25. PREDICTING THE LONG-TERM PRODUCTIVITY, ECONOMIC FEASIBILITY AND SUSTAINABILITY OF SMALLHOLDER HEDGEROW AGROFORESTRY SYSTEMS USING THE WANULCAS MODEL

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The long-term productivity, economic feasibility and sustainability of *Eucalyptus*-maize hedgerow agroforestry system were simulated and predicted using the WaNuLCAS model. WaNuLCAS is a process-based model of water, nutrient and light capture in agroforestry systems. It is the most flexible model currently available for evaluation of management options in agroforestry systems based on site-specific information and farmer management objectives. The results of this simulation were compared with the results of the simulation of a continuous maize monocropping system. The model was calibrated using experimental data and survey results in a study conducted at Claveria, Southern Philippines. Simulation revealed that more than half of the total nitrogen in the two systems is tied up in the soil organic matter (SOM). Leaching and lateral flow are the main avenues of nitrogen loss in both systems. Modelling the water balance of the two systems showed that a eucalypt-maize hedgerow system had higher subsurface flow and surface run-off. Maize yield was initially higher in the continuous annual cropping system (2.4 t/ha) than under the eucalypt-maize hedgerow system (1.8 t/ha). The benefit obtained from the maize cropping system is the grain produced while those from the eucalypt-maize hedgerow system are maize grain and timber. Financial analysis showed that the eucalypt-maize hedgerow system had a higher NPV after nine years of simulation (PhP306,536), compared with the continuous maize (PhP16,998). Results of this study have shown that the eucalypt-maize hedgerow system provides substantial improvements to a range of biophysical and economic measures of productivity and sustainability.

INTRODUCTION

In Claveria, Misamis Oriental, monocropping has been a major contributory factor to soil degradation, and a reason why farm production has been unstable and remained at a subsistence level. This was despite the introduction of several farming techniques to improve the production of crops.

Agroforestry is a dynamic, ecologically-based, natural resource management system that, through the integration of trees in farm, diversifies and sustains smallholder production for increased social, economic and environmental benefits (Leakey 1996). In agroforestry systems, trees and crops interact in relation to total nutrient and water cycles, as well as light capture. The positive interactions of tree-crop combination on a farm not only improve the farm biophysical conditions but also enhance the food security in the farming household. The introduction of trees in the cropping system can help prevent land degradation, increase biodiversity and at the same time allow the continued use of the land for agricultural crop production. Moreover, growing trees alongside crops has been demonstrated to improve both the productivity and sustainability of the land (Wise and Cacho 2002).

Mature trees in agroforestry systems could yield a number of positive effects on cropped fields (Garcia-Barrios and Ong 2004). Among these are increased soil fertility and physical improvement via organic matter addition through litter, reduced soil erosion through stabilization of loose soil surfaces by tree roots, extraction of leached nutrients from deep soil layers inaccessible to crops, reduced soil water evaporation, reduced leaf temperature and evaporative demand by crops via tree shade, increased soil infiltration rate, protection against wind and runoff, weed population reduction and potential slowdown of windborne pest and diseases. However, an increase in tree density, size and ability to capture resources can exert strong competition for light, water and nutrients and may result to yield reduction of crops if not carefully selected and managed. Nonetheless, a weak competition can be observed under particular circumstances in a system (Garcia-Barrios and Ong 2004). When tree roots reach below the crop root zone, accumulated water in deeper soil layer are used by the tree. Residual water in the crop zone can then be used when crops are harvested. In a system where nitrogen-fixing trees are used as hedgerows, an alternative source of N for trees can reduce competition with crops. Radiation is also shared between hedgerows and crops when trees have a low leaf area index (LAI).

WaNuLCAS is a process-based model of water, nutrient and light capture in agroforestry systems developed by Van Noordwijk *et al.* (2004). It is the most flexible model currently available for the evaluation of management options in agroforestry systems based on site-specific information and farmer management objectives. Simulation results that can be generated by the models include nutrient dynamics, water balances, light use, crop and tree biomass, and crop yield.

The study reported here was designed to predict and assess the long-term productivity, economic feasibility and sustainability of a eucalypt-maize hedgerow agroforestry system using the WaNuLCAS model. Outputs of simulation of this system are compared with those of a continuous maize mono-cropping system.

THE PROJECT SITE

Claveria is a land-locked agricultural municipality in the province of Misamis Oriental (Figure 1). It has a total land area of about 82,500 ha, with generally rugged topography, characterized by gently rolling hills and mountains with cliffs and escarpments. The soil is classified as Jasaan Clay, with a deep soil profile (greater than 1 m) and rapid drainage. It is generally acidic (pH 3.9 to 5.2), with low cation exchange capacity (CEC), low to moderate organic matter content (1.8%), high aluminium saturation, and low levels of available phosphorus and exchangeable potassium.

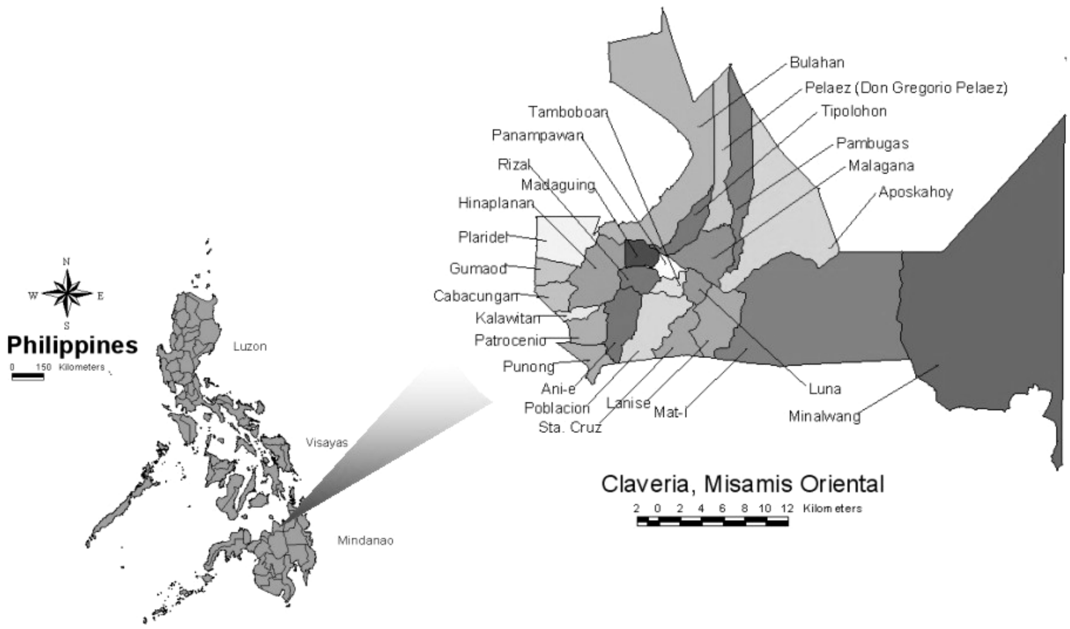

Figure 1. Location and administrative map of Claveria, Northern Philippines

Claveria has a rainfall distribution of five or six wet months (>200 mm/month) and two or three dry months (<100 mm/month). Rainfall patterns throughout the municipality vary with elevation, with the upper areas having a relatively greater amount of rainfall than the lower areas. The rainfall pattern strongly influences cropping patterns and land use across Claveria's landscape.

The cultivated land area in Claveria is estimated at 26,055 ha. The dominant crop is maize, with 51% of the arable land devoted to its production. In high elevation areas, 1,837 ha are planted to tomatoes. Cassava is a widely grown root crop in lower Claveria. Tree-based agricultural systems are widely adopted by the farmers, the most frequent timber tree species planted being *Gmelina arborea*, *Eucalyptus deglupta* and *Paraserianthes falcata*. Bananas are widely grown; other fruit trees found in the municipality are *Cocos nucifera*, *Durio zibenthinus*, *Mangifera indica*, *Nephelium lappaceum* and *Lansium domesticum*.

RESEARCH METHOD

Bioeconomic Modelling using WaNuLCAS

The biophysical and economic modelling was done using the Water, Nutrient, and Light Capture in Agroforestry Systems (WaNuLCAS), version 3.01. Parameter values for the model were gathered through field measurements, literature survey and interviews of farmers. The parameters were used as inputs into the WaNuLCAS model, either directly or else indirectly through the sub-routines including Functional Branch Analysis (FBA), Pedotransfer and WOFOST.

Tree and crop database

A survey form (Treeparam) to describe trees was designed together with the WaNulCAS model for parameterization of the tree component. A translation of the Treeparam survey form to local dialect (Visayan dialect) was devised to obtain tree-silvical information needed to construct a tree-specific database using FBA protocol (Van Noordwijk and Mulia, 2002). Default values for the various parameters for the maize crop are available in the crop database of the model. The tree and crop parameters in the databases are part of the input parameters required in the simulation using WaNuLCAS model.

WaNulCAS parameterization

The land-use scenarios modelled were a continuous maize (*Zea mays*) cropping system and a bagras (*E. deglupta*) and maize hedgerow agroforestry system. A seven year old bagras hedgerow with a spacing of 1 x 10 m intercropped with maize was selected for the simulation. The plot was divided into four zones with corresponding predefined zone widths (Table 1). Nitrogen (N) and phosphorous (P) fertilizers were applied at a rate of 15.65 g/m^2 and 16.65 g/m^2 respectively for all plots. P fertilizer was applied at planting, while N fertilizer was applied 30 days after emergence (DAE). Climatic data were collected from the field site and Misamis Oriental State College of Agriculture and Technology (MOSCAT) Agromet station. Soil samples were collected from the field and analyzed for chemical and physical properties.

Table 1. Land-use scenarios simulated using WaNuLCAS

Land use scenario	Zone width (m) and composition			
	Zone 1	Zone 2	Zone 3	Zone 4
Continuous *maize* cropping system	1 Crop	3 Crop	3 Crop	3 Crop
Eucalyptus + maize hedgerow AFS	1 Tree, crop	3 Crop	3 Crop	3 Tree, crop

Annual net returns and net present value (NPV) computation

Annual net returns were computed by subtracting costs (labour, seeds, fertilizer) from the revenues (grain yield and timber yield) for each cropping season. Two crops of maize were raised per year while *E. deglupta* timber was harvested during the ninth year of tree growth. Net present value (NPV) was computed at a discount rate of 12%. The economic data and assumptions used in the simulation runs for the various land uses are presented in Table 2.

Table 2. Summary of assumptions used in the simulation and analysis

Description	Value (PhP)	Source
Input costs		
man-labour (md)	100.00	Field survey, primary data
man-animal (mad)	200.00	Field survey, primary data
maize seeds (kg)	50.20	Current price, Cagayan de Oro, Misamis Oriental, Phil.
E. deglupta (seedling)	2.00	Current price, Cagayan de Oro, Misamis Oriental, Phil.
inorganic fertilizer		Current price, Cagayan de Oro, Misamis Oriental, Phil.
(kg)	9.00	
Urea	7.00	
Solophos		
Output prices		
Maize (kg)	10.00	Current price
E. deglupta wood (kg)	15.88	Forest Management Bureau, 2002 Statistics
Annual discount rate (%)	12.0	Assumption (rates vary between 5 and 20%)

RESULTS AND DISCUSSION

Nutrient, Water and Soil Dynamics

Simulation results show that a major portion of soil nitrogen is tied up in the soil organic matter (SOM) component of the two land use systems (Table 3). The hedgerow system has a higher N in SOM (85%) and lower N losses than the continuous maize system. Lateral flow and leaching are the major avenues of N losses from the continuous maize cropping. Much of the P in both land-use systems is also tied in the SOM. Maize monocropping has greater amount of P lost mainly through lateral flow. Harvesting of maize grain removes 3–4% of P from the system (Table 3).

Tree litter and crop residue also contributes to the increase in SOM via decomposition. The leaf litter and maize biomass contain considerable amounts of N, which upon decomposition add organic matter to the soil. Bagras leaves have 2.3% N and maize leaves about 2% N. The mulch also provides soil surface cover that reduces the impact of rainfall, thereby minimizing surface runoff and soil erosion, and reducing nutrient losses.

Table 3. Distribution of nitrogen and phosphorus in the soil and other components of the three land uses, for nine year farming system simulation

Component	Maize monocropping	Hedgerow AFS	Maize monocropping	Hedgerow AFS
	N (%)		P (%)	
Surface litter	0.19	0.80	0.71	1.12
Soil organic matter	54.85	86.14	66.90	71.28
Immobilized	1.75	2.75	4.27	4.55
Lateral flow	22.76	4.52	21.73	18.70
Crop harvest	0.38	0.21	4.27	1.09
Tree biomass		1.9		1.45
Run-off	0.61	0.95		
Volatilization	0.04	0.04		
Leaching	21.74	2.73	2.11	1.80

In both systems, subsurface flow and water draining into the various soil zones and layers account for more than half of the soil water. Losses of water through soil evaporation are higher in maize monocropping. However, canopy evaporation is higher in the hedgerow systems. Crop water uptake by maize is higher than tree uptake in the deglupta hedgerow system.

Results of modelling the water balance of the three systems showed that deglupta-maize hedgerow system had a higher subsurface flow compared with the other two systems (Table 4). The larger leaf area of trees tends to increase canopy evaporation losses of the hedgerow AFS. However, soil evaporation losses were substantially reduced under hedgerow AFS as compared to maize monocropping. The shade provided by the presence of trees can help offset soil evaporation losses. In the absence of trees, sloping upland farms practicing monocropping will tend to loose soil water more rapidly than those land uses with hedgerow agroforestry systems. These losses may vary with different soil characteristics and slope.

Table 4. Total soil water under the two land use systems (li/m^2)

Component	Hedgerow AFS	Maize monocropping
Surface run-off	18,343	18,284
Subsurface flow	214,206	204,186
Drainage	146,600	153,844
Soil evaporation	274	9555
Canopy evaporation	1962	342
Crop uptake	4753	21,514
Tree uptake	9237	

Continuous maize cropping resulted in greater soil loss than the bagras-maize hedgerow AF system. This is due to the cultivation of soil for cropping maize in the alley areas in the hedgerow systems.

Financial Comparison of the Maize and Deglupta-maize Hedgerow Systems

Results showed strong competition for light between trees and crops under the deglupta-maize hedgerow system. This interaction is reflected in the low maize biomass and yield in the hedgerow system. Maize yield was initially higher in the continuous annual cropping system (2.4 t/ha) compared with maize yield under the deglupta-maize hedgerow system (1.8 t/ha). Yields of maize declined through the years. Tree biomass increased as trees grew during the simulation period.

The benefits obtained from the maize cropping system are the grain yield and from the deglupta-maize hedgerow system, the maize grain yield and timber. Annual net returns were higher in the maize monocropping system compared with the returns from the hedgerow system in the first three years of simulation. The annual returns from maize yield were declining for both systems due to maize yield decline as a result of soil fertility loss due to soil erosion in these rolling upland areas. The high annual return for the hedgerow system on the ninth year of simulation was due to the harvested *E. deglupta* timber. Financial analysis showed that the deglupta-maize hedgerow system generated a higher NPV after nine years of simulation (PhP306,536.69) compared with the continuous maize (PhP16,998.69) (Table 5). The financial analysis of any agroforestry system depends on financial variables including output prices, establishment cost, labour cost and discount rate. It may also depend on management decisions such as the area planted to crops and trees (Wise and Cacho 2002).

Table 5. Simulated annual net returns and net present values of the two land use systems

Year	Annual net returns (PhP)	
	Maize monocropping	Hedgerow agroforestry
1	23,514.00	17,454.00
2	4814.00	3,641.20
3	1414.00	(1480.40)
4	(1186.00)	(3498.00)
5	(3186.00)	(3653.20)
6	(3186.00)	(4118.80)
7	(3186.00)	(4118.80)
8	(3886.00)	(4118.80)
9	(4586.00)	327,272.12
NPV[a]	16,998.69	306,536.69

a. NPV is derived for a 12% discount rate.

SUMMARY AND CONCLUSION

Simulation using the WaNuLCAS model proved a powerful method for examining differences in the dynamics of resources including nitrogen, phosphorus and water of the alternative land-use systems. N and P are lost from the maize system via leaching, lateral flow and crop uptake. Nutrients are tied to the soil organic matter, tree biomass and leaf litter in hedgerow systems. Water loss through evaporation from the soil surface is greatly reduced in the hedgerow agroforestry system.

The integration of trees into the cropping system may minimize nutrient losses via dynamic tree-crop interaction. Trees can help prevent land degradation, increase biodiversity and at the same time allow the continued use of the land for agricultural crop production. Continuous maize monocropping may result in land degradation, yield undesirable crop performance with time and in the long run leads to irreversible change.

Proper management practices of hedgerow agroforestry systems are needed to reduce the possible negative effects to crops grown under this system. Shoot pruning and accumulation of mulch, if not removed in the alleys of agroforestry system, reduce light competition and facilitate nutrient accumulation in the crop zones for crop allocation. Tree distances can also be increased to minimize shading effect and allow greater space for crop cultivation. Proper selection of tree species and planting density as well as choice of annual crop is necessary to maximize benefits from the hedgerow agroforestry systems.

WaNuLCAS is a very useful tool in providing predictions of the possible consequences of management practices to productivity and sustainability of alternative land use system being modelled. However, considerable resources are required to required to gather estimate input parameters before reliable simulation results can be generated. Simulation results should also be validated with field data.

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