, *Acacia* spp., and *Eucalyptus* spp. Are popularly used.

While tree growing was known to be profitable and effective in the control of *Imperata* via shading (Gouyon, 1992; Menz and Grist, 1996), it is also an approach in promoting carbon fixation by sequestering atmospheric carbon through their growth process (Nowak, 1993).

This paper attempts to assess the biophysical and economic consequences of land-use change from *Imperata* grasslands to continuous maize cropping and *Gmelina* plantation systems in Claveria, Northern Mindana, Philippines through bioeconomic modeling approach. The paper determines the longer term productivity, economic feasibility and sustainability of the three land-uses – *Imperata*, maize and *Gmelina*.

2. METHODOLOGY

2.1 Overview of the three land use systems

The three land-use systems modeled in this study are: (1) *Imperata* system – uncultivated and unburned *Imperata* grasslands with 90% of the aboveground biomass harvested annually; (2) maize cropping system – continuous cultivated open field maize farming with 2 crops of maize grown annually; and (3) *Gmelina* plantation system – *Gmelina* plantation with a 7-year growth cycle.

Harvested *Imperata* leaves were collected, cleaned, and packed into bundles ready to be used or sold by farmers as roofing materials. Maize cropping involved soil cultivation prior to planting and application of inorganic fertilizers (60 kg N/ha/cropping and 50 kg P/ha/cropping). The corn cob was harvested at the end of the growing season and dried corn stover was incorporated back into the soil as mulch. *Gmelina* seedlings were block planted with a 3m x 4m spacing, yielding a density of 833 trees/ha. *Gmelina* branches and twigs were pruned during the first two years of tree growth to induce straight growth of main trunk. The pruned branches and twigs were either used as fuelwood for domestic purposes or sold.

2.2 Modelling

Soil Changes Under Agroforestry (SCUAF) version 4.01 (Young et al., 1996) was used to model and simulate the different systems studied. The biophysical model was linked to a cost-benefit spreadsheet (Fig. 1). SCUAF is a simple, deterministic model that can be used to predict crop and tree yield as a function of changes in soil carbon, nitrogen and phosphorus content. These changes in soil nutrient levels are results of soil erosion, recycling of plant materials and nutrient uptake by plants and trees in the specified agroforestry system. Erosion was calculated in the model based on climatic, soil erodibility, slope and crop cover factors using the FAO (1979) Modified Universal Soil Loss Equation (MUSLE).

The economic component of the model (Fig. 1) calculates the net present value (NPV) of the system using a cost benefit framework. The cumulative net present value of the system over *n* years was computed using the following equation:

$$NPVt = \sum_{t=0}^{n} \frac{(Bt - Ct)}{(1+r)} \qquad (1)$$

where B_t and C_t are the total benefits and total costs in year t, and r is the discount rate. Discounting of future benefits and costs was done to equate current and future income streams. Private benefits were calculated by multiplying the farm gate price to marketable outputs of the system resulting from SCUAF simulation.

2.3 Description of the study site

Claveria, Misamis Oriental lies on an undulating plateau between a coastal escarpment and mountainous interior, ranging in elevation from 200 to more than 800 m above sea level. There are two distinct seasons in the area, the wet season (May – October) and dry season (rest of the year) with an average annual rainfall of 2673 mm (IRRI, 1993). Soil characteristics in the site are as follows: well-drained oxisol, acidic (pH between 4.5 and 5.0), more than one meter soil profile depth (Garrity and Agustin, 1995).

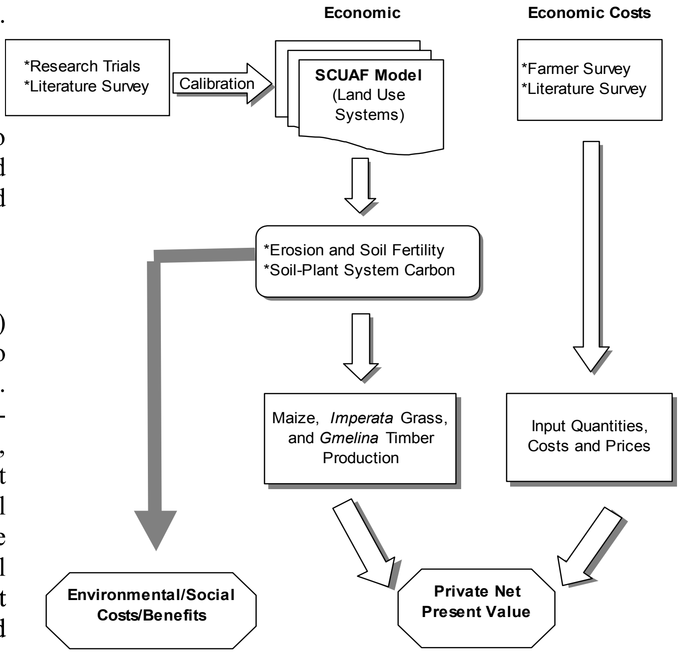

Figure 1. The bioeconomic model used in the study

2.4 Biophysical data used in model calibration and analysis

Most of the data used in modeling *Imperata* system was based on empirical study of Sajise (1980) in the Philippine grasslands (Table 1). Belowground biomass (roots and rhizomes) production was specified to be 60% of total biomass production or approximately 5.72 t/ha/yr, with 0.5% nitrogen and o.4% phosphorus.

The initial aboveground biomass production of the *Gmelina* plantation system specified in the model was 16.9 t/ha, with production at 12.5 t/ha, and leaf production at 4.4 t/ha. These figures were based on the *Gmelina* plantation production observed by Halenda (1993) in Malaysia and Kawahara et al. (1981) in Mindanao, Philippines. The total mean biomass of a 6.6 year old *Gmelina* plantation was 85 t/ha or a mean annual biomass (MABI) of 12.8 t/ha/year (Halenda, 1993).

The nitrogen content of *Gmelina* foliage, fruit, wood, and roots was 2.25, 3.95, 0.258, and 1.12%, respectively (Mamicpic, 1997). The phosphorus content of *Gmelina* biomass was 0.23% for foliage, o.25% for fruit, 0.02% for wood, and 0.04% for roots (Mamicpic, 1997). The carbon fraction of the oven-dried biomass was set at 0.5 (Schroeder, 1994).

In continuous maize cropping system, maize biomass and yields were parameterized in the SCUAF model using average yields reported by farmers interviewed in Claveria. The default value in SCUAF for the underground biomass was 40% of above ground biomass, which was equivalent to 2,960 kg/ha/yr.

The plant nutrient demand was calculated in SCUAF based on the nutrient components of the plant parts and the rate of growth. The SCUAF default values of 2.0% nitrogen from crop residues (leaf), 3.0% for maize grain and 1.5% for root parts were used in the model. The SCUAF default value for phosphorus content of maize grain and roots was 0.5%.

Table 1. Biophysical data and sources used in the modeling of Imperata system.

Parameter	Value	Source
Dry matter production of *Imperata*	3.81 t/ha/yr	Sajise, 1980
Nitrogen content of *Imperata* aboveground biomass	0.94%	Sajise, 1980
Phosphorus content of *Imperata* aboveground biomass	0.70%	Sajise, 1980
Proportion of below-ground biomass to the total biomass	60%	Sajise, 1980

2.5 Economic data used in model calibration and analysis

Labor is the most significant input of production in a smallholder farming system. Harvesting a hectare of *Imperata* grass requires 15 man-days while cleaning, drying and packing the harvested leaves into bundles require 6 man-days (Pasicolan, per comm. 1998).

In the maize cropping system, production activities requiring labor include land preparation, maize sowing, replanting, fertilizer application, interrow weeding, hand weeding, harvesting and post-harvest processing. The annual total labor required per hectare of maize was about 103 man-days and 32 man-animal days (Nelson et al., 1996).

Planting of young *Gmelina* seedlings (834 trees/ha) requires about 9.6 days of man-labor (Magcale-Macandog and Rocamora (1997). Pruning and weeding operations were done twice a year for the first two years of the growth cycle. Other economic data and assumptions used in cost-benefit analysis are presented in Table 2.

Table 2. Other economic data and assumptions used in the analysis.

Data description	**Value**
Input costs	
man-labor (₱/md)	40.00[a]
man-animal labor (₱/mad)	100.00[a]
animal labor (₱/ad)	50.00[a]
maize seeds (₱/kg)	6.50[b]
inorganic fertilizer (₱/kg)	
urea (₱/kg)	7.00[a]
amophos (₱/kg)	5.30[a]
Output price	
maize (₱/kg, average for all months)	6.30[b]
Gmelina fuelwood (₱/ton)	1200.00
Gmelina lumber (₱/bdft)	7.00[c]
Imperata leaves for roofing material (₱/bundle)	10.00[c]
marginal value of carbon emission (US $/tC)	5.00[e]
Number of kg per bundle of *Imperata* roofing materials (kg/bundle)	10[f]
Moisture content (%) of output when sold	
Maize	18[a]
Gmelina timber	54[b]
Gmelina fuelwood	48[b]
Imperata leaves for roofing materials	50[f]
Discount rate (%)	10[g]

Sources:
[a] Nelson *et al*. (1996)
[b] Mamicpic (1997)

[c] Magcale-Macandog & Rocamora (1997)
[d] Gerrits *et al.* (1996)
[e] Nordhaus (1993) cited in Tomich *et al.* (1996)
[f] Authors' estimate
[g] Medalla *et al.* (1990)

2.6 Valuation of carbon sequestration benefits

The carbon content of both crop and wood biomass was estimated to be 50% by weight (Schroeder, 1994), with wood density value of 0.35 t/m^3 (Mamicpic, 1997).

Carbon stored in maize crop residue and *Gmelina* non-timber products was assumed to decay at the year of harvest. On the other hand, carbon in *Imperata* leaves and *Gmelina* timber was assumed to be released back into the atmosphere exponentially based on a half-life (after harvest) of three and 10 years, respectively. The value of carbon sequestered for all land-use systems was calculated using the minimum price level of carbon emissions of US $5/tC (Nordhaus,1993).

3. RESULTS

3.1 Yield of *Imperata*, maize and *Gmelina*

The predicted amount of harvested foliage from *Imperata* grasslands and maize crop declined continuously through the simulation period (Fig. 2). *Gmelina* trees were harvested on the 7th year of growth.

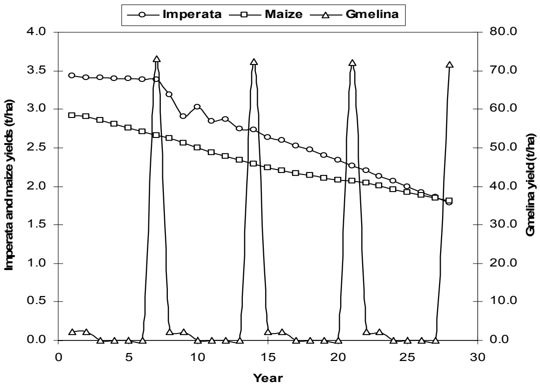

Figure 2. Predicted annual yield of the three land-use systems.

3.2 Predicted cumulative soil loss

The cumulative soil loss from the *Gmelina* plantation system is the lowest among the three systems (Fig. 3). Among the three systems, continuous cultivation and planting to maize crop resulted to the greatest soil loss. At the end of the 28th year, total cumulative soil loss in the maize system was 1600 t/ha, about 64 times higher than the soil loss in the *Gmelina* system.

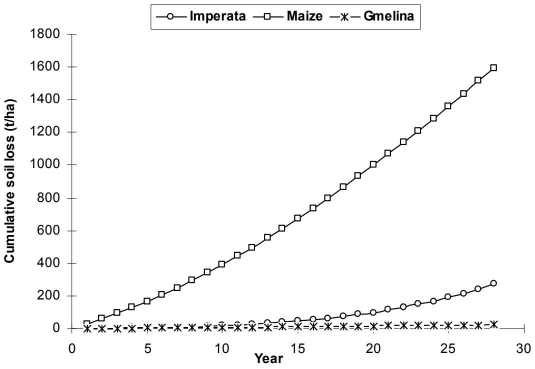

Fig.3. Predicted cumulative soil loss of the three land-use systems.

3.3 Changes in soil carbon

In all the three systems, the predicted total soil carbon content decreased throughout the simulation priod. The rate of reduction in total soil carbon was slowest in the *Gmelina* plantation while the maize system had the highest rate of soil carbon reduction, amounting to 30% reduction of the initial total soil carbon content (Fig. 4).

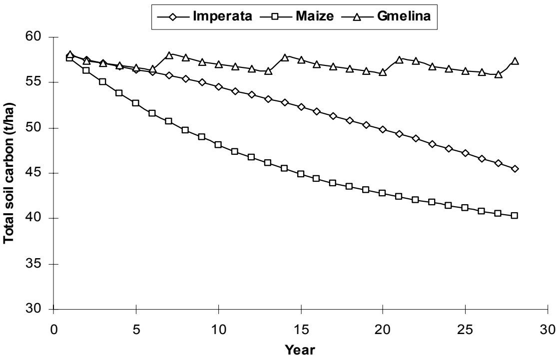

Figure 4. Predicted annual soil carbon of the three land-use systems.

3.4 Private benefits from the three land-use systems

Throughout the period of analysis, the predicted annual returns from the *Imperata* and maize cropping systems were positive, but declining over time. In contrast, predicted annual net return from *Gmelina* system was always negative in the first year until the sixth year of each tree-growth cycle. However, the benefits from tree harvest on the seventh year outweigh the deficits incurred in the preceding years. The *Gmelina* system gave the highest net returns among the three systems over a period of 28 years.

Using a discount rate of 10%, the predicted cumulative net present value from *Imperata* system ranged from P6,018/ha to P53,871/ha over the 28 years of cropping. The NPV of the maize cropping system ranged from P12,213/ha to P79,807/ha. The *Gmelina* system incurred a loss during the first six years and recovered to a level greater than that of *Imperata* and maize cropping systems on the harvest year (7th yr). The NPV of the *Gmelina* system amounted to P925,240/ha after four cycles of tree growth.

For all the three land-use systems considered, cumulative net present value significantly increased when carbon sequestration benefits were included in the analysis (Fig. 5).

Figure 5. Private and social cumulative net present value of the three land use systems at 10% discount rate (WOC = without carbon sequestration, WC = with carbon sequestration).

4. DISCUSSION

The slower rate of soil carbon reduction in the *Imperata* system compared with the maize system is attributed to the humification of underground biomass including rhizomes and roots. *Imperata* allocates 60% of its biomass to below ground structures. Another source of soil C in *Imperata* grasslands is litterfall.

Continuous maize cropping is an extractive system that resulted to the highest decline in soil carbon. Even if maize stover and roots were applied back to the soil as mulch/green manure and that humification of these residues significantly to soil carbon, the maize system encountered higher soil carbon losses. Simulated results have shown that cultivation process enhances loses of the carbon-rich topsoil through soil erosion.

The level of total soil carbon was sustained in the *Gmelina* system. This is attributed to the higher rate of *Gmelina* litter fall. The *Gmelina* system showed additional gains in organic carbon resulting from the humification of the *Gmelina* leaf litter. *Gmelina* leaf litter amounts to about 5t/ha with a decomposition rate of about 3-4 months (Florece, 1996).

The cost-benefit analyses showed financial profitability of *Gmelina* system is superior compared with *Imperata* and maize cropping systems. However, it takes time for the investment in *Gmelina* to be translated into positive revenues. Thus, the attractiveness of the *Gmelina* system primarily relies on the ability of smallholder to absorb the loss in the first six years of operation.

The imputed value of the carbon sequestered is substantially higher in *Gmelina* systems than *Imperata* and maize cropping systems, both in the carbon storage from soil and biomass accumulation.

5. CONCLUSIONS

Modelling is a valuable research tool that can be used in lieu of the expensive traditional experimental research to study the long-term impacts of land-use change. While accuracy is not the primary goal of the study, modeling results can be used to predict future trends which are useful in decision-making process.

The *Gmelina* system appears to be superior compared with the other systems studied since it had the least cumulative soil loss, highest organic C retained in the soil-plant system, greater amounts on nitrogen conserved/recycled in the soil.

There exists an economic incentive for smallholders to transform *Imperata* grasslands or maize cropping system to *Gmelina* system, given its strong private benefits.

6. ACKNOWLEDGEMENTS

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