Soil Erosion and Sustainability of Different Land Uses of Smallholder *Imperata* Grasslands in Sea

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Abstract: Soil erosion is a prominent environmental problem in cultivated upland areas and *Imperata* grasslands in tropical Asia. *Imperata* grasslands cover about 35 million ha in Asia. In Indonesia, *Imperata* grasslands cover about 8.5 million ha. About 17% of the surface cover of the Philippines is *Imperata* grasslands. *Imperata cylindrica* is the dominant species in these grasslands which generally represent degraded, acidic, low organic matter content and dry areas susceptible to soil erosion.

Grasslands in tropical areas have expanded rapidly and encroached indiscriminately due to deforestation and consequent proliferation of shifting cultivation. In typical upland *Imperata* areas of Southeast Asia, shifting cultivators face falling economic returns as fallow lengths shorten. The environmental consequences of shifting cultivation in upland areas can be severe. Conversion of *Imperata* grasslands into upland crop farms planted to rice and maize is triggered by the interacting factors of rapidly increasing population, landholding policies and declining area of arable land per farmer in the lowlands. Attractive market-driven demand for fast-growing timber species like *Gmelina arborea* is also another driving force for the development of smallholder timber plantations.

Long-term sustainability of these different land uses of smallholder *Imperata* grasslands was examined and simulated using Soil Changes Under Agroforestry (SCUAF) model. SCUAF is a simple, deterministic model that can be used to predict crop yield as a function of changes in soil carbon, nitrogen and phosphorus content. Changes in soil carbon, nitrogen and phosphorus contents are results of erosion, recycling of plant materials and mineral uptake by plants in a specified system within a given environment. Soil erosion is predicted in SCUAF using the FAO Modified Universal Soil Loss Equation (MUSLE) and was calculated based on climatic, soil erodibility, slope and crop cover factors.

Simulation results showed that a change in land use from *Imperata* grassland or maize cropping system to *Gmelina* plantation system can provide significant improvements to a range of on-site and off-site biophysical quality measures. The *Gmelina* system appears to be superior with the other systems studied since it has the least cumulative soil loss, highest organic carbon retained in the plant-soil system, greater amounts of nitrogen and phosphorus conserved or recycled in the soil. Simulation results of maize monocropping system showed the highest reduction in total soil C, total soil organic N and total soil organic P as well as highest cumulative soil loss. *Imperata* grassland system had a lower cumulative soil loss compared with maize monocropping system.

The study has demonstrated the usefulness of biophysical model in predicting long-term scenario of soil fertility changes due to soil erosion under different land uses of *Imperata* grasslands. Modelling is a valuable research tool that can be used in lieu of the expensive traditional experimental research to study long-term impacts of land use change. While accuracy is not the primary goal of the study, modelling results can be used to predict future trends which are useful in decision-making process. However, finding s should be interpreted with caution and needs to be validated whenever additional database is available from secondary source or by conducting a follow-up field verification study.

Keywords: SCUAF, biophysical model, soil erosion, *Imperata* grasslands, shifting cultivation, land use change

1 Introduction

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 fire climax nature. *Imperata* grasslands generally represent degraded, acidic, low organic matter and areas susceptible to erosion. Thus, *Imperata* grassland areas are generally considered to have low potential for further land use developemtn except for pasture (Pasicolan *et al.*, 1996). Revegetation fo *Imperata* grasslands is quite difficult due to its resistance to pests, diseases, competition and burning (Mendoza, 1978).

However, conversion of these grasslands into upland crop farms planted to maize, upland rice, and cassava is likewise 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.

This paper attempts to assess the biophysical changes and productivity of different land uses for *Imperata* grasslands through biophysical modelling approach. Specifically, it examines the changes in soil carbon, nitrogen, phosphorus and soil erosion of the three land uses, namely *Imperata* grasslands, continuous maize cropping and *Gmelina* plantation systems in Claveria, Northern Midanao, Philippines.

2 Methodology

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; (3) *Gmelina* plantation system – *Gmelina* plantation with a 7year growth cycle. The assumptions used in the modelling activity for both maize cropping and *Gmelina* plantation systems were based on the actual farmers' practice in Claveria.

Imperata system refers to uncultivated *Imperata* -dominated grasslands that has not undergone any burning. In the modeling activity, about 90% of the aboveground biomass (leaf sheath) were harvested annually during the dry season. Harvest *Imperata* leaves were collected, cleaned, and packed into bundles ready to be used or sold by farmers as roofing materials. The remaining *Imperata* parts were allowed to regrow for the coming rainy season until the next harvesting period.

Maize cropping refers to the traditional upland farming system where the soil is cultivated prior to planting maize seeds. In the model, inorganic fertilizers (60 kg N/(ha • yr), and 50 kg P/(ha • yr)) were applied during the growing season and only the corn cob was harvested at the end of the growing season. The dried corn stover was incorporated back to the soil as mulch and allowed to decompose in the field.

Gmelina seedlings were block planted with a 3 m × 4 spacing, yielding a density of 833 trees per hectare. Branches and twigs were pruned during the first two years of *Gmelina* growth to induce straight growth of *Gmelina* main trunk. The pruned branches and twigs were used as fuelwood. *Gmelina* was grown for seven years and the trees were harvested for timber at the end of the 7^{th} year.

3 Modelling

The three systems were modeled using Soil Changes Under Agroforestry (SCUAF) model (version 4.01 (Young *et al.*, 1996). SCUAF is a simple, deterministic model that can be used to predict crp yield as a function of changes in soil carbon, nitrogen and phosphorus content. Changes in soil carbon, nitrogen and phosphorus contets are results of erosion, recycling of plant materials and mineral uptake by plants in a specified agroforestry system within a given environment. Erosion in predicted in SCUAF using the FAO (1979) Modified Universal Soil Loss Equation (MUSLE) and was calculated based on climatic, soil erodibility, slope, and crop cover factors. Since SCUAF determines plant growth and soil changes on a per hectare basis, all land-use systems were modeled on a hectare of land area.

Imperata and maize cropping systems were modeled in SCUAF as agricultural monoculture. Maize monoculture was represented as a single period composed of two cropping seasons annually with area under tree component set to zero. On the other hand, *Imperata* was treated as a single period with area under tree component set to 100.

Gmelina arborea plantation was modeled as plantation forestry with no understorey vegetation. *Gmelina* plantation was modeled for a 7year cycle of tree growth. Simulation was done for four cycles of tree growth, or a total of 28 years.

Data used in the calibration of the models for the three systems

The average above ground dry matter production of *Imperata* used in the model was 3.81 t/(ha • yr) (Sajise, 1980). This is close to the 4.0 t/(ha • yr) biomass production of *Imperata* grasslands cited by Castillo and Siapno (1995). The nitrogen and phosphorus contents of *Imperata* above ground biomass were 0.94% and 0.70%, respectively (Sajise, 1980). Below ground biomass (roots) 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 above ground biomass production of the *Gmelina* plantation system specified in the model was 16.9 t/ha, with wood 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 about 85 t/ha or a mean annual biomass increment (MABI) of 12.8 t/(ha • yr) (Halenda, 1993). Average biomass production observed in less than 10 years old fast growing plantation species like *Paraserianthes falcataria* and *Gmelina* arborea was 83.4 t/ha (Kawahara *et al.*, 1981). Likewise, Chijoke (1980) reported a wood MABI ranging from 9.3 to 20.8 t/(ha • yr) for *Gmelina* in Brazil and Nigeria.

Nutrient composition of *Gmelina* biomass was derived from the study of Mamicpic (1997) at Claveria site. The nitrogen content of *Gmelina* foliage, fruit, wood, and roots was 2.25, 3.95, 0.258, and 1.12%, respectively. The phosphorus content of *Gmelina* biomass was 0.23% for foliage, 0.25% for fruit, 0.02% for wood, and 0.04% for roots. 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. Average yields reported by farmers for open-field farming were 2,660 kg/(ha • yr) for wet seson crops and 780 kg/(ha • yr) for dry season crops (Nelson et al, 1996). The total dry matter maize biomass specified in SCUAF was 7,400 kg/(ha • yr) (Agus, 1994). 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 for crop residues (leaf), 3.0% for maize grain and 1.5% for root parts were used in the model. Similar nitrogen content of maize crop residue was observed at Tranca, Laguna (Paningbatan,, pers. Comm.) The phosphorus content of maize leaf biomass of 0.2% was obtained from Lowry *et al.* (1992). The SCUAF default value for phosphorus content of maize grain and roots was 0.5%.

Farmers at Claveria applied inorganic fertilizers in maize production system. Elemental nitrogen was applied at the rate of 120 kg/(ha • yr) while elemental phosphous was applied at the rate of 100 kg/(ha • yr).

The data used in calibrating soil erosion in the model was derived from various sources. Except for the cover factor, the MUSLE input for soil erosion parameters in SCUAF were the same for all the three systems studied. An adjusted climate factor of 700 mm was used, based on one-half of the annual average rainfall monitored at Compact over four years (1989—1992). This fine tune adjustment was done so that the simulated erosion results will approximate the actual average erosion (26.6 t/(ha • yr)) measured over five years of continuous open-field maize crop farming (Agus, 1994). A soil erodibility factor of 0.09 (Nelson *et al.*, 1996); Limbaga, 1993) and slope factor of 1.5, which was based on moderately steep experimental plots (Nelson *et al.*, 1996), were used in all the systems. Cover factor was set at 0.01 for the *Imperata* system, 0.3 for the maize cropping system, 0.006 for the *Gmelina* plantation system in the SCUAF model (Nelson *et al.*, 1996; Young, 1989).

4 Results

4.1 Predicted cumulative soil loss from the three land use systems

The cumulative soil loss from the Gmelina forestry plantation system is the lowest among the three systems (Fig. 1). The predicted total cumulative soil loss from the Gmelina plantation was about 25 t/ha in the 28year simulation period. Imperata grasslands somehow provided protection from topsoil loss during the first 13 years. Afterwards, soil loss in the *Imperata* grasslands increased (Fig. 1). Predicted cumulative soil loss in the *Imperata* grasslands was 271 t/ha in 28 years about 10 times higher than the soil loss in the *Gmelina* system. Among the three systems, continuous cultivation and planting to maize crop resulted to the greatest soil loss among the three systems studied. At the end of the 28th year, total cumulative soil loss in the maize system was 1,600 t/ha, about 64 times higher than the soil loss in the *Gmelina* system.

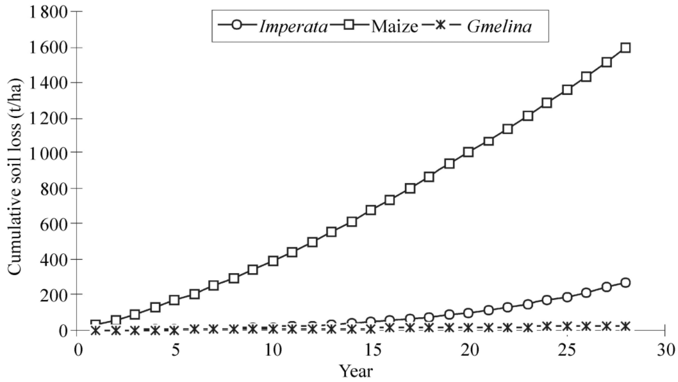

Fig. 1 Predicted cumulative soil loss of the three land use systems

4.2 Changes in soil carbon

In all the three systems, the predicted total soil carbon content decreased throughout the simulation period. The rate of reduction in total soil carbon was the slowest in the *Gmelina* plantation, with a 1.33% reduction only in the 28 years of simulation (Fig. 2). The maize system had the highest rate of soil carbon reduction, amounting to 30% reduction of the initial total soil carbon content. The rate of decrease in total soil carbon content in the maize system was faster in the first ten years of cropping than in the succeeding years (Fig. 2). The predicted total soil carbon reduction in the *Imperata* grassland was 21.6 % of the initial total soil carbon content (Fig. 2). The rate of decrease in total soil carbon was faster in the maize system compared with the *Imperata* grasslands.

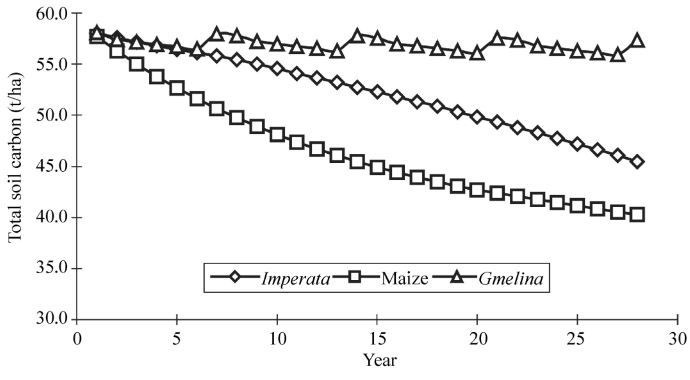

Fig. 2 Predicted annual soil carbon of the three land use systems

4.3 Total soil organic nitrogen

The total soil organic nitrogen of the *Gmelina* plantation forest system was steady after 4 cycles of the tree growth (Fig. 3). Even though there was decline in soil organic nitrogen during the tree growth, the soil organic nitrogen increased at a higher level after timber harvest, though not of the same level as the initial N content. However, as indicated in the graph (Fig. 3), the soil total nitrogen slowly built up such that at the beginning of the 5th cycle of the tree growth, the soil total nitrogen content was very close to its initial value.

Maize system had the highest rate of decline in soil total organic nitrogen during the first 15 years and then its decline decreased at a slower rate thereafter (Fig. 3). The decline in the *Imperata* system is linear throughout the simulation period and occurred at a much slower rate compared with the maize system. The predicted reduction in total soil organic nitrogen was 26% in the maize system and only 17% in the *Imperata* system (Fig. 3).

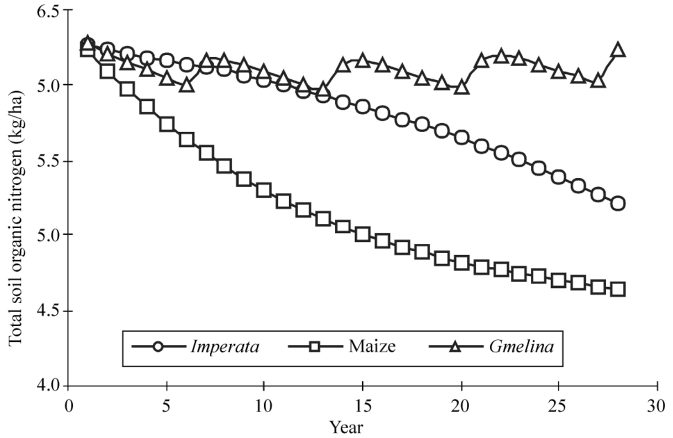

Fig. 3 Predicted annual total soil organic nitrogen of the three land-use systems

4.4 Total soil organic phosphorus

All the three systems resulted to a decline in the total soil organic phosphorus levels. The *Gmelina* plantation forest system had the least reduction, amounting to only 8.6% of the initial phosphorus levels after four cycles of *Gmelina* tree growth (Fig. 4).

The maize system resulted to the least total soil organic phosphorus after 28 years, losing about 30% of the initial P content. The loss in total soil organic phosphorus in the *Imperata* system amounted to 22% of the initial content (Fig. 4).

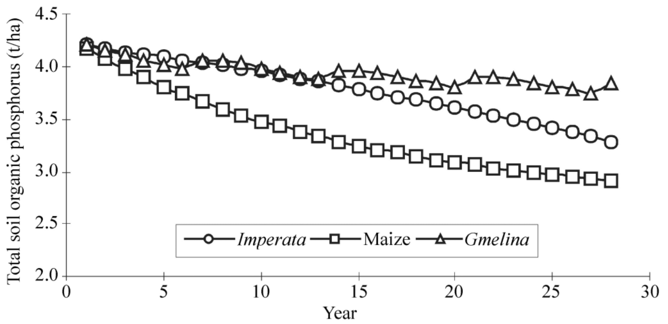

Fig. 4 Predicted annual total soil organic phosphorus of the three land-use systems

4.5 Yield of Imperata , maize and Gmelina

The predicted amount of harvested foliage from *Imperata* grasslands declined

continuously throughout the simulation period (Fig. 5). The decline was very gradual during the first six years and rate increased in the succeeding years of simulation. In the initial year, the harvested foliage was about 3.4 t/ha. At the end of the 28-year simulation period, the amount of harvested *Imperata* leaves was reduced down to nearly 1.8 t/ha, about 47% reduction in harvest (Fig 5).

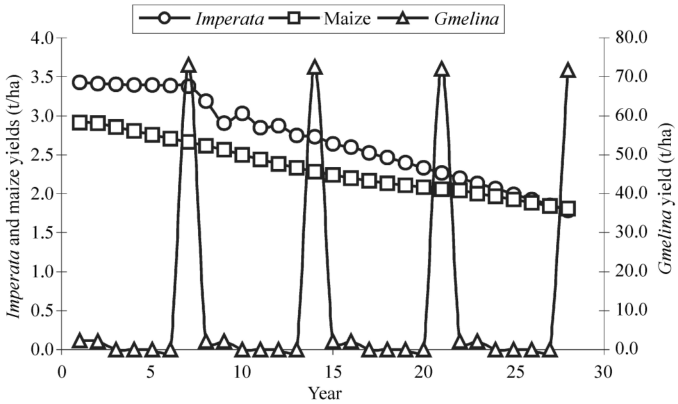

Fig. 5 Predicted annual yield of the three land use systems

Maize yield refers to the harvested maize grain at the end of the growing season. The harvested maize grain declined steadily throughout the simulation period. The initial predicted maize yield was 2.9 t/ha. This decreased down to 1.8 t/ha on the 28th year, about 38% reduction in yield (Fig. 5).

There was no annual harvest in the *Gmelina* plantation during the six years of *Gmelina* growth, and the trees were harvested only on the 7^{th} year. The amount of biomass harvested from *Gmelina* plantation in the first cycle was 73 t/ha and was reduced down to 71.7 t/ha on the 4^{th} cycle, about 2% reduction in yield (Fig. 5). Among the three systems, it is the *Gmelina* plantation that exhibited the least yield reduction.

5 Conclusion

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, modelling results can be used to predict future trends which are useful in decision-making process. However, the findings should be interpreted with caution and needs to be validated whenever additional database is available from secondary sources or by conducting a follow-up field verification study.

A change in land use from *Imperata* grassland or maize cropping system to *Gmelina* plantation system can provide significant improvements to a range of on-site and off-site biophysical quality measures. The *Gmelina* system appears to be superior compared with the other systems studied since it had the least cumulative soil loss and greater amounts of nitrogen and phosphorus conserved/recycled in the soil. Nonetheless, *Imperata* grassland system had a lower cumulative soil loss compared with maize cropping system.

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