Assessment of Sustainability Criteria and Carbon Stocks, for Selected Land Use Options for Philippine Uplands

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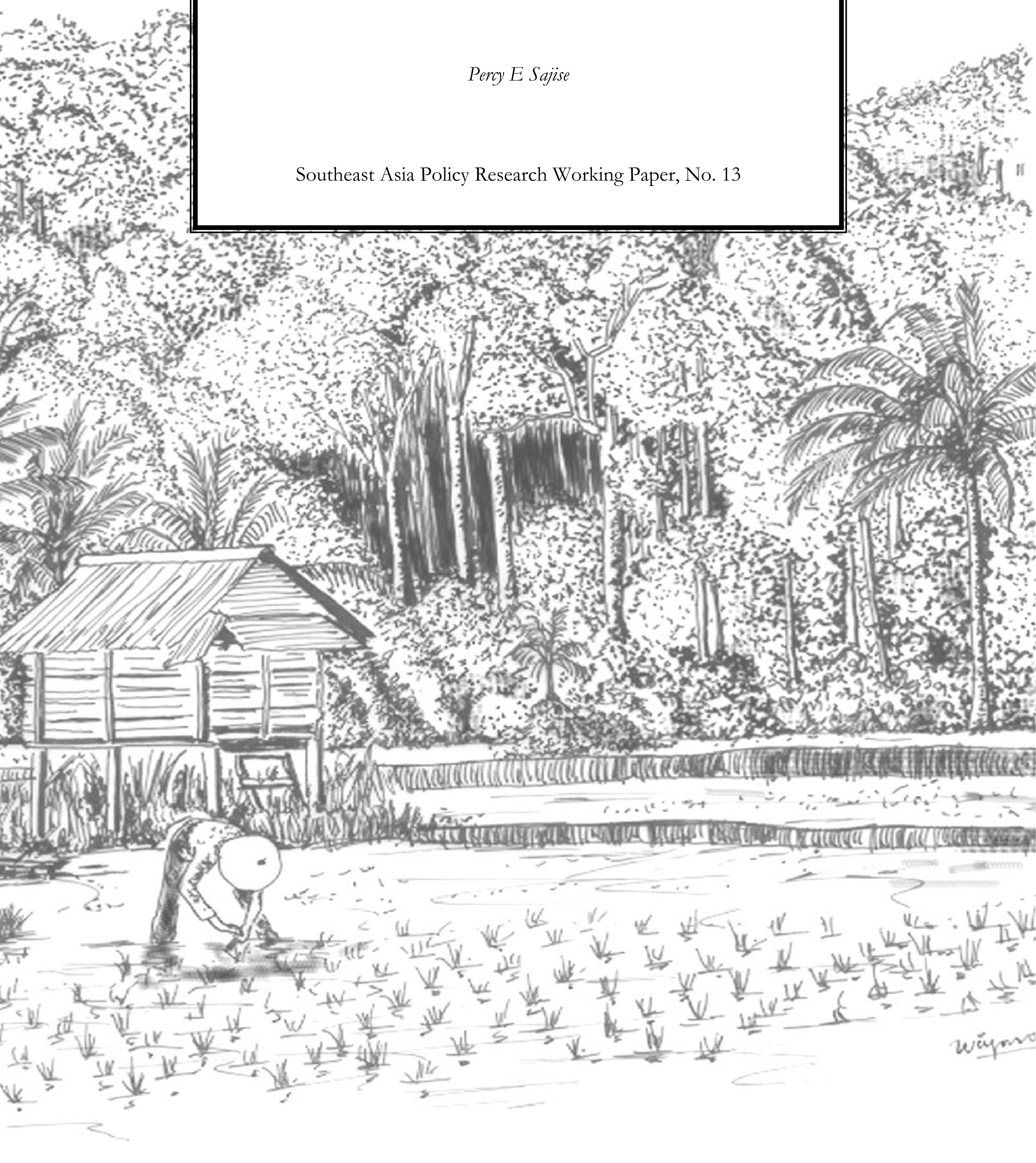

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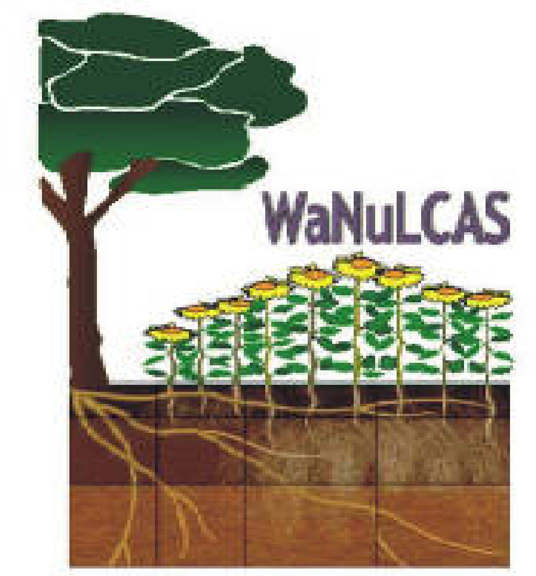

Assessment of Sustainability Criteria and Carbon Stocks for Selected Land Use Options for Philippine Uplands

An ICRAF-SEARCA Research Project

In collaboration with UP Los Baños

Completion Report

November 2000

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EXECUTIVE SUMMARY

SEAMEO-SEARCA and ICRAF-SEA reached an agreement to implement a collaborative research project entitled, "*Assessment of Sustainability Criteria and Carbon Stocks for Selected Land Use Options for Philippine Uplands*".

The objectives of this research project are:

(1) To assess the longer term implications for soil properties, nutrient, water and organic matter balance of a range of land use alternatives for upland agriculture and agroforestry, to estimate the possible trade-offs between profitability, sustainability and carbon sequestration; and

(2) To test a generic method for deriving sustainability, profitability and carbon stock indicators form a comprehensive tree-soil-crop interaction model. (Refer to Appendix A and B for details)

The pre-implementation stage of the WaNuLCAS Project involved a series of project team meetings, analysis of the model, and project workplan finalization. Most of the project time was spent on model parameterization and/or calibration using existing as well as secondary data from differenr sources like past research project results in the study site. Parameterization included activities such as sensitivity analysis and curve-fitting.

Two agroforestry-based farming systems or landuse options were considered, namely the Corn Monocropping System (CMS) and the Corn-*Gliricidia* Cropping System (CGCS). These two systems which are dominant in the sloping uplands of Northern Mindanao were modelled and their long -term sustainability performance was assessed using the selected sets of indicators and criteria.

Simulation results show that CMS appears to be less unprofitable or more profitable compared to CGCS. But from sustainability standpoint, the latter is still better than the former.

Analysis of the model performance indicated that, WaNuLCAS provides the best well-rounded simulation at the plot level. The very detailed simulation output it provides can easily be generalized or transformed and inputted to other simulation models focus at higher hierarchical level of agroecosystems.

Moreover, during the course of model parameterizations, observations on the model input data requirements and simulation outputs were noted and documented. These are deemed important in assessing the model input data necessary considering the data availability, reliability, and importance at a particular level in the hierarchy of systems.

DESCRIPTION OF PRODUCTION SYSTEMS

Location of the Project Site

The agroforestry production systems considered in the study are located in Barangay (village) Songco, Municipality of Lantapan, Province of Bukidnon, Mindanao, Philippines as shown in **Figure 2-1**.

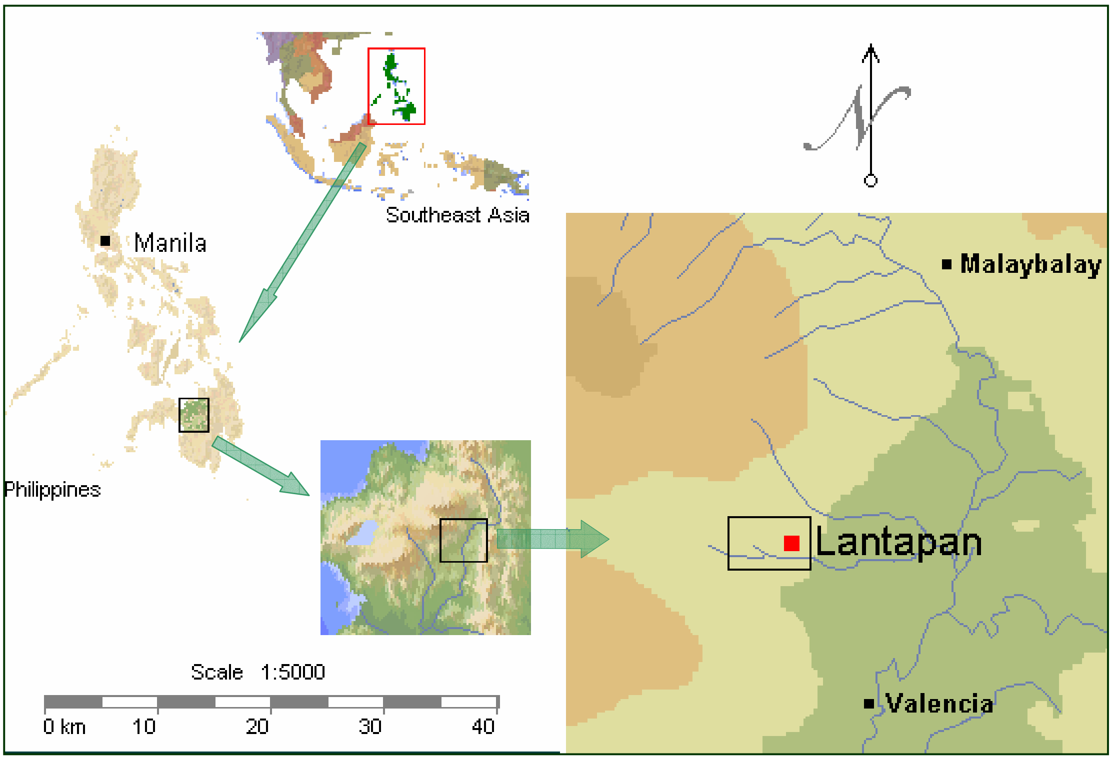

Figure 2-1. Relative location of the project site in Lantapan, Bukidnon, Philippines.

The project site is located between the coordinates of 124^0 52" - 124^0 54" East and 8^0 02" and 8^0 04" North. The area's elevation ranges from 800 m asl to 1400 m asl. It belongs to type four climate characterized by even distribution of rainfall through the year.

Barangay Songco is approximately 30 kms from Malaybalay, Bukidnon's' capital and is accessible through the municipal unpaved road. Travel time is approximately 30 minutes using public utility vehicles (e.g., jeepney or mini bus).

Corn-Corn Monocropping System

Plot Description

The total plot width was set to 5 meters or 1.25 meter per zone. The CMS is schematically illustrated in **Figure 2-2**. The initial slope was set to 40% or about18 degrees. Runon from one adjacent uphill plot was allowed. It is observed that each of the 4 zones received equal amount of inputs (e.g. rainfall, fertilizer, and other inputs).

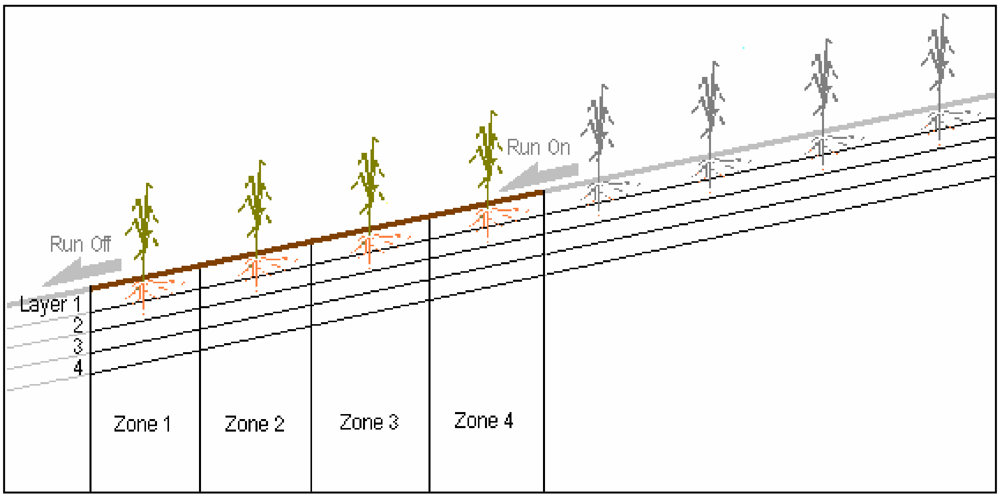

Figure 2-2. Schematic diagram of corn monocropping system.

Farm Management/Operations Schedule

1. <u>Land preparation</u> was practiced only for the first cropping season. It is usually done anytime within 30 days before planting. Land clearing through slashing was practiced 7 to 14 days before planting. The earliest planting date was between the second and third weeks of February. Plowing and harrowing were done twice while furrowing was done once within 7 days before planting, using cow as draft animal, during the first cropping season. Farmers practiced minimum or zero tillage during the second cropping season. It should be noted that the simulation model does not have an option yet as to how many times ploughing can be done.

2. <u>Planting</u> of *Tiniguib* or hybrid corn variety was usually done manually between March and April, and in September for the first and second cropping seasons, respectively. The common seeding rate was 21-24 kg/ha. The common planting distance was either 75 cm x 25 cm or 50 cm x 25 cm. Planting dates were set on Julian day (JD) 61 (March) and JD 270 (September) and were used in the model for the first and second cropping season, respectively.

3. <u>Weeding</u> by hand was performed as the need arises, only during the first cropping season; while interrow cultivation using light hoe was usually done 30 days after planting during the first and second cropping season.

The effect of pest and diseases on crop growth and development as well as weed growth were not simulated.

4. Fertilization was done through split basal application method during planting and 30 days after planting (DAP) for both cropping seasons. Fertilization rate varied from 7-7-7 to 35-35-35 using 14-14-14 and/or 18-46-0 fertilizers and chicken manure. Split fertilizer application schedule of JD61 and JD91 and JD270 & JD300 were used for first and second cropping season, respectively, using the fertilization rate of 60-60-0.

Soil Characteristics

The soil in the study site, which is currently under corn monocropping system, is fertile and very porous. It has a high clay content but low bulk density. The soil belongs to yellow-red soil group and is very similar to the soils of Lampung, Indonesia. **Table 2-1** details the soil profile and the crucial soil physical and chemical properties of the plot currently under corn in Songco, Lantapan.

Table 2-1. Soil Profile Description.

Location	: Barangay Sungko, Lantapan, Bukidnon, Philippines
Longitude	: 124^o 56'.24" E
Latitude	: 08^o 03'.21" N
Physiographic position	: side slope
Elevation	: approx. 1220 m asl
Land use	: corn land
Parent material	: volcanic
Evidence of erosion	: moderately eroded
Rock outcrops	: none
Depth of water table	: not measured

Depth (cm)	**Description**
0-13	Brown to dark brown (7.5YR4/4) slightly moist, clay; sticky, plastic, firm, moderately weak fine sub-angular blocky structure; few fine and very fine roots; clear smooth boundary.
12-49	Strong brown (7.5YR5/6) slightly moist, clay; sticky, plastic friable; moderately weak fine sub-angular blocky structure; few fine and very fine roots; clear smooth boundary.
49-94	Strong brown (7.5YR5/8) slightly moist, clay; sticky, plastic, friable; moderately fine sub-angular blocky structure; very few fine roots; presence of few soft highly weathered volcanic materials; clear smooth boundary.
55-86	Brownish yellow (10YR4/4) moist, clay; sticky, plastic, friable, moderately fine.
94-184	Brownish yellow (10YR6/8) slightly moist, clay; sticky, plastic friable, moderate fine sub-angular blocky structure.

Some physical and chemical properties of the soil from the corn-corn land use.

Land Use	Cover (Jan)	Cover (July)	BD (g/cc)	PH	Total N (%)	OM (%)	Avail. P (ppm)	Exch. K (me/100g)	CEC (me/100g)
Corn-corn	40	45	0.96	4.97	0.2587	2.77	3.9	0.33	26.33
Corn-corn	30	70	0.84	4.53	0.1908	2.93	4.04	0.37	18.67

Some physical and chemical properties of the soil at different soil depth.

Depth (cm)	BD (g/cc)	pH	OM (%)	Total N (%)	Avail P (ppm)	Exch. K (m.e./100g)	CEC (m.e/100g)
0-13	-	6.09	5.93	0.29	4.72	0.33	21.29
12-49	-	5.89	4.11	0.20	3.32	0.35	23.60
49-94	-	5.99	1.31	0.06	3.46	0.14	15.11
94-184	-	5.03	1.10	0.05	3.60	0.67	19.91

Source (BSWM, Soil Survey Report of Bukidnon, 1963.)

Climate

Rainfall. The site received an abundant amount of rain throughout the year. The mean monthly rainfall based on a 2-year monthly average, was 213 mm (**Table 2-2**).

Table 2-2. Monthly rainfall for three years (1994-96) in Lantapan, Bukidnon, Philippines.

Month	**Rainfall (mm)**			
	1994	*1995*	*1996*	*Mean*
January	82	207	162	150
February	159	95	123	126
March	139	64	77	94
April	94	72	329	165
May	259	470	355	361
June	422	290	274	329
July	163	316	117	199
August	397	509	347	418
September	135	406	162	235
October	230	502	250	328
November	70	---	83	76
December	93	---	67	80
Total	2245	2932	2346	
Mean				213

The three-year mean monthly rainfall values were used as input to the simulation model’s built-in daily rainfall generator (type2) for ten-year simulation (equivalent to 3653 days) instead of daily rainfall. This is because: (1) only three-year daily rainfall is available, and (2) Stella's graphical function created within a flow or converter can only hold up to 1500 data points (equivalent to 1500 days or four years).

Soil temperature. Likewise, the three-year mean monthly soil temperature at the depth of 5 centimeters was used. See section 5d for details on climate parameterization.

Soil erosion and sedimentation

The area is moderately eroded. The soil loss component of the simulation model was modified by adding the Rose soil erosion and sedimentation equation. The Rose model was further modified by adding another parameter, the sediment concentration (E_SedConc). (Modification details can be found in Methodology portion.)

Crop parameters

All but two default values for the model parameter were used. Parameter value of 45 instead of 30, and 75 values instead of 60 were used for parameters Cq_TimeGen (length of generative stage for each crop) and Cq_TimeVeg (length of vegetative stage for each crop), respectively. This is because corn in the site usually matures after 4 months instead of 3 months. Late maturity which could mean longer filling period for storage organs, is attributed to relatively higher elevation and cooler climate.

Corn-*Gliricidia* Hedgerow System

Plot Description

The CGCS is illustrated in **Figure 2-3**. The total plot width was set to 7.25 meters. Zone 1 width equals 0.5 meter while each of the three zones measured 2.25 meters width. Wider crop zone spacing was set to offset hedgerow shading. The initial slope was set to 40% or about 18 degrees. Runon from one adjacent uphill plot was allowed. Each of the 4 zones received equal amount of inputs like rainfall. Fertilizers were applied only to crop zones.

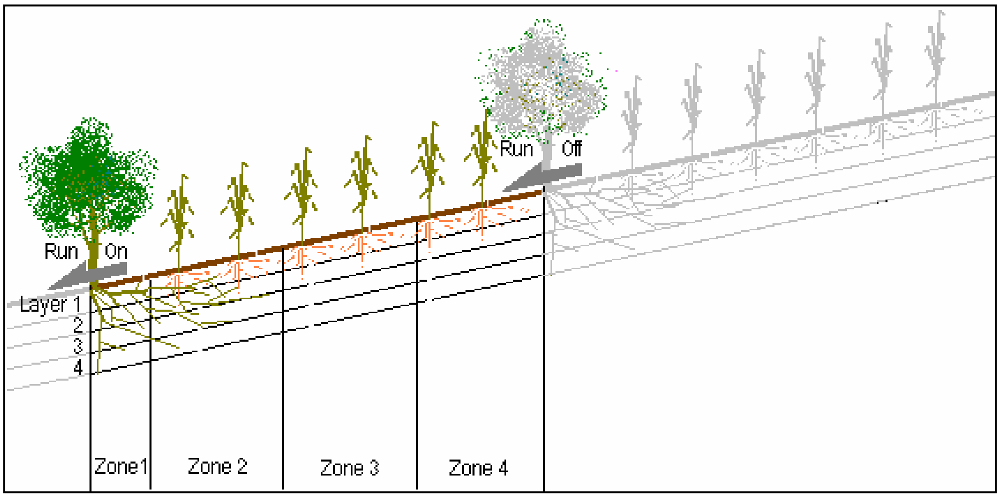

Figure 2-3. Schematic diagram of corn-*Gliricidia* cropping system.

Farm Management/Operations Schedule

Farm operations and management schedule for this system is similar to CMS except for planting and pruning of *Gliricidia* which served as hedgerow. *Gliricidia* was planted as hedgerow with population of 4000 trees or bushes per hectare of farming area. The soil, climate and crop parameters set for corn-*Gliricidia* cropping system, were similar to the corn monocropping system.

Pruning_was done ten days before each planting operation and 60 days thereafter. All pruned materials were returned to the crop zones 2, 3 and 4.

The soil, climate and parameters set for CGCS were similar to the CMS.

METHODOLOGY

a. Selection of agroforestry-based productions systems

Selection of agroforestry-based production systems for modeling was based on secondary data gathered from previous research results in the area (SANREM-CRSP, 1995), and from the several project team field visitations during the early phase of the project. Initially, there were four productions systems identified and selected for modelling. However, due to lack of secondary data and limited time, the project team decided to model just two predominantly common production systems. These are the Corn Monocropping System (CMS) and the Corn-*Gliricidia* Cropping System (CGCS).

b. Selection of sustainability indicators

There were seven indicators of sustainability identified for this study, namely:

(1) runoff
(2) erosion
(3) soil organic matter
(4) soil depth
(5) crop and tree biomass and/or yield
(6) net return or profit and
(7) Carbon sequestered or C-stocks

For any food production system to be tagged as sustainable, it should satisfy at least three criteria, that is, the system should be biophysically suitable, economically viable and socially acceptable. The two production systems selected for modelling each were evaluated for their bioeconomic sustainability. The systems' social acceptability was not considered.

Profitability and carbon stocks can be isolated and can be discussed independently from sustainability. However, in this study, they are included in the integrated evaluation of the systems' sustainability.

The first four indicators are considered under biophysical suitability analysis. Yield and profit or net return are relevant variables for economic viability evaluation. Carbon stocks analysis was also included in the analysis of biophysical suitability. Prior to an integrated sustainability evaluation, the simulation results of each of the selected indicators were analyzed separately.

Profitability

There are four indicators that can be used to determine the economic viability, in particular, and sustainability, in general, of the specific cropping patterns. The cost and return analysis indicates the net returns per year to the specific cropping patterns. It is an undiscounted measure, which will indicate whether the cropping pattern is getting a positive (negative) return for each year of the project life.

The net present value (NPV), on the other hand is a discounted measure of profitability that is derived by adding the discounted net benefits (or net returns) from each year of the project life. If a cropping system's NPV is positive, then it can be accepted. If its NPV is negative, i.e. its discounted cost exceeds its discounted benefits, then the cropping pattern is not acceptable.

The internal rate of return (IRR) is the discount rate that, if used to discount a project's costs and benefits, will just make the project's net present value equal to zero. It can be thought of as the minimum discount rate at which it would be just worthwhile doing the project. It is the interest rate that the project can afford to pay on its funds and would still be able to recover all its investment and operating costs.

The payback period is the number of years a certain investment is expected to take from the beginning of the project until the sum of its net returns equals the cost of the project's initial capital investment.

c. Setting of sustainability evaluation criteria

To simplify the test of systems' bioeconomic sustainability, numeric values and/or ranges and indicators' trend over time, were set for each of the selected indicators. These values were based from the recommendation of team experts. Table 3c-1 shows details.

Table 3c-1. Sustainability test.

Sustainability Indicators	Criteria
Biophysical suitability	
Runoff	Less or equal to 20% of effective rainfall
Soil erosion	< 10 tons/ha/yr
Soil organic matter loss	< 2.5% of system total
Soil depth loss	< 10 mm/ha/yr
Yield trend	Non-negative
Economic viability	
Yield trend	Non-negative
Net return/ trend	Non-negative
Carbon stocks	
Carbon sequestration	Non-negative
System Sustainable?	

d. Model parameterization

Climate variables

Three-year actual daily rainfall data gathered through automatic weather station situated in Songco, Lantapan were utilized for type 2 and type 3 rainfall pattern of the simulation model. The values for the six input parameters required for rain type 2 that were drawn from the three-year daily data, are as follows:

Rain_DayP	12 monthly values from 3-year daily rainfall data
Rain_HeavyP	0.12
Rain_Light	7 mm
Rain_Heavy	20 mm
Rain_BounHeaLi	15 mm
Rain_CoefVar	1.7

Rain_DayP values were derived by dividing the number of rainy days by the number of days for each month.

For type 3 rainfall, 3-year mean monthly rainfall was used. (Refer to Table 2-2 for details on monthly rainfall values used.)

The simulation model was run for 400 days using three different rainfall datasets, namely: (1) 365-days historical rainfall from AWS, (2) 365-days SIMMETEO-simulated daily rainfall, and (3) WaNulCAS randomly generated daily rainfall with input parameters value derived from the three-year historical rainfall records. The differences in simulation results of selected sustainability indicators, using the three different rainfall input datasets were studied.

Soil parameters

The soil erosion and sedimentation sector was parameterized using the most recently characterized soils of Songco, Lantapan. (Refer to Table 2-1 for details of the soil used.) As mentioned in section 2, the soil used in this modelling project is fertile and very porous.

Tree/ hedgerow parameters

Except for the number of trees per hectare, all of the default input parameters' values were used because there are no available secondary data that suit the specific model requirement for the tree input paramaters. Number of trees per hectare was changed from 200 to 4000 trees per hectare. Use of default parameters' values

Crop Parameters

There were only 2 crop parameters modified, the Cq_TimeGen (length of generative stage for each crop) and Cq_TimeVeg (length of vegetative stage for each crop). Value of 45 and 75, instead of 30 and 60 days were used for Cq_Time_Veg and Cq_Time_Gen, respectively.

Table 3d-1 shows the summary of all input values used in the simulation analysis.

e. Model modification

A minor modification was done on the soil erosion and sedimentation sector of the model. Sediment concentration was added to the existing Rose sedimentation equation to account for the quality of the runoff water.

Table 3d-1. Input parameter modifications from default to simulate corn monocrop and corn-Gliricidia system and generate output parameters

Parameter			**Location on WaNulCAS**	**Remark**
Input/Default Value	**New Value**		**Input/Output Section**	
	Corn Mono	*Corn-Gliricidia*		
Percentage of clay	45	45	Excel sheet Pedotransfer	Very porous soil, well drained
Percentage of silt	30	30	.	
Percentage of organic matter	5.93	5.93	.	
Top soil?	1	1	.	
Bulk density	0.84	0.84	.	
Rain_Data	.	.	Excel sheet Weather	Lantapan weather data used
Temp_DailyData	.	.		Lantapan weather data used
Ca_PlantDoY[Zn1] ……. [Zn4]	61.27	61.27	Excel sheet Crop Management	
Ca_PlantYear[Zn1] 0	X	15	.	
Ca_FertAppRat 2.6	0	0	.	
T_PrunY 0	X	1.1,2.2,3.3, …10	.	
T_PrunDoY 0	X	0, 260, 50, 260, … 50, 260	.	
T_PlantY[Sp1] 100	X	1, 100	.	
Cq_PlantDoY[Sp1]	X	1, 61	.	
Cq_TimeGen (Maize) 30	45	45	Excel sheet Crop Library	Longer corn growth period in Lantapan
Cq_TimeVeg (Maize) 60	75	75	.	due to lower daily temperature
Peso	*Rupiah*	*Rupiah*		
P_CfertPrice[N] 14	2442	2442	Excel sheet profitability	
P_CfertPrice[P] 17	2965	2965	.	
P_ExtOrg[1] 10	1744	1744	.	
P_ExtOrg[2] 12	2093	2093	.	
P_CPestContPrice 400	69767	69767	.	
P_FencePrice 350	61047	61047	.	
P_UnitLabCost 150	26163	26163	.	
P_CFertPrice[N] 11	1919	1919	.	
P_CFertPrice[P] 13	2267	2267	.	
P_ExtOrg[1] 10	1744	1744	.	
P_ExtOrg[2] 12	2093	2093	.	
P_CPestContPrice 380	66279	66279	.	
P_FencePrice 350	61047	61047	.	
P_UnitLabCost 125	21802	21802	.	
P_CPlantLab	12	12	.	
P_CWeedLab	18	18	.	
P_CPestContLab	6	6	.	
P_CHarvLab	16	16	.	
P_CSeedPrice[Social]	9	9	.	
P_CSeedPrice[Private]	14	14	.	
P_CYieldPrice[Social]	5	5	.	
P_CYieldPrice[Private]	4.5	4.5	.	

Table 3d-1. Input parameter modifications from default to simulate corn monocrop and corn-Gliricidia system and generate output parameters

Parameter				Location on WaNuLCAS	Remark
Input/Default Value		**New Value**		**Input/Output Section**	
		Corn Mono	*Corn-Gliricidia*		
Rain_Atype	1	3	3	Rainfall	
Rain_MonthTot	1 200	179	179	.	Lantapan rainfall data
	2 200	135.8	135.8	.	
	3 200	171.5	171.5	.	
	4 200	207.5	207.5	.	
	5 200	322.5	322.5	.	
	6 200	353.3	353.3	.	
	7 200	301	301	.	
	8 200	418	418	.	
	9 200	329.7	329.7	.	
	# 200	294.4	294.4	.	
	# 200	143.7	143.7	.	
	# 200	127.3	127.3	.	
AF_ZoneTot	3.5	4	7.25	Agroforestry Zone	
AF_Zone[Zn1]	0.5	1	0.5	.	
AF_Zone[Zn2]	1	1	2.25	.	
AF_Zone[Zn3]	1	1	2.25	.	
AF_ZoneWidthUphill	0	1	1	Agroforestry Zone/Uphill neighbours	
AF_RunOn	0	0.5	0.5	.	
AF_DepthLay1		0.13	0.13	Agroforestry Zone/Soil LayersThickness	
AF_DepthLay2		0.41	0.41	.	
AF_DepthLay3		0.38	0.38	.	
AF_DepthLay4		0.9	0.9	.	
AF_DeepSubSoil		3	3	Agroforestry Zone/Soil LayersThickness	
AF_DepthGound		0	0	.	
E_ErosiType	0	1	1	Soil Erosion and Sedimentation	
E_FilterF	0.9	0.25	0.75	.	
E_BulkDens		0.84	0.84	.	
E_PloughDoy		264.54	264.54	.	
T_GroRespInit[Sp1]	0.02	0	0.02	Tree Parameters	
S_SurfInfiltrInit[Zn1]	100	20	20	Soil Structure	
S_SurfInfiltrDef[Zn1]	25	20	20	.	
Temp_Atype	1	3	3	Soil Temperature	

RESULTS AND DISCUSSION

Rainfall

The simulation study requires input data value of weather variables specifically rainfall. Prior to simulation analysis, appropriate rainfall data set to be used has to be determined.

For this study, the volume and distribution of (1) rainfall gathered from automatic weather station (AWS), (2) SIMMETEO-generated (SIM), and (3) WaNuLCAS-generated (WaN) rainfall were compared. There was no significant difference found between the AWS and SIM-generated three-year total and mean monthly rainfall as compared to WaN-generated rainfall, which deviated from the first two data sets in terms of volume and distribution (**Figure 4-1, 4-2**). Based on these results, model modification to minimize the difference between the historical and model-generated rainfall data is therefore recommended.

Similar observations were noted when the monthly standard deviations (SD) and coefficients of variability (CV) of the three rainfall data sets were plotted (**Figure 4-3, 4-4**). Moreover, when the 10-year cumulative daily rainfall from the three rain data sets were plotted against each other, a reasonably similar trend/ pattern was observed (**Figure 4-5**).

However, while the total rainfall generated by WaNulCAS model was similar to the and the SIM-generated rainfall, the daily rainfall distribution was significantly different from the two rainfall datasets as shown in **Figure 4-6**.

The differences in rainfall distribution, especially the erosive rainfall events, would significantly affect the simulation results. This was the case when selected simulated outputs/ results such as runoff, erosion, and crop biomass, using different rain datasets were compared (**Figures 4-7 to 4-9**).

The following were conducted as part of the comparative analysis

1) using rain type1, run model for 10 years using historical one-year and three-year daily rainfall data;
2) using rain type1, run model for 10 years using historical and SIM-generated one-year and three-year daily rainfall; and
3) using rain type 3, run model for 10 years using historical and SIM-generated one-year and three-year mean monthly rainfall.

For the simulation analysis, the team decided to use rain type2, due to the following reasons: (1) there is not enough historical daily rainfall data available (ten years) to suit rain type1; (2) rain type1 can only allow maximum of 1500 input rainfall data points or approximately four years; (3) based from the sensitivity analysis, rain type2 is the best suited option; and (4) the six input parameters for rain type 2 can be extracted from the historical data and through other tested weather generator like SIMMETEO.

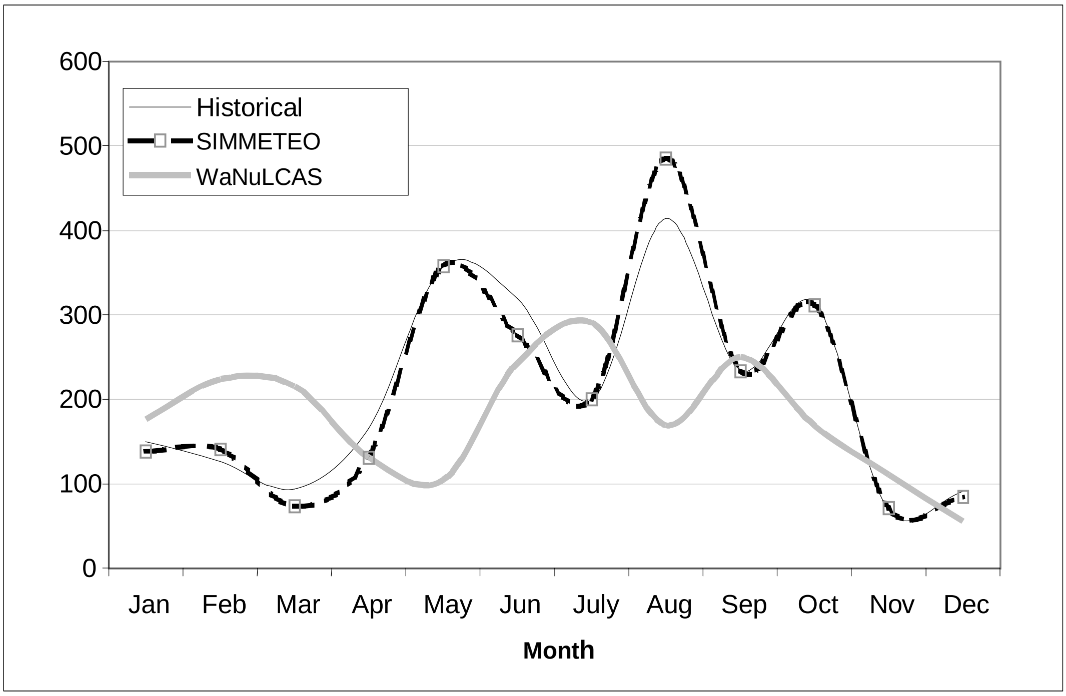

Figure 4-1. Comparative three-year ***total monthly rainfall*** from different data

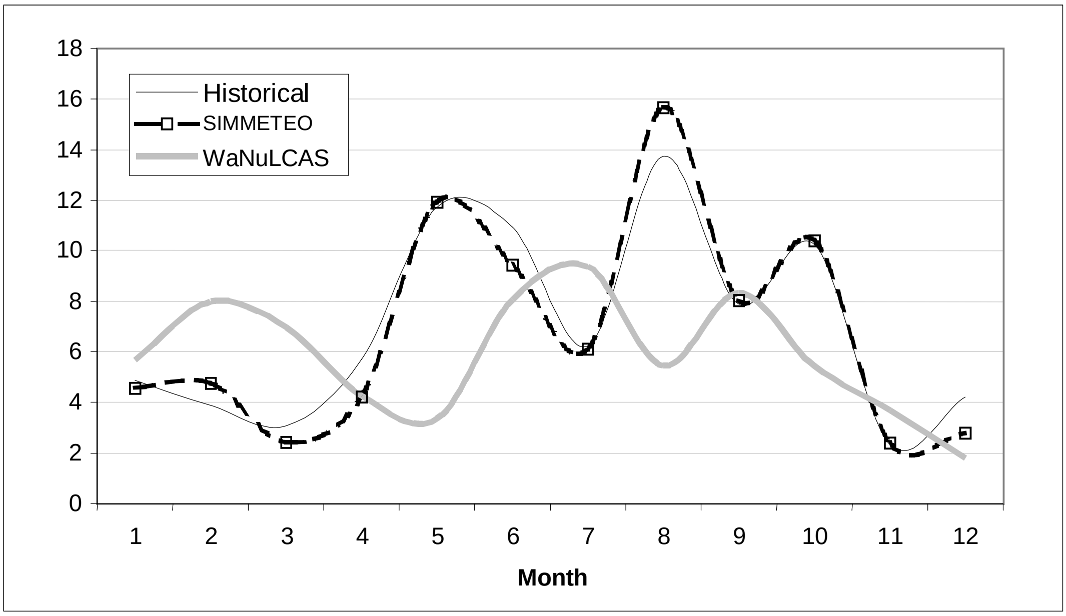

Figure 4-2. Comparative three-year ***mean monthly rainfall*** from different sources.

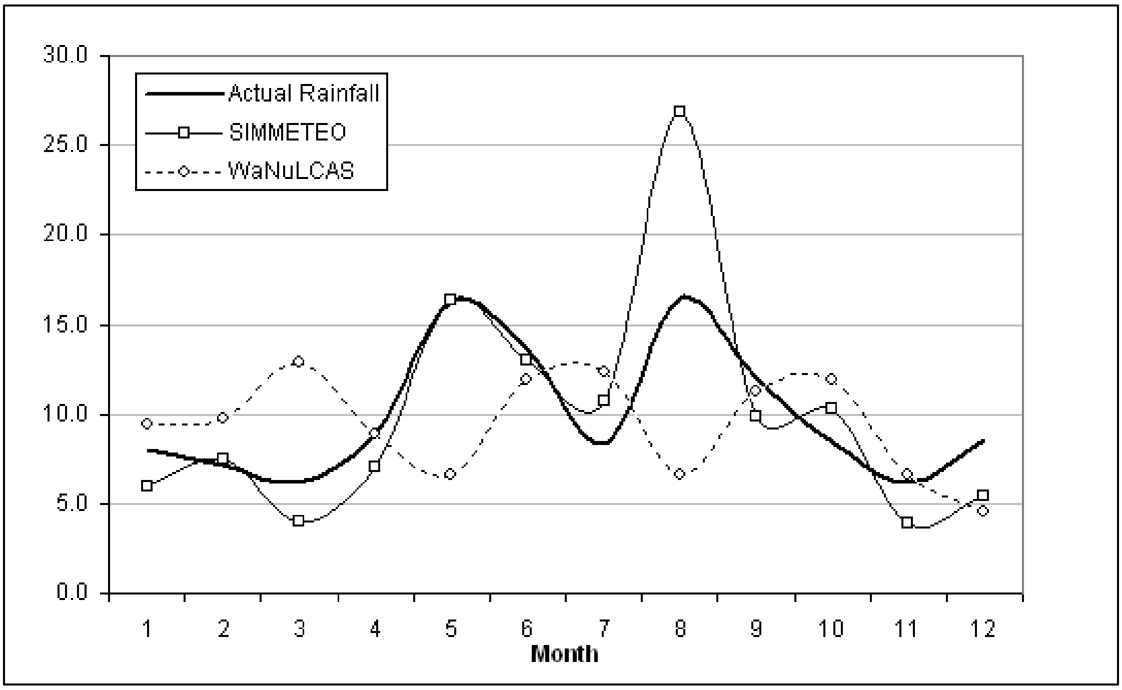

Figure 4-3. Comparison of monthly standard deviations of three-year rainfall data from different sources.

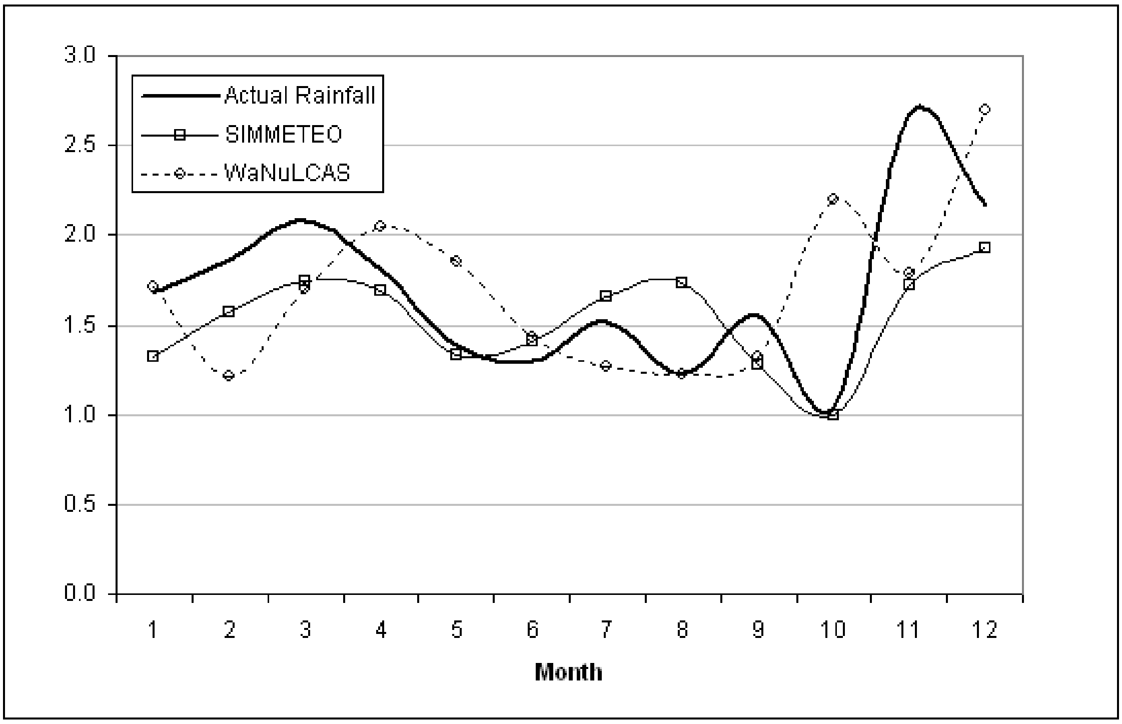

Figure 4-4. Comparison of monthly coefficients of variations of three-year rainfall data from different sources.

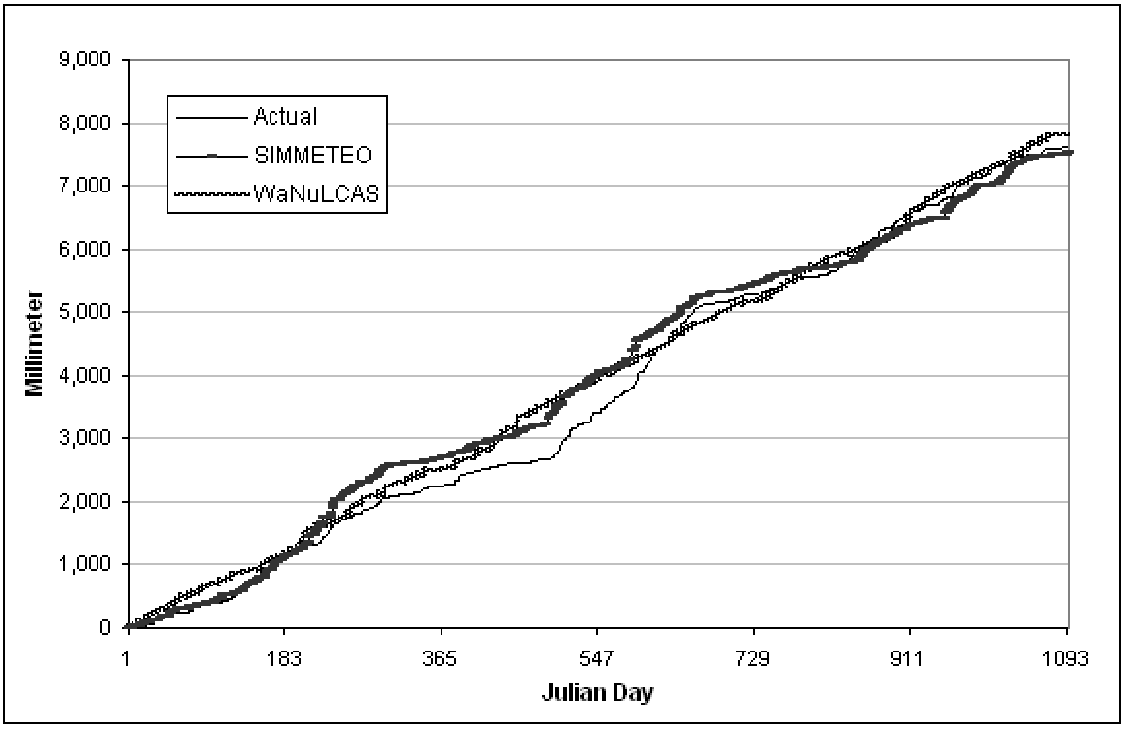

Figure 4-5. Comparison of ten-year cumulative daily rainfall from different
data sources.

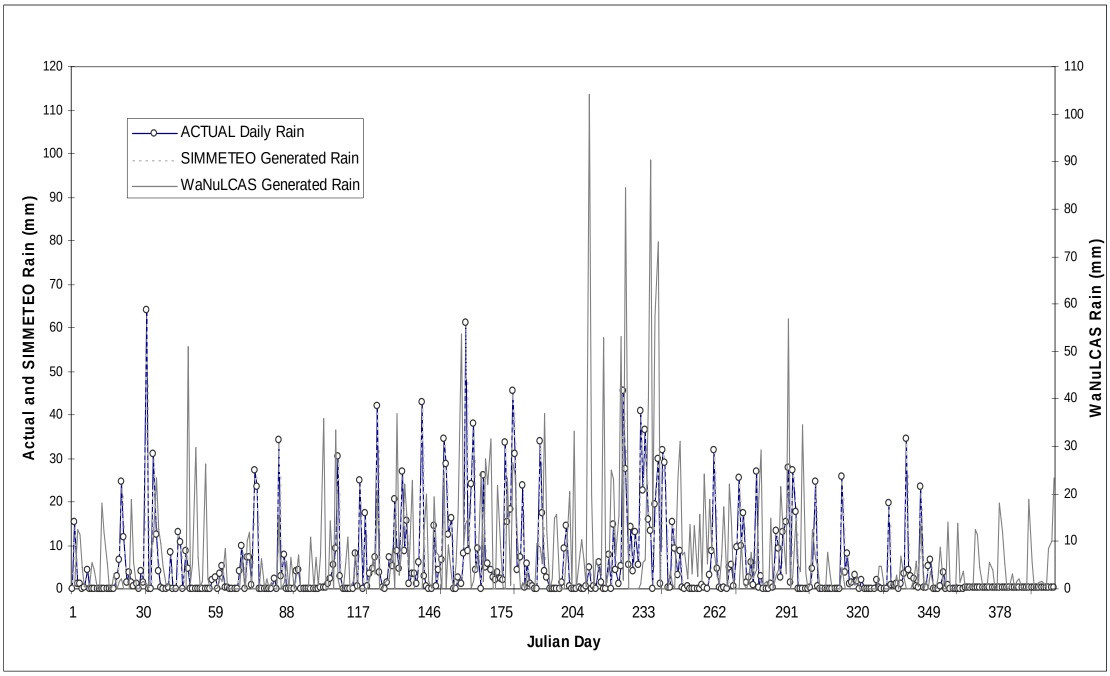

Figure 4-6. Comparison of daily rainfall from different data sources.

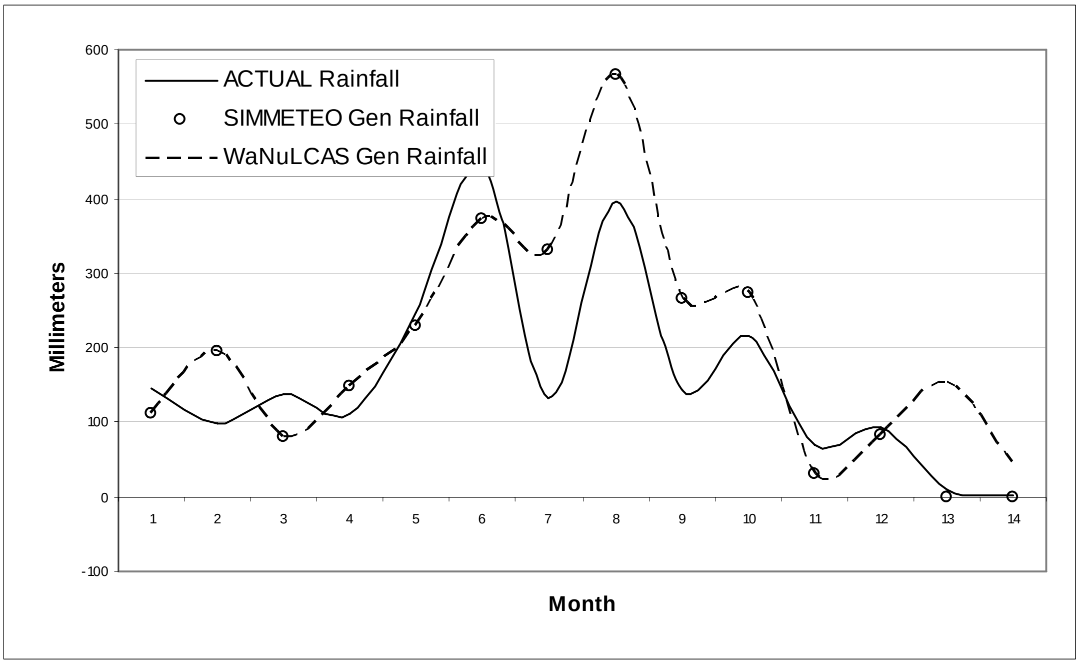

Figure 4-7. Comparison of mean monthly rainfall from different data sources

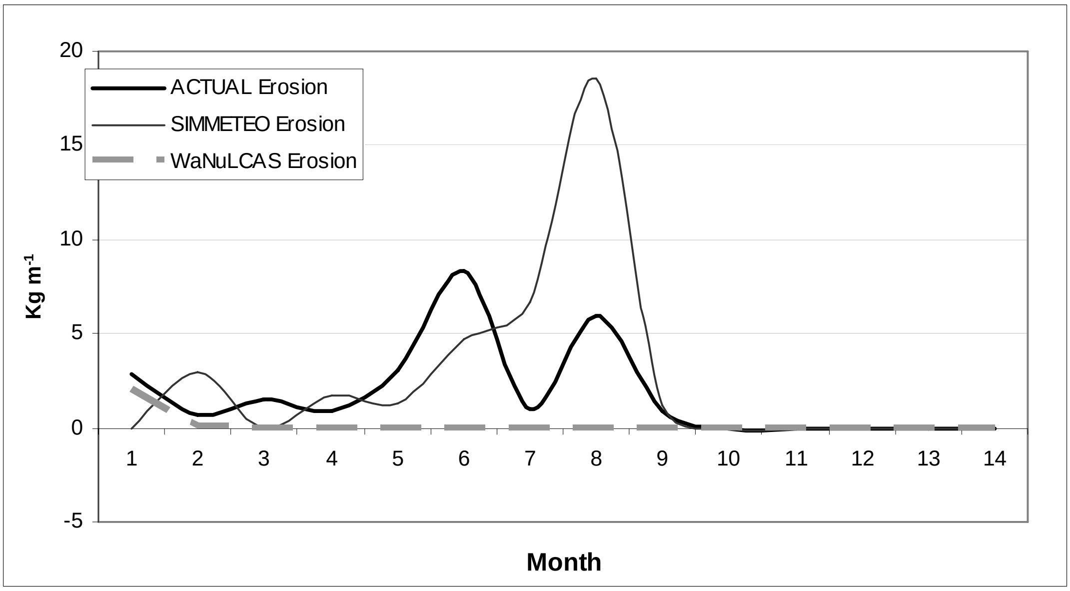

Figure 4-8. Comparison of simulated mean monthly erosion from different data

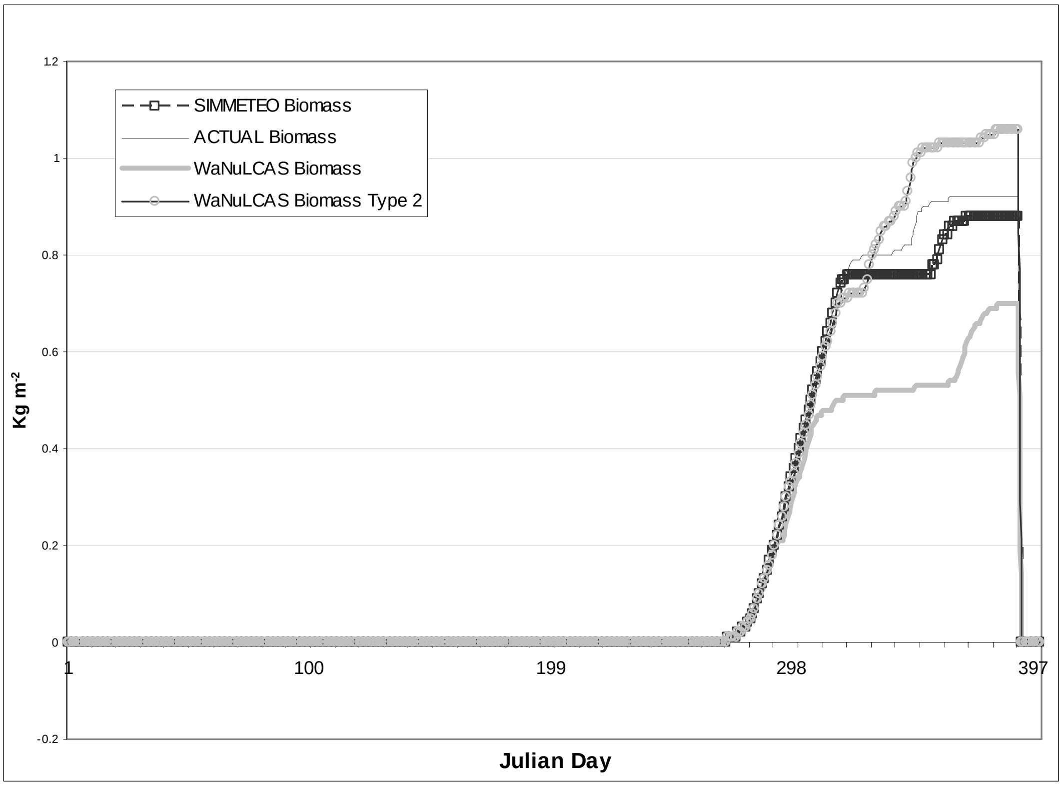

Figure 4-9. Comparison of simulated daily crop biomass using rainfall datasets from different sources.

Soil Erosion

Corn Monocroppping

The simulated ten-year monthly rainfall, runoff and soil erosion are shown in **Figures 4-10**, **4-11, and 4-12,** respectively. Annual amounts of these three output parameters when plotted are also shown in **Figure 4-13 and 4-14**. There were very intense rainfall events that produced more runoff. These events occurred in year 2 and year 4. This was attributed to the water runon from the adjacent upper plot and from the subsurface lateral flow of water.

In the simulation study, the cumulative or total amount of soil loss is 60.09 tons/ha over the period of 10 years or an average of 6 tons/ha/year. This was within the tolerable soil erosion rate of less than 10 tons/ha/year. Moreover, the variation of the ten-year monthly runoff and erosion was significantly high. There was almost zero simulated erosion in some months of year 6 and year 7 while there were significant soil loss observed in months of years 1, 3, 8 and 9.

The ten-year cumulative erosion was equivalent to 60 mm total soil depth lost. Year 1 was observed to have the greatest soil depth lost. There were 110 rainfall events with at least 10 mm runoff each. Erosion was produced by 74 erosive rainfall events. There were 21 events that produced soil loss of 1 ton or more per hectare. While there were many erosive rainfall events that produced high soil loss during the growing period of the crop, there were soil losses that were observed in between crop growing period.

Corn-Gliricidia Cropping System

The simulated ten-year monthly rainfall, runoff and soil erosion are shown in **Figures 4-15**, **4-16, and 4-17,** respectively. Annual values of these three output parameters when plotted against each other are shown in **Figure 4-18 and 4-19**.

The cumulative or total amount of soil loss was 37.38 tons/ha over the period of 10 years or an average of 3.7 tons/ha/year which was within the tolerable soil erosion rate of less than 10 tons/ha/year. Moreover, the variation of the ten-year monthly runoff and erosion was significantly high. Most of the recorded erosion events were observed during the months of year 1 and year 10 only. This observation, especially for year 1 could be attributed to the management schedules. Crop failure occurred during year 1.

The ten-year cumulative erosion was equivalent to 3.7 cm total soil depth lost. Year 1 was observed to have the greatest soil depth lost.

There were 67 rainfall events with at least 10 mm runoff each. All 67 rainfall events were erosive, which means that each of the 10-mm rainfall events produced soil loss. There were 9 events that produced soil loss of equal to or greater than 1 ton per hectare.

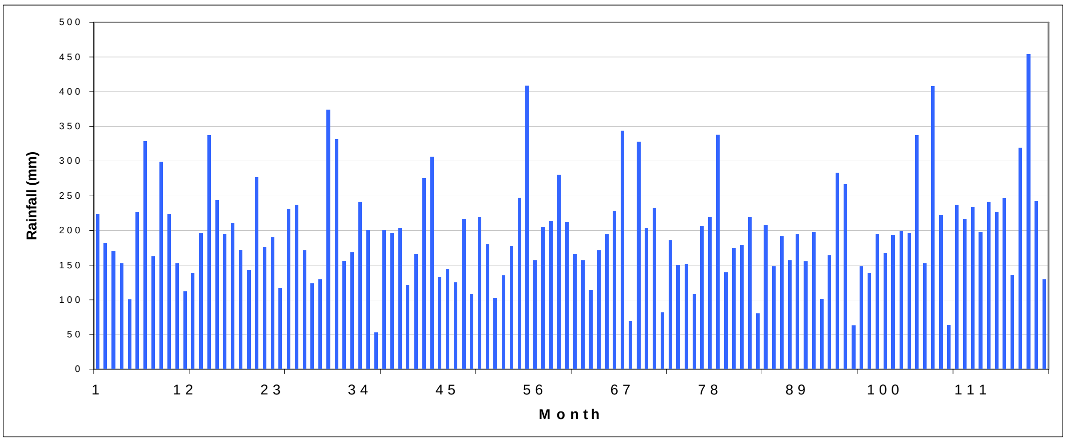

Figure 4-10. WaNuLCAS model-generated ten-year total monthly rainfall (rain type2).

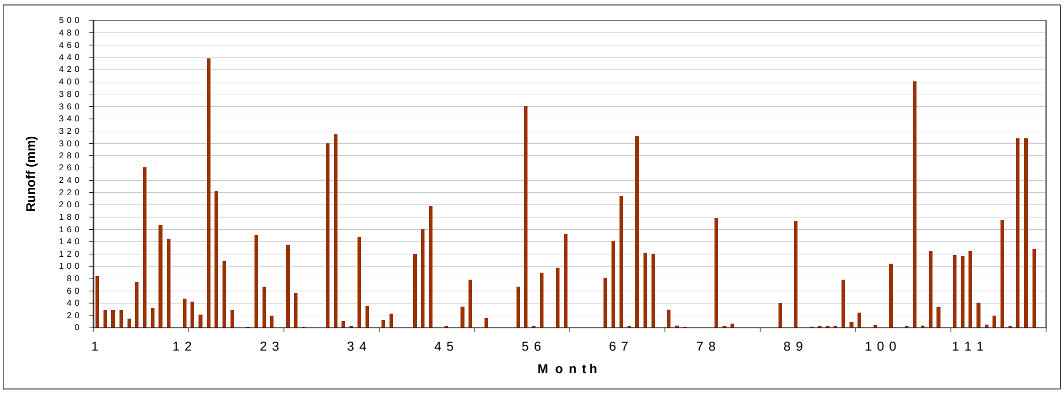

Figure 4-11. Simulated total monthly runoff using WaNuLCAS-generated rainfall (rain type 2).

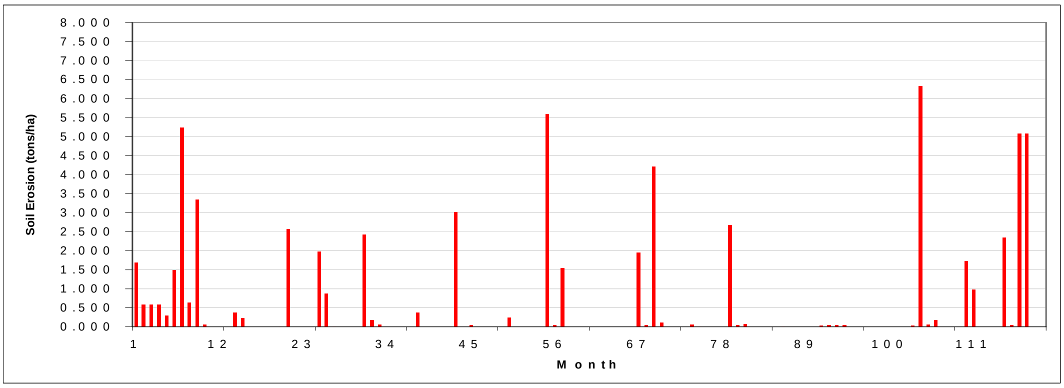

Figure 4-12. Simulated total monthly erosion using WaNuLCAS-generated rainfall (rain type2).

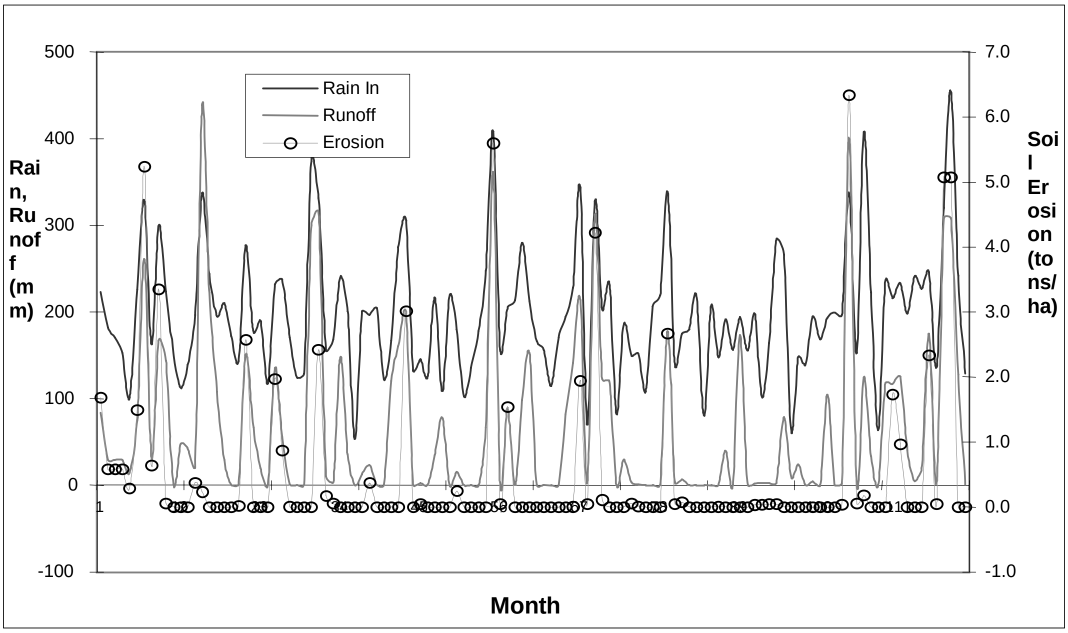

Figure 4-13. Simulated ten-year annual total runoff and soil erosion for corn monocropping system.

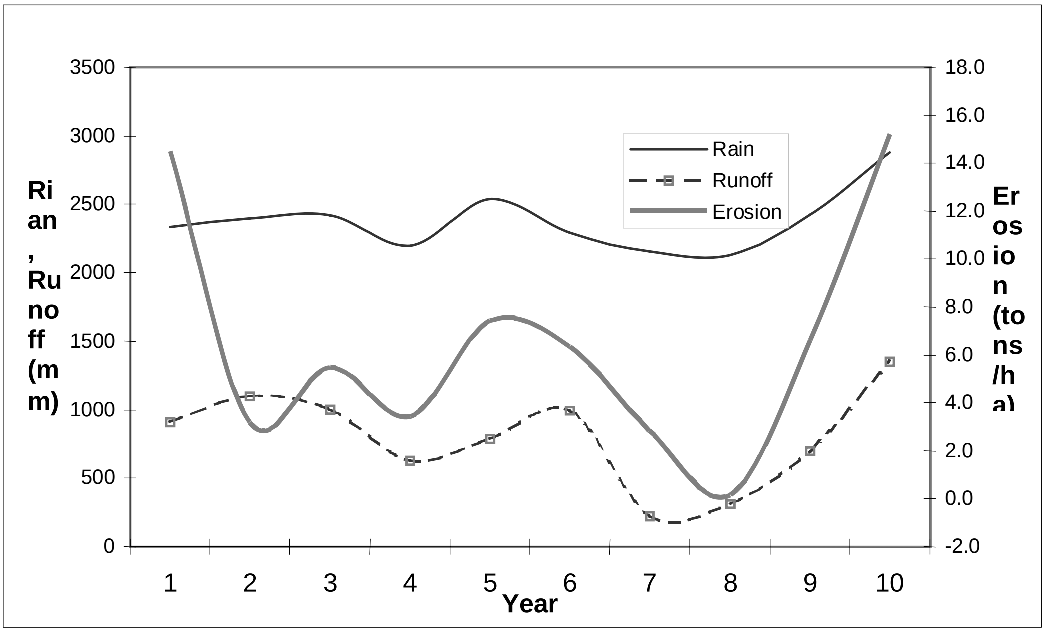

Figure 4-14. Simulated ten-year annual runoff and soil erosion using WaNuLCAS model generated ten-year rainfall (rain type2), corn monocropping system.

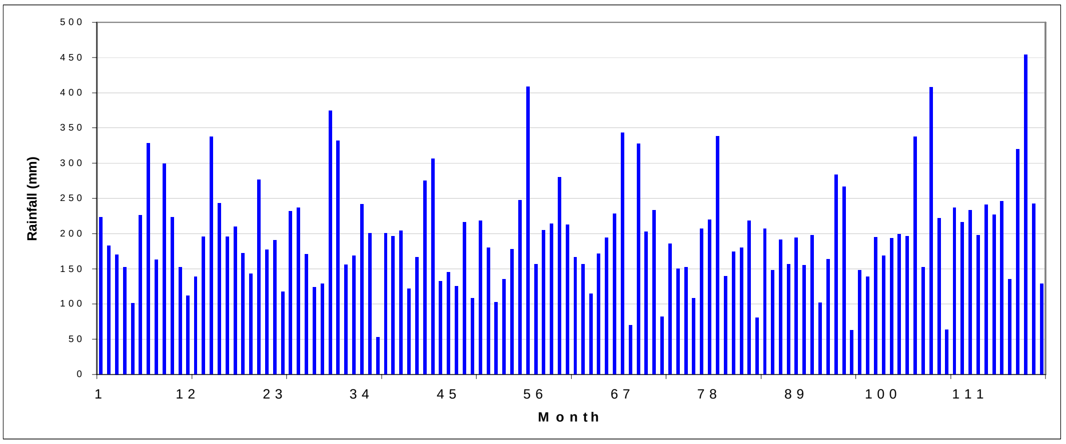

Figure 4-15. WaNuLCAS Model-generated ten-year total monthly rainfall (rain type2).

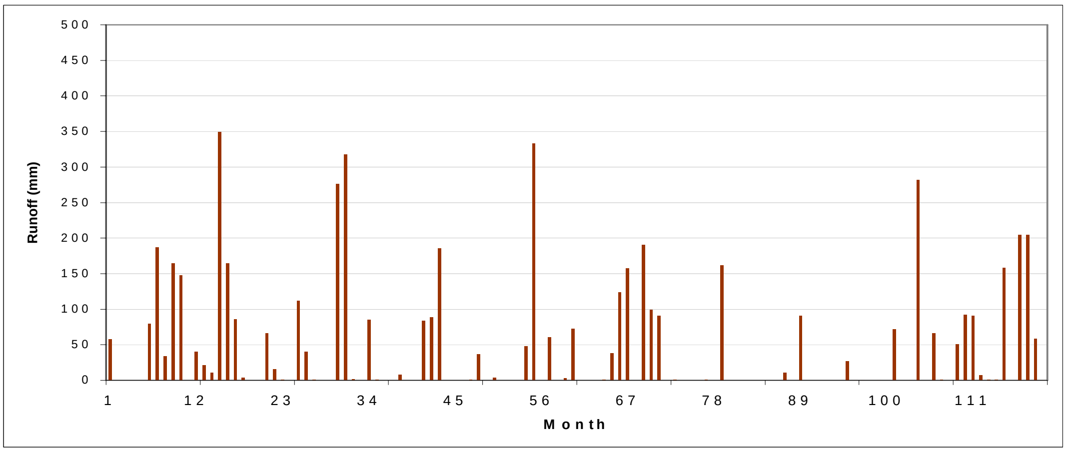

Figure 4-16. Simulated total monthly runoff using WaNuLCAS-generated rainfall (rain type2).

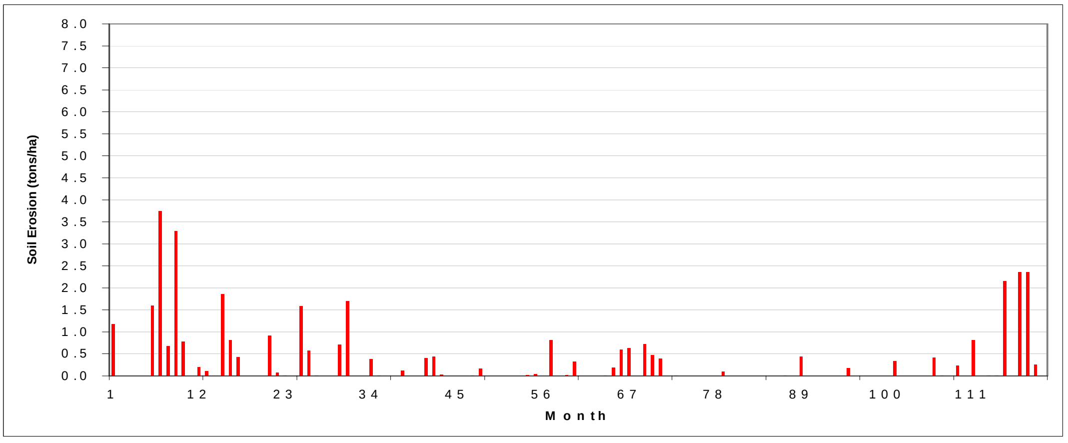

Figure 4-17. Simulated total monthly erosion using WaNuLCAS-generated rainfall (rain type2).

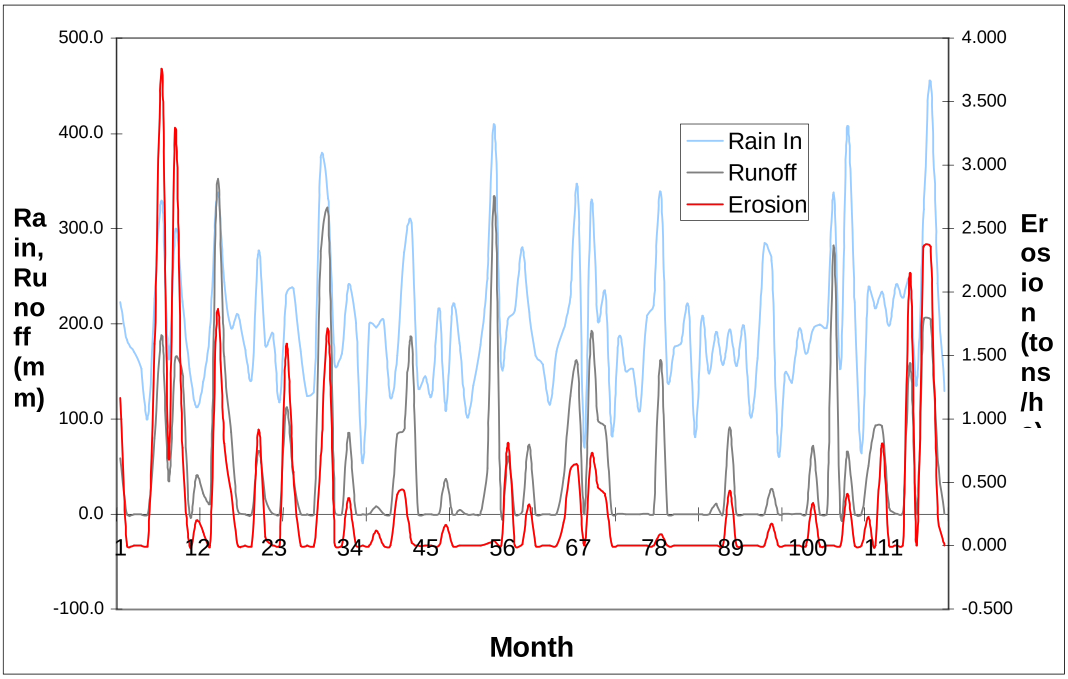

Figure 4-18. Simulated ten-year monthly total runoff and soil erosion for corn-*Gliricidia* cropping system.

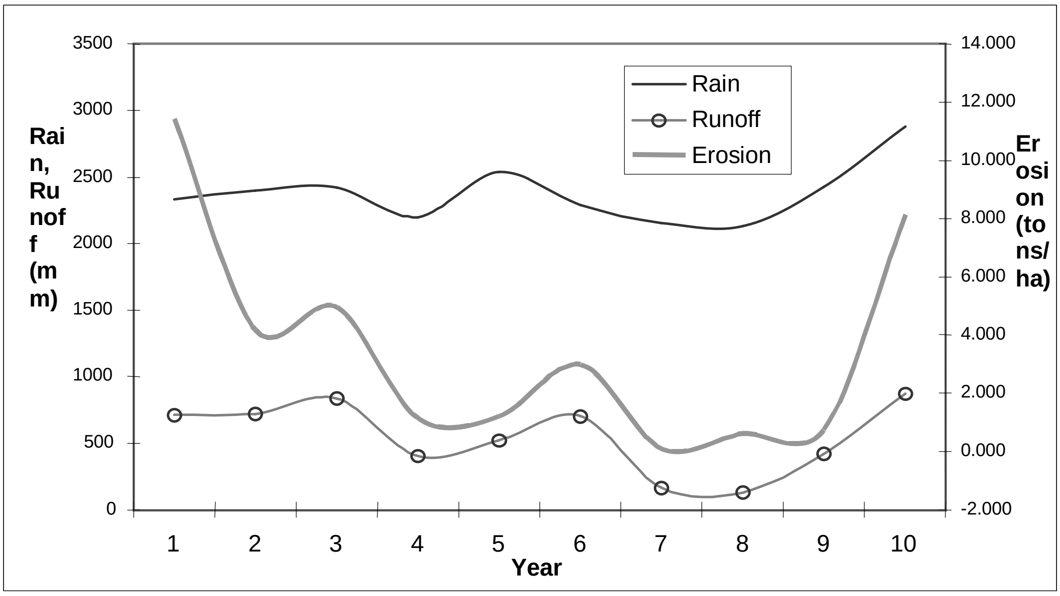

Figure 4-19. Simulated ten-year annual runoff and erosion using WaNuLCAS model generated ten-year rainfall (rain type2) for corn-*Gliricidia* cropping system.

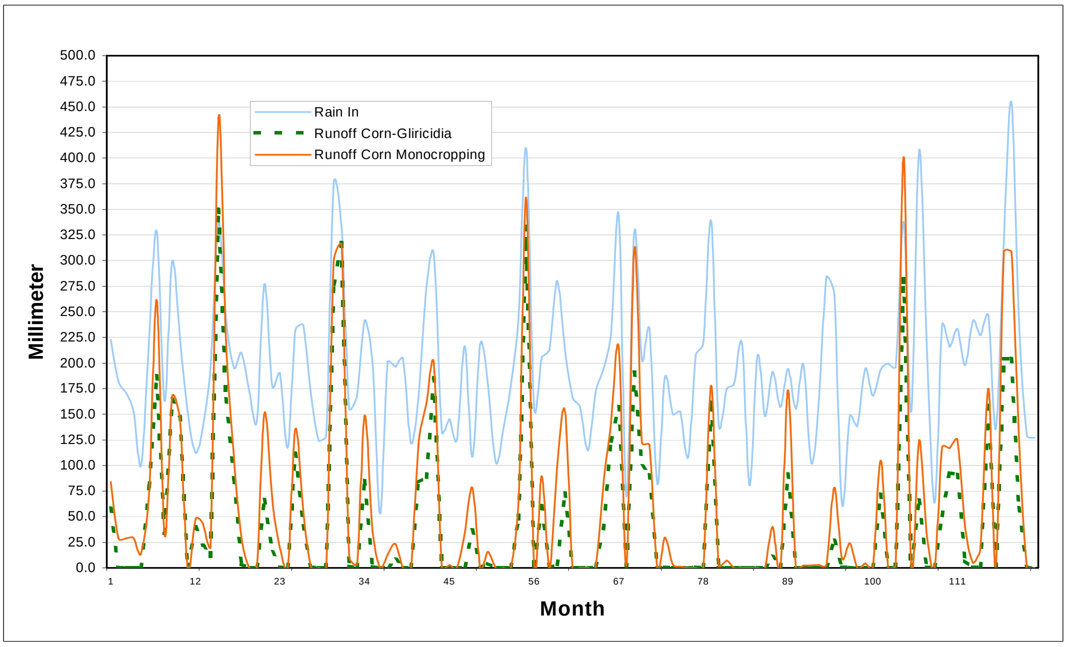

Figure 4-20. Comparison of simulated runoff of corn monocropping system and corn-*Gliricidia* cropping system.

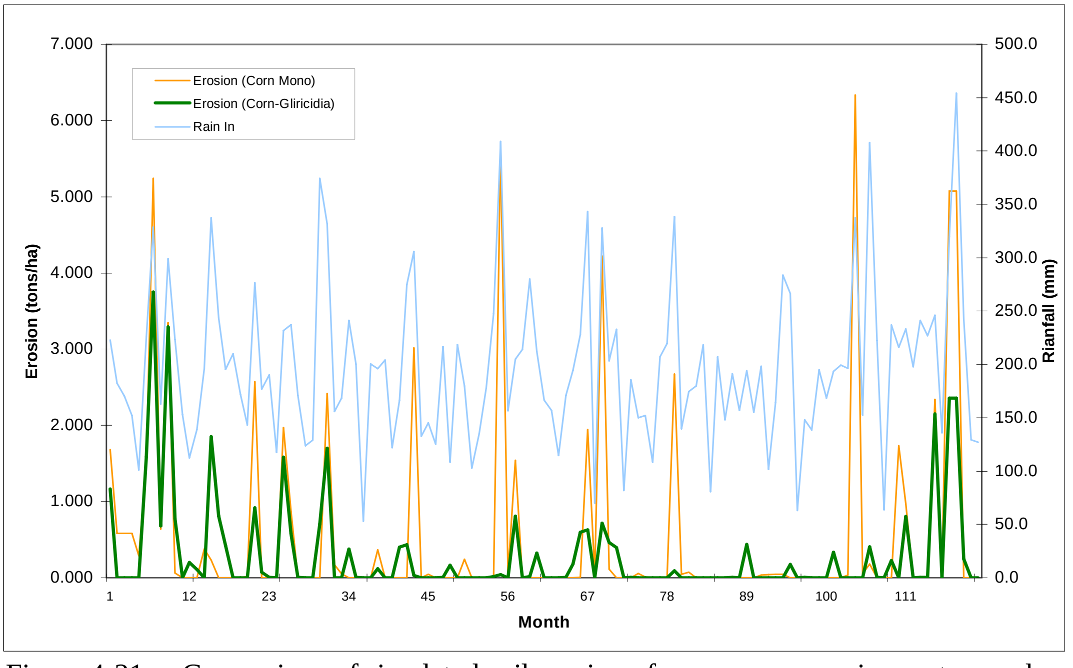

Figure 4-21. Comparison of simulated soil erosion of corn monocropping system and corn-*Gliricidia* cropping system.

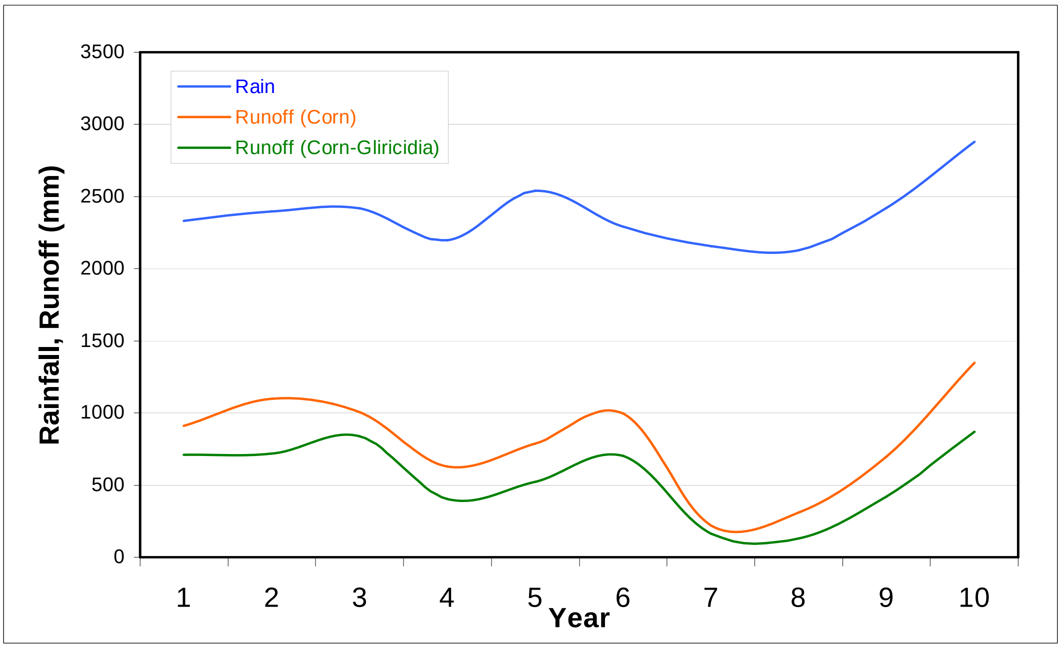

Figure 4-22. Comparison of simulated annual runoff of corn-monocropping system and corn-*Gliricidia* cropping system.

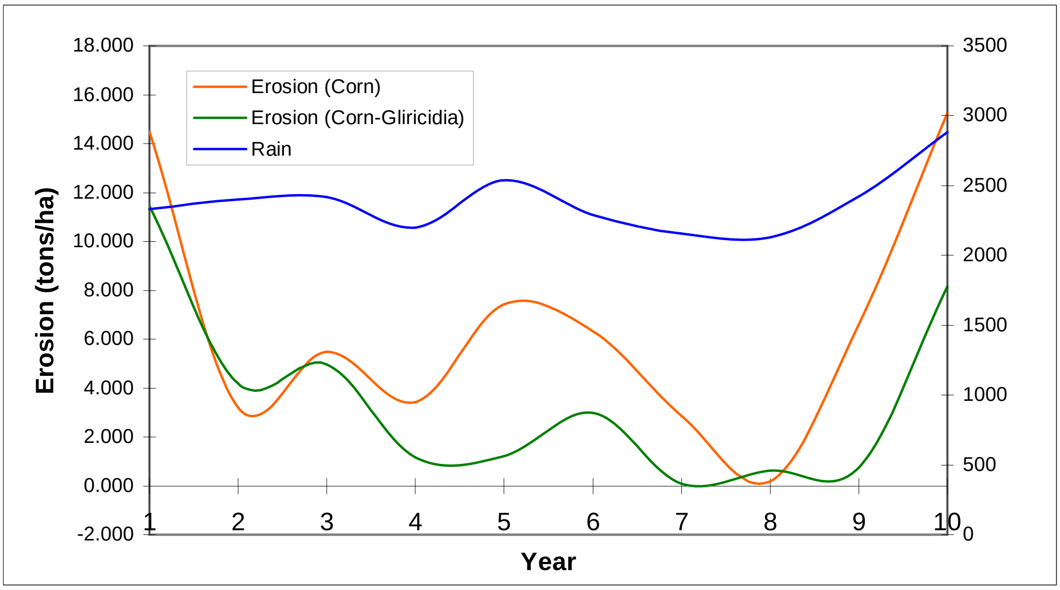

Figure 4-23. Comparison of simulated annual soil erosion of corn-monocropping system and corn-*Gliricidia* cropping system.

Comparison between corn monocropping and corn-Gliricidia cropping systems

Figure 4-20 and **Table 4-1** compares the simulated ten-year monthly runoff of corn monocrop farming and corn-*Gliricidia* cropping systems, while **Figure 4-21** compares the simulated ten-year monthly erosion of the two cropping systems. **Figures 4-22** and **4-23** compares the ten-year annual simulated runoff and erosion of the two cropping systems.

Despite lesser total annual effective rainfall received by corn-*Gliricidia* system compared to corn monocropping, there were more total runoff and, correspondingly, more soil loss observed in the latter cropping system.

Table 4-1. Comparison of runoff and soil erosion between CMS and CGCS.

Year	Corn-Monocropping System			Corn-*Gliricidia* System		
	Effective Rainfall	Runoff	Erosion	Effective Rainfall	Runoff	Erosion
	mm	mm	t/ha	Mm	mm	t/ha
1	2272	955	14.50	2458	733	11.56
2	3405	1887	5.17	2489	810	5.66
3	2090	882	3.52	2367	724	7.54
4	1993	618	3.43	2228	403	1.16
5	2203	786	7.43	2491	522	1.20
6	2048	1024	6.33	2327	701	2.99
7	1952	192	2.86	2157	163	0.09
8	1655	334	0.13	1933	130	0.62
9	2152	789	6.55	2369	473	0.98
10	2208	921	10.17	2468	614	5.58
Total	21979	8388	60.09	23285	5275	37.38
Mean	2198	839	6.01	2329	527	3.74

There were lesser erosive rainfall events and lesser soil losses observed in the corn-*Gliricidia* cropping system compared to corn monocropping system (**Table4-2**).

Table 4-2. Runoff, erosion and erosive rainfall events

System	**Runoff (> 10mm)**	**Erosive Rainfall Events**	**Number of events with 1-Ton Erosion**
Corn Monocropping System	110	74	21
Corn-*Gliricidia* Cropping System	67	67	9

3650-day simulation period

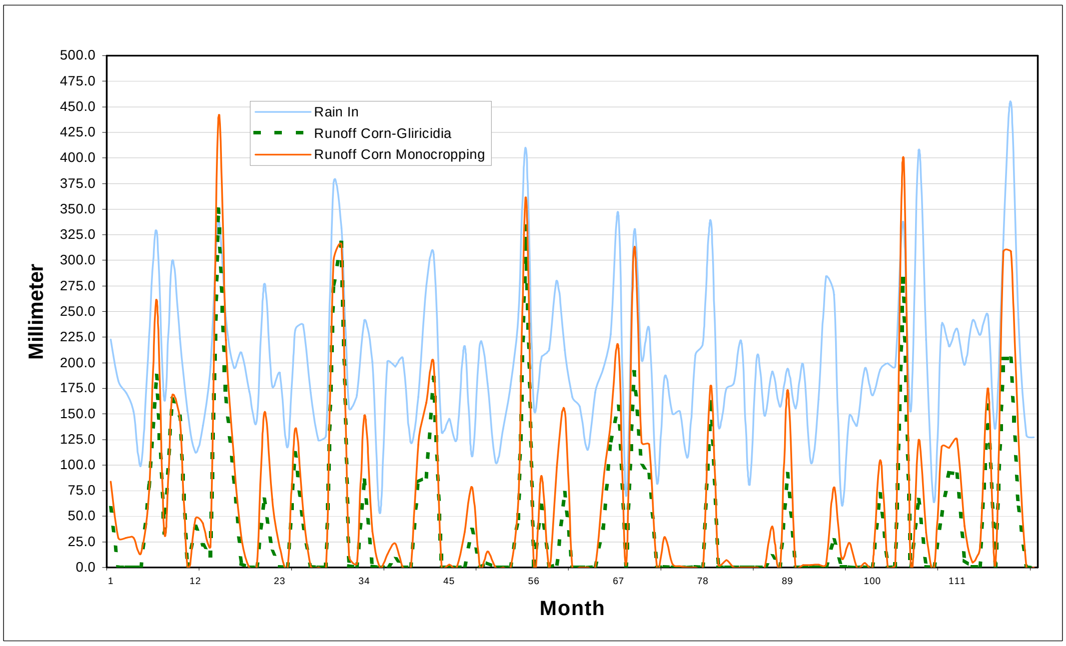

Figure 4-20. Comparison of simulated runoff of corn monocropping system and corn-*Gliricidia* cropping system.

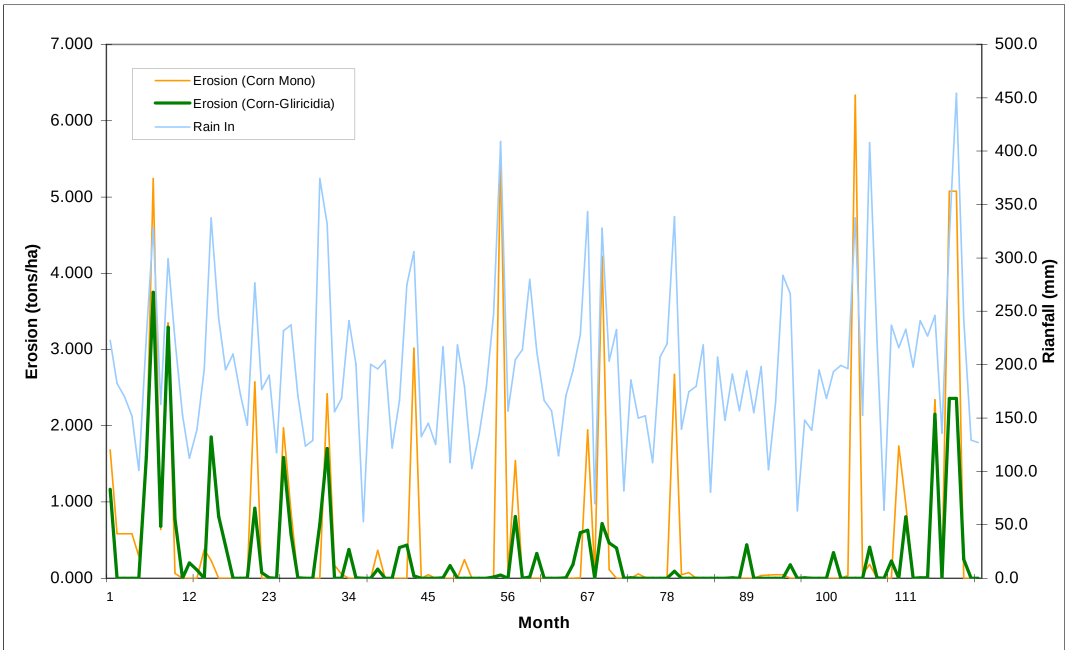

Figure 4-21. Comparison of simulated soil erosion of corn monocropping system and corn-*Gliricidia* cropping system.

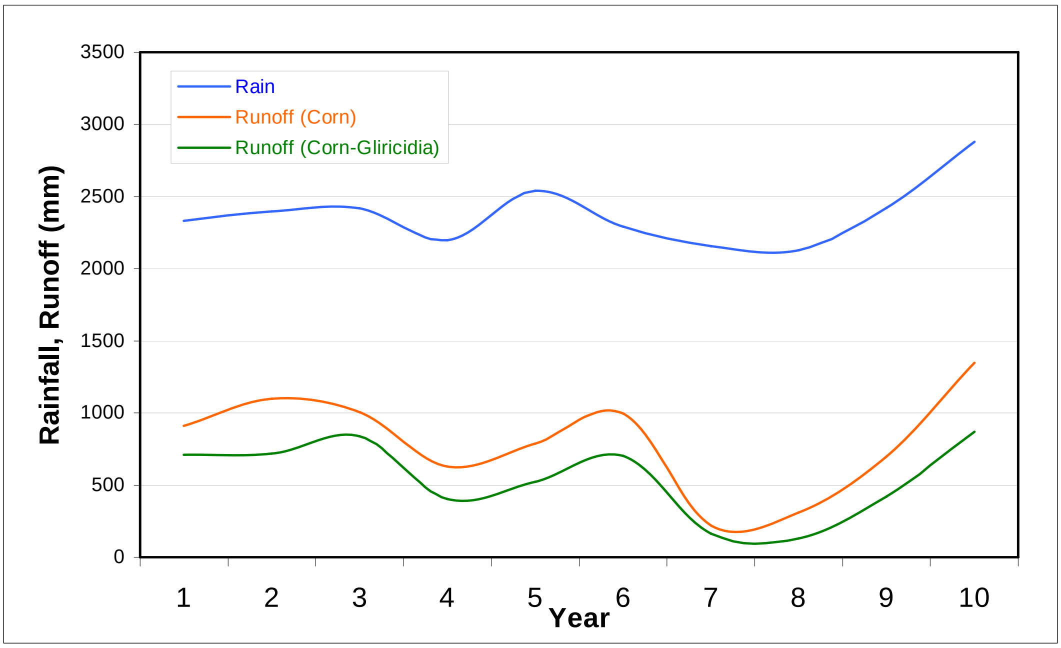

Figure 4-22. Comparison of simulated annual runoff of corn-monocropping system and corn-*Gliricidia* cropping system.

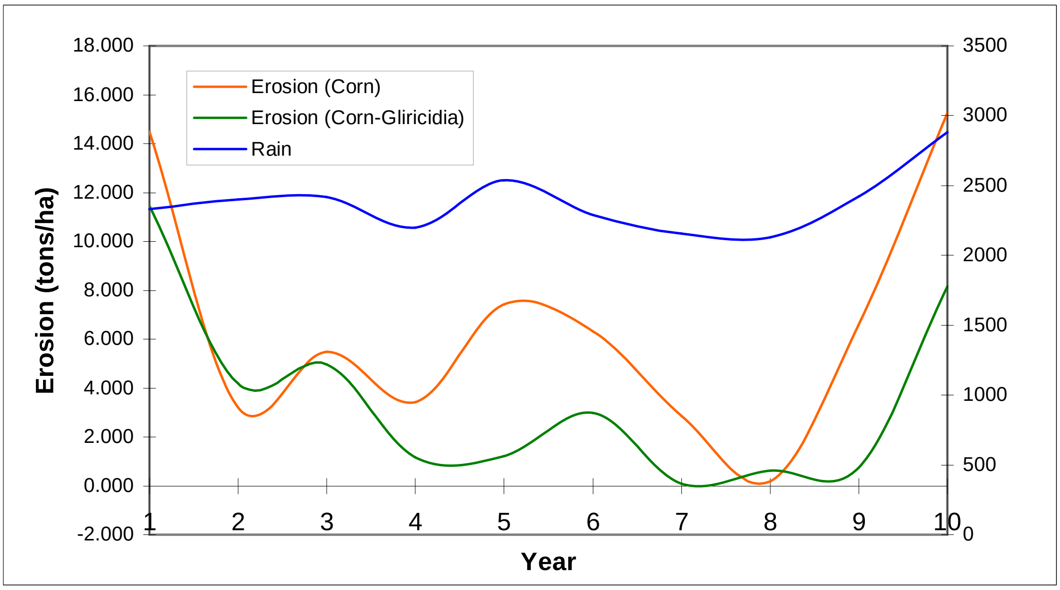

Figure 4-23. Comparison of simulated annual soil erosion of corn-monocropping system and corn-*Gliricidia* cropping system.

Crop Yield

The crop failure observed during the first season of year 1 for both cropping systems can be attributed to management schedule (**Figure 4-24 and Table 4-3**). As discussed in the earlier section, the project used only two planting schedules for the entire simulation period.

The simulated crop yield level for both cropping systems, were relatively higher than the documented historical or observed crop yield in the locality. This was due to yield-reducing factors such as weeds, pests, disease, that were unaccounted potential yield-reducing factors (e.g., pests and diseases).

Relatively higher seasonal yields were observed for CMS as compared to the CGCS over the period of ten years. This observation is due larger cropped area in the former cropping system. The sudden drop in yield of corn-*Gliricidia* system, during the second season of year 8, can be accounted to the management schedule (e.g., planting date).

Based from the results of this simulation, the yield trends of both systems are still not conclusive. Further tests and sensitivity analyses should be performed to single out what causes such behavior.

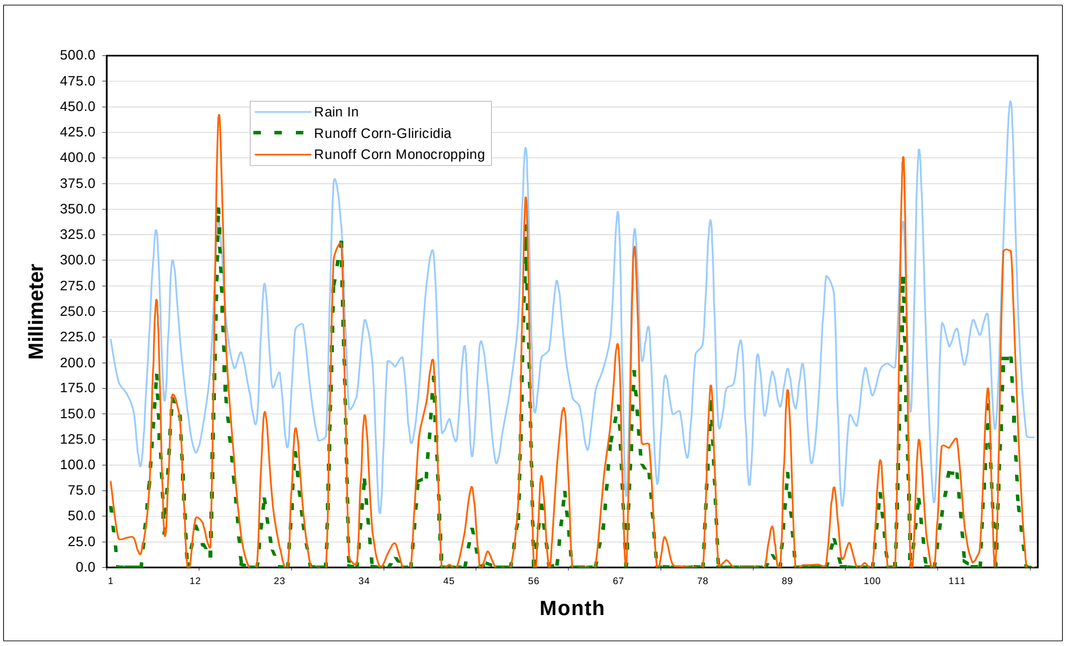

Figure 4-20. Comparison of simulated runoff of corn monocropping system and corn-*Gliricidia* cropping system.

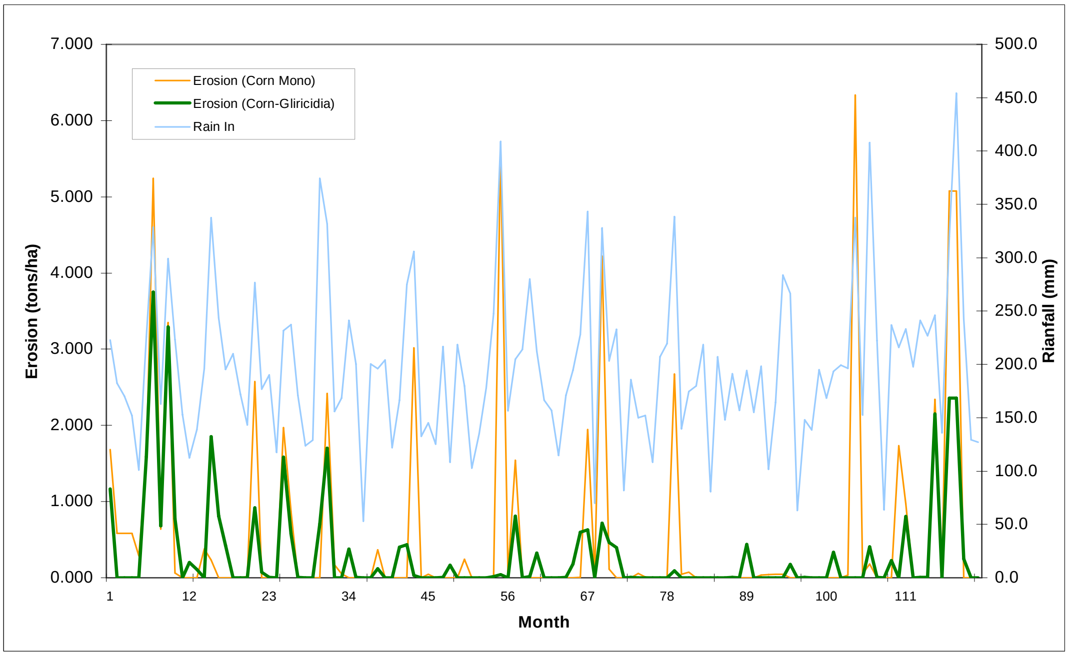

Figure 4-21. Comparison of simulated soil erosion of corn monocropping system and corn-*Gliricidia* cropping system.

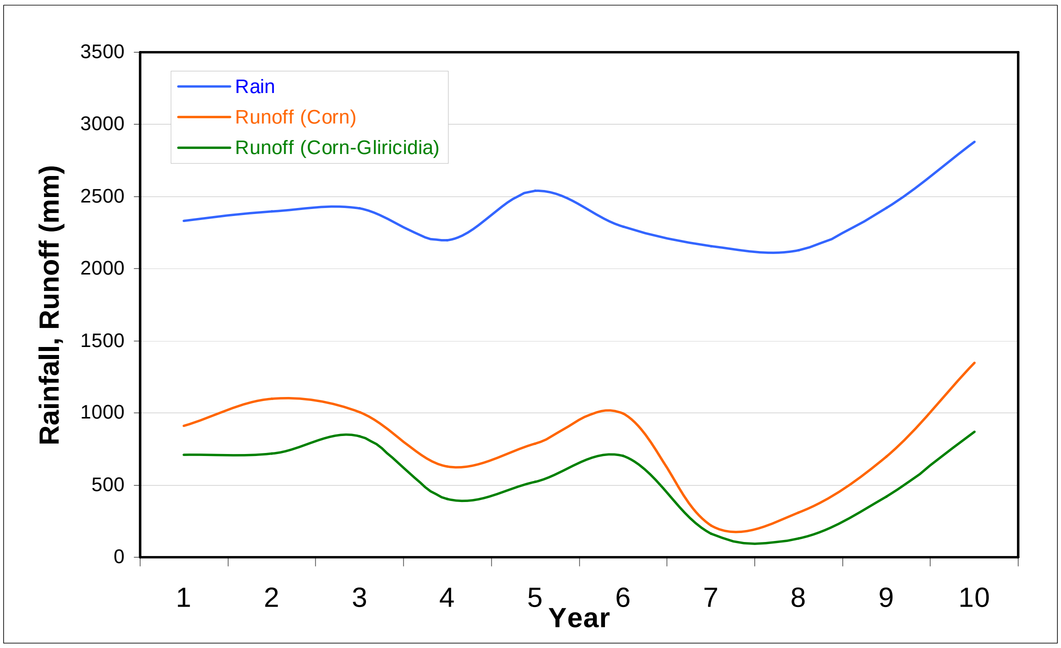

Figure 4-22. Comparison of simulated annual runoff of corn-monocropping system and corn-*Gliricidia* cropping system.

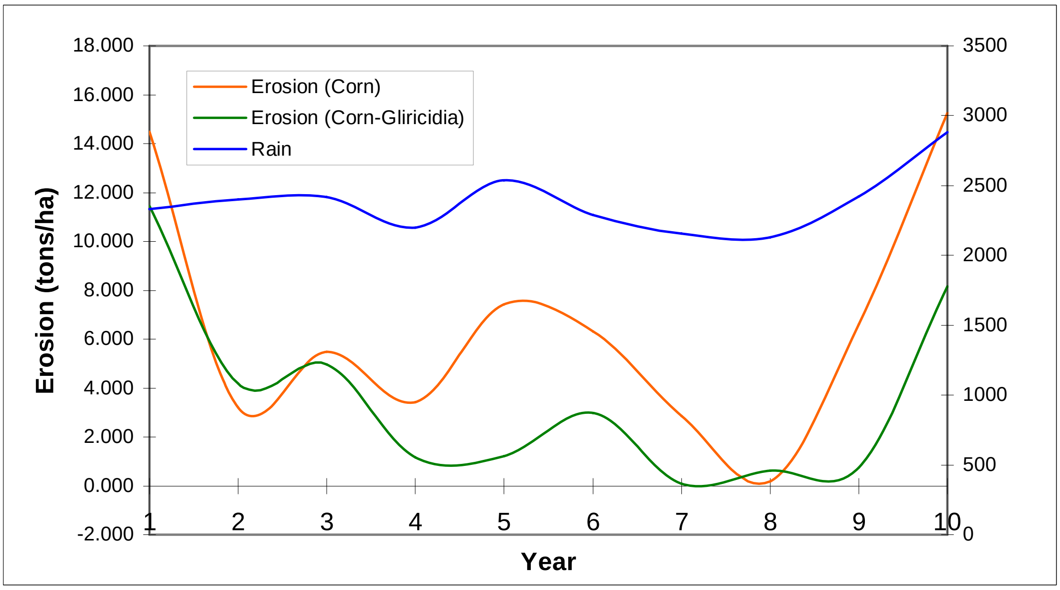

Figure 4-23. Comparison of simulated annual soil erosion of corn-monocropping system and corn-*Gliricidia* cropping system.

Profitability

The following section presents the financial performance of the two cropping systems, namely, the corn monocropping and corn-*Gliricidia*. The financial analysis considered the following: the costs and returns for the ten-year simulation period, the payback period or the number of years it takes to recoup back the investments and/or expenses, the net present value (NPV) for the returns to the investments and other costs incurred for the operation of the project and the Internal Rate of Return (IRRI).

Corn Monocropping System

Table 4-4 and **Figure 4-25a and 4-25b** show the yearly and cumulative cost and returns to the project as well as the calculation of the financial indicators of profitability for the corn-monocropping system. Table 4-4 shows that the net return was negative only for year 1. During the other years, the net return was positive although it dropped during year 6. The drop during year 6 was due to a substantial drop in yield possibly due to the interaction of the biophysical variables. It is usual that the investment costs required for establishing a particular crop is high while the returns is low during the first year. This however will vary with the particular investment or cropping pattern. In this particular case, the cumulative net return was positive during the ten-year period under study. The investment was very profitable so that this is recovered during the second year. The net present value for the 10-year period under study was P87,112 assuming a discount rate of 10% but increased to P115,256 if the assumed discount rate is 5%. The internal rate of return was very high at 205% making this a very worthwhile investment.

Corn-Gliricidia Cropping System

The costs and returns as well as estimates of the indicators of profitability for the corn-*Gliricidia* cropping pattern is shown in **Table 4-5** and illustrated in **Figures 4-26a and 4-26b**. Results show that this particular cropping is not as profitable as the corn-monocropping. Table 4-5 shows that losses were incurred during years 1 and 8. The loss during the first year was expected because normally investment costs were high during year 1, while returns were expectedly low right after establishment. The loss during year 8 was due to a substantial increase in the cost of operations as well as a drop in the yield. This was a function of the physical and biological factors inherent in the environment of the particular production system.

The corn-*Gliricidia* cropping system is profitable though not as profitable as the corn-monocropping system. It will take 3 years before the initial investment is gained back (see Table 4-5 and Figure 4-26b). The net present value at a discount rate of 5% was P40,332 but dropped to P29,274 if the assumed discount rate is 10%. The internal rate of return was high at 63% though it is not as high as that for corn-monocropping.

Table 4-4. Annual and cumulative costs and returns for corn mono cropping system

Year	Total Cost	Net Return	Cumulative Cost	Cumulative Net Return
1	27,234	-9,909	27,234	-9.909
2	28,585	22,163	55,829	12,255
3	30,025	16,538	85,854	28,792
4	31,526	14,961	117,380	43,753
5	33,103	26,912	150,483	70,666
6	34,758	1,171	185,241	71,837
7	36,496	21,658	221,736	93,495
8	38,320	17,079	260,057	110,574
9	40,248	22,933	300,293	133,495
10	42,248	23,307	342,542	156,802
Total	342,541	156,802	1,746,647	711,760

NPV	*10%*	*87,112*
	5%	*115,256*
IRR		205%
Payback Period		2 years

Table 4-5. Annual and cumulative costs and returns for corn-Gliricidia cropping system

Year	Total Cost	Net Return	Cumulative Cost	Cumulative Net Return
1	29,634	-16,159	29,634	-16,159
2	29,225	15,387	58,859	-772
3	30,687	6,074	89,545	5,302
4	32,221	3,749	121,766	9,051
5	33,832	18,383	155,598	27,434
6	35,524	5,984	191,122	33,418
7	37,300	5,453	228,421	38,872
8	39,165	-7,677	267,586	31,195
9	41,123	7,160	308,709	38,355
10	43,179	18,357	351,888	56,712
Total	351,888	56,712	1,803,129	223,407

NPV	*10%*	*29,274*
	5%	*40,332*
IRR		63%
Payback Period		3 years

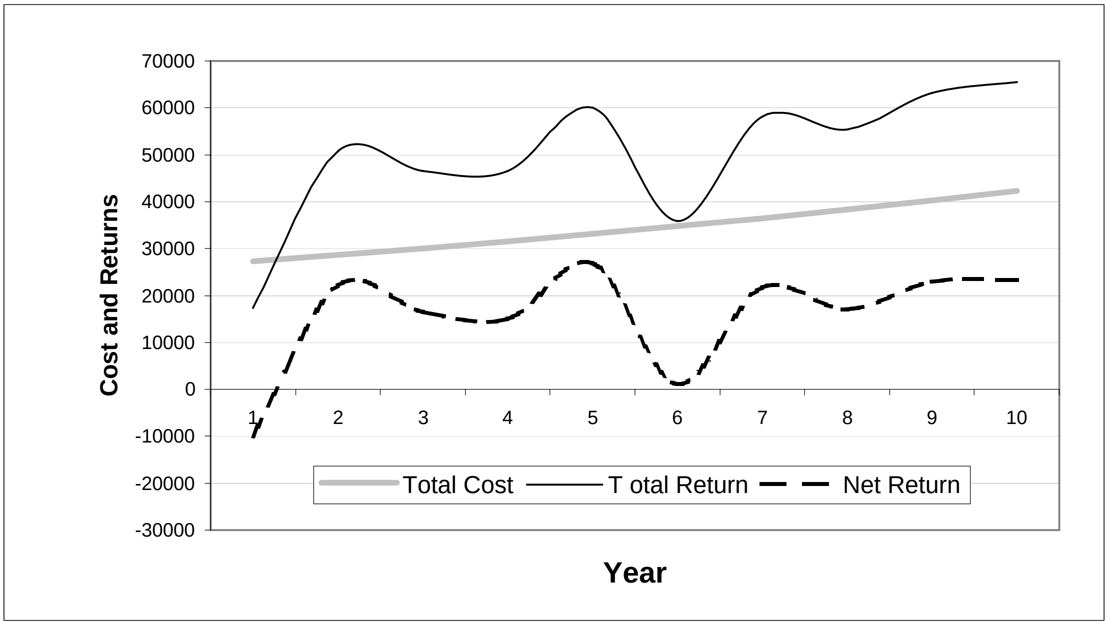

Figure 4-25a. Comparison of annual total costs and net returns for corn monocropping system.

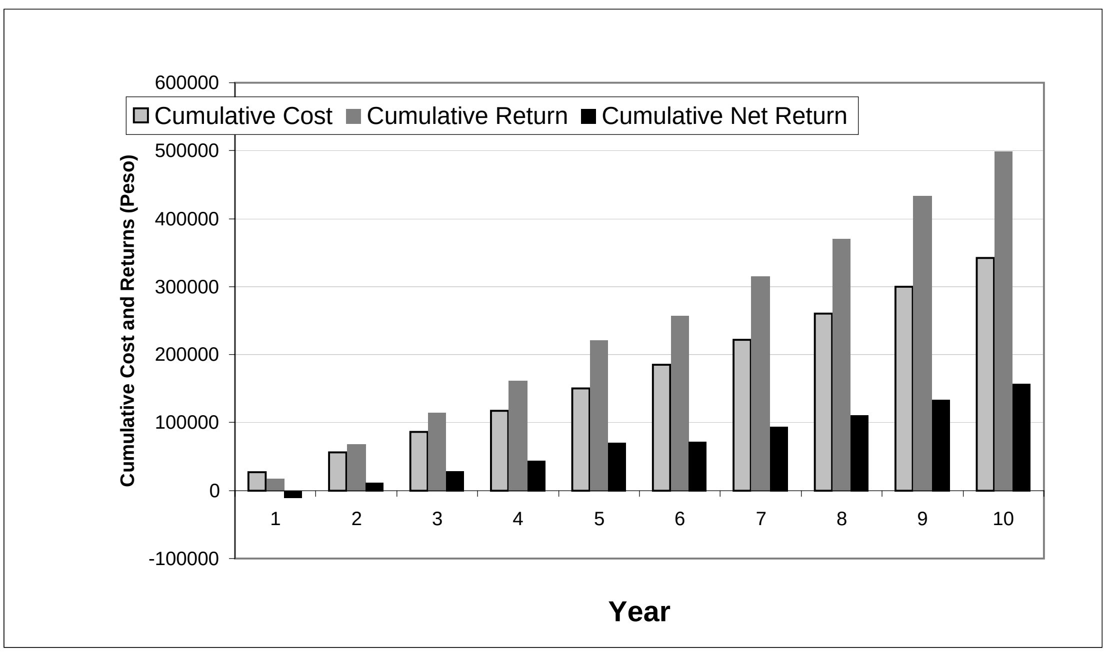

Figure 4-25b. Comparison of cumulative total costs and net returns for corn monocropping system.

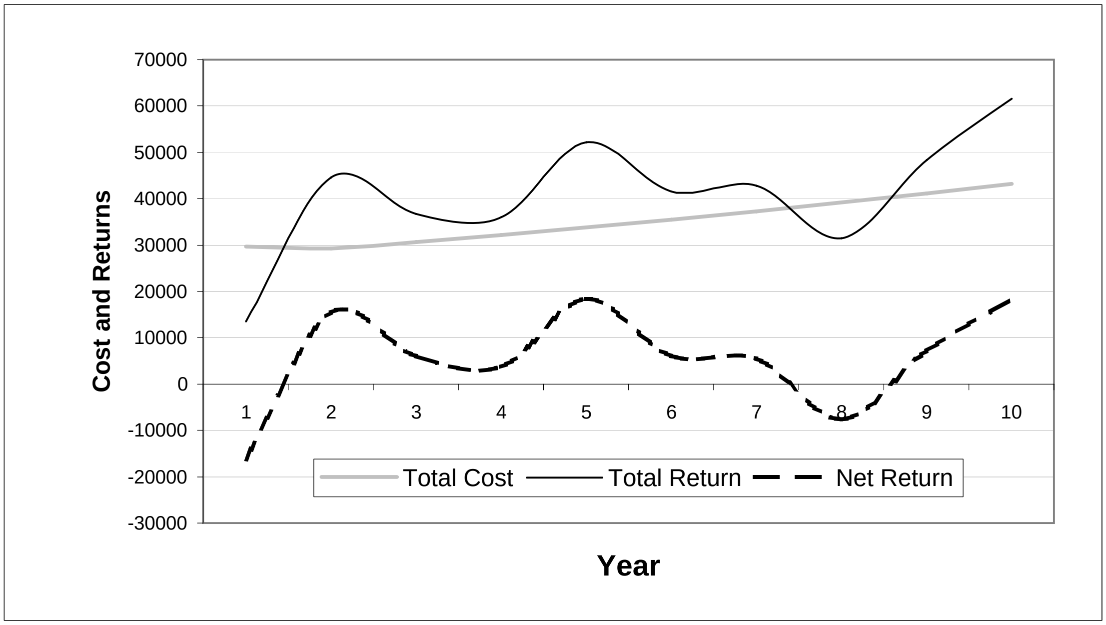

Figure 4-26a. Comparison of annual total costs and net returns for corn-Gliricidia cropping system.

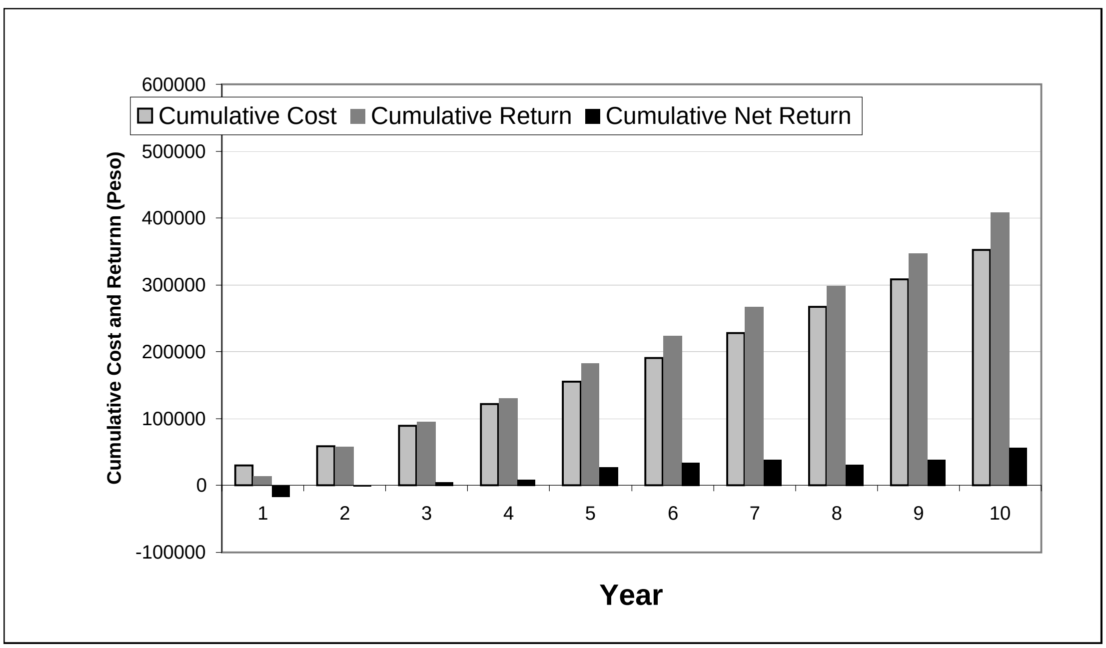

Figure 4-26b. Comparison of cumulative total costs and net returns for corn-Gliricidia cropping system.

Carbon Balance

Corn Monocropping System

The output of the 10-year simulation of the carbon (C) balance under a corn monocropping system is shown in **Table 4-6**

The major store of C in the system came from the soil organic matter (SOM) and surface litter pools (16,876 gm m^{-2}). Carbon gained by the system was 10,954 gm m^{-2} which was the total amount of C produced by the crop through photosynthesis. On the other hand, harvest of crop products and respiration contributed to the loss of C from the system. At the end of the simulation period, 8,113.70 gm m^{-2} has been removed from the field in crop products while 4,101.0 gm m^{-2} was lost through respiration. Consequently, the C balance showed a decrease in soil C from 16,876 to 15,636 gm m^{-2} (or 168.76 to 156.36 Mg ha^{-1}). This was equivalent to a 7.28% decline of the soils' initial C stock.

Carbon loss under corn monocropping was higher than corn-Gliricidia as reflected in the amount of SOM (**Figure 4-27**). This was due to the non-inclusion in the balance sheet of C loss in eroded soil. In sloping areas, soil erosion was considered as one of the major causes of nutrients and soil C loss. The output factors used in the model for the computation of the C balance were only crop removal (from harvest) and C released into air (during SOM and surface litter pools).

On the other hand, the potential contribution by crop roots to the C-input was not also taken into account. Roots contributed a large amount of biomass and C to the soil. In a study in N. Lampung, Indonesia (Hairiah and Sitompul, 2000), it was estimated that of the total crop C input to the soil (shoot + roots), about 65% was contributed by maize roots. It would appear that a significant change in the C balance will be expected if such contribution by crop roots can be factored into the model.

Overall, the time-averaged C stock declined during the simulation with a final value of 16,356 gm m^{-2}. Thus, C sequestration value of the system was negative, making it a net C emitter of about 509 gm m^{-2} or 5.10 Mg ha^{-1}. Consequently, sequestration of C declined (**Figure 4-28**).

Corn-Gliricidia System

Table 4-7 shows the carbon balance sheet under a corn-*Gliricidia* hedgerow intercropping system. Under this production system, the combined C input from the plant components was 14,088 gm m^{-2}. Total photosynthesis by corn was higher than that of *Gliricidia* (8,803 and 5,221,11 gm m^{-2}, respectively). The C production of corn, however, was lower compared to that obtained under corn monocropping.

Carbon losses from the removal of crop and tree products totaled 7,147 gm m^{-2}, a large portion of which came from corn harvest which generally increases (**Figure 4-29**). Plant respiration during N-fixation accounted for the loss of 685 gm m^{-2}. Meanwhile, respiration by soil fauna during soil organic matter (SOM) transformation contributed the

Table 4-6. Carbon stocks of corn monocropping system.

Year	Season	JD	BC SOMInit	BC Crop	BC HarvestedC	BC TotalRespired	BC SOM	BC TimeAvg CStock	BC Sequestered
			g/m2	g/m2		cum	g/m2	g/m2	
1	1	183	16,876	0	0	137.49	16739	16806	-70
	2	392	16,876	415	0.2969	286.74	16708	16817	-60
2	3	548	16,876	647	0.4861	463.22	16692	16835	-41
	4	757	16,876	550	0.3991	697.71	16609	16812	-64
3	5	913	16,876	505	0.3761	892.11	16544	16798	-78
	6	1122	16,876	572	0.4164	1,111.39	16481	16755	-111
4	7	1278	16,876	555	0.4176	1,308.43	16421	16746	-130
	8	1487	16,876	501	0.3690	1,532.41	16329	16736	-170
5	9	1643	16,876	560	0.4177	1,718.09	16285	16683	-193
	10	1852	16,876	785	0.5735	1,941.10	16274	16652	-224
6	11	2008	16,876	362	0.2709	2,168.82	16137	16625	-251
	12	2217	16,876	440	0.3232	2,368.38	16054	16583	-293
7	13	2373	16,876	625	0.4737	2,543.94	16030	16559	-317
	14	2582	16,876	607	0.4416	2,769.93	15969	16522	-354
8	15	2738	16,876	592	0.4416	2,969.63	15920	16499	-377
	16	2947	16,876	553	0.3981	3,196.05	15848	16463	-413
9	17	3103	16,876	691	0.5156	3,388.72	15831	16441	-435
	18	3312	16,876	632	0.4600	3,625.88	15765	16408	-469
10	19	3468	16,876	690	0.5136	3,825.45	15742	16386	-490
	20	3677	16,876	505	0.3705	4,064.82	15636	16352	-524

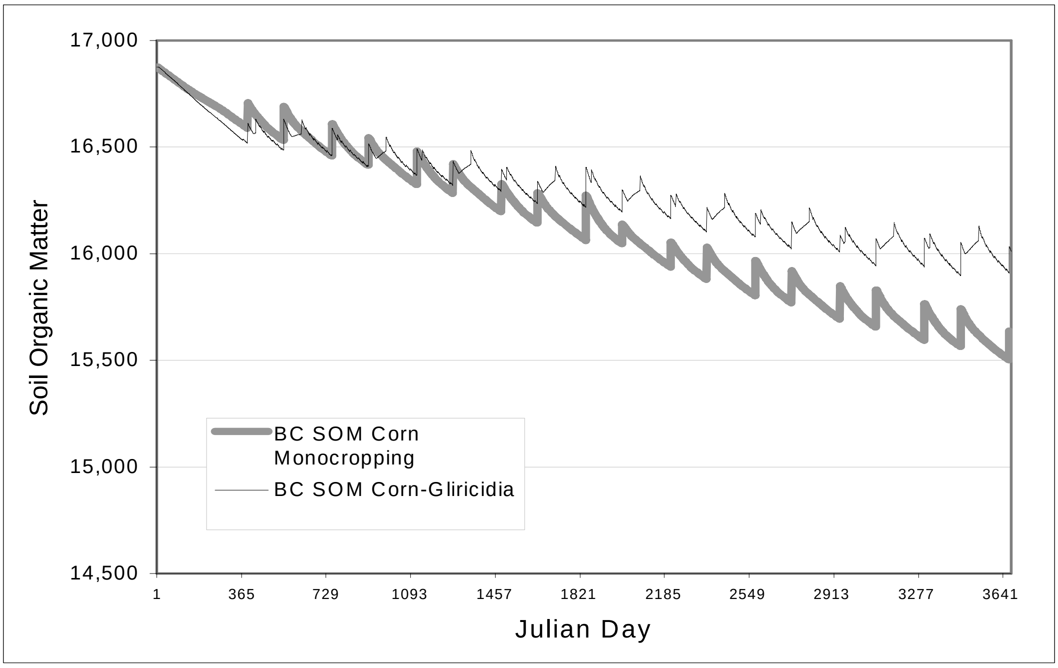

Figure 4-27. Simulated Carbon sequestered.

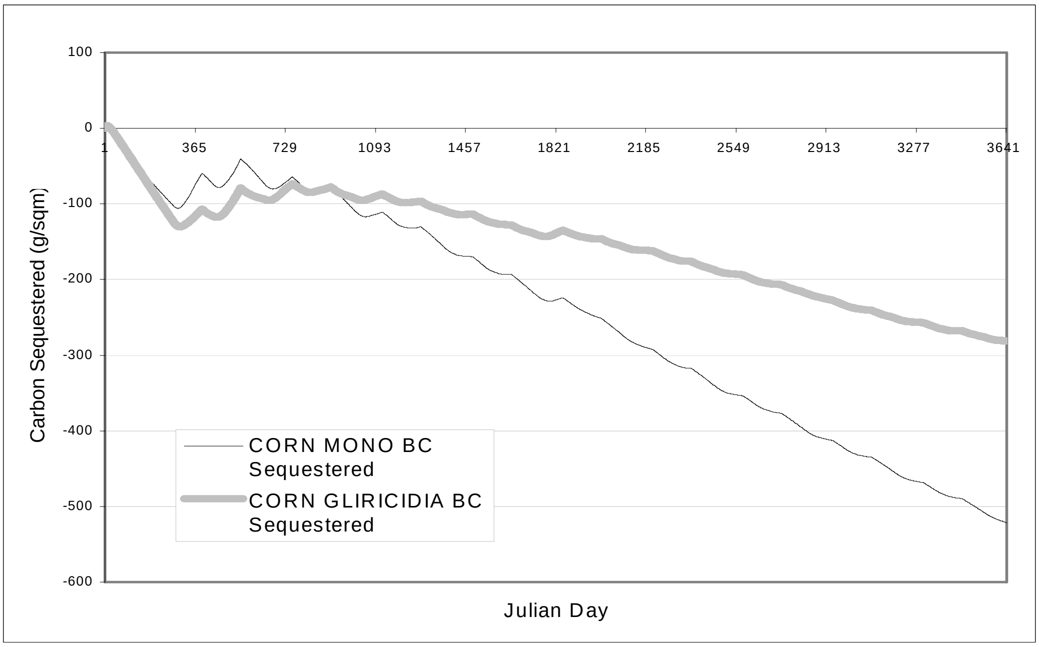

Figure 4-28. Simulated soil organic matter.

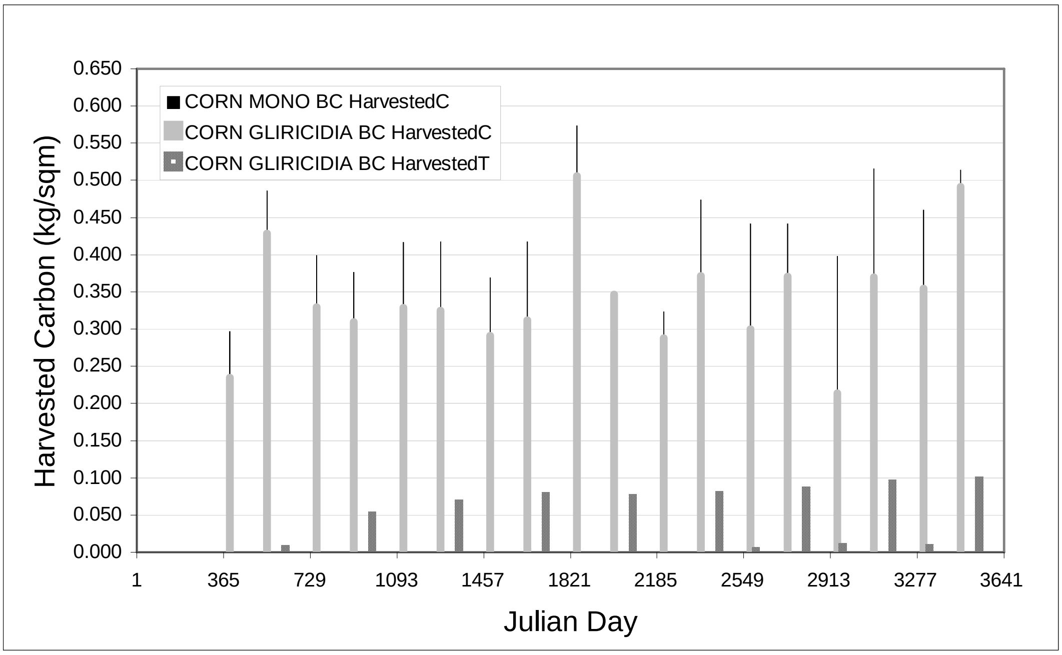

Figure 4-29. Simulated harvested Carbon.

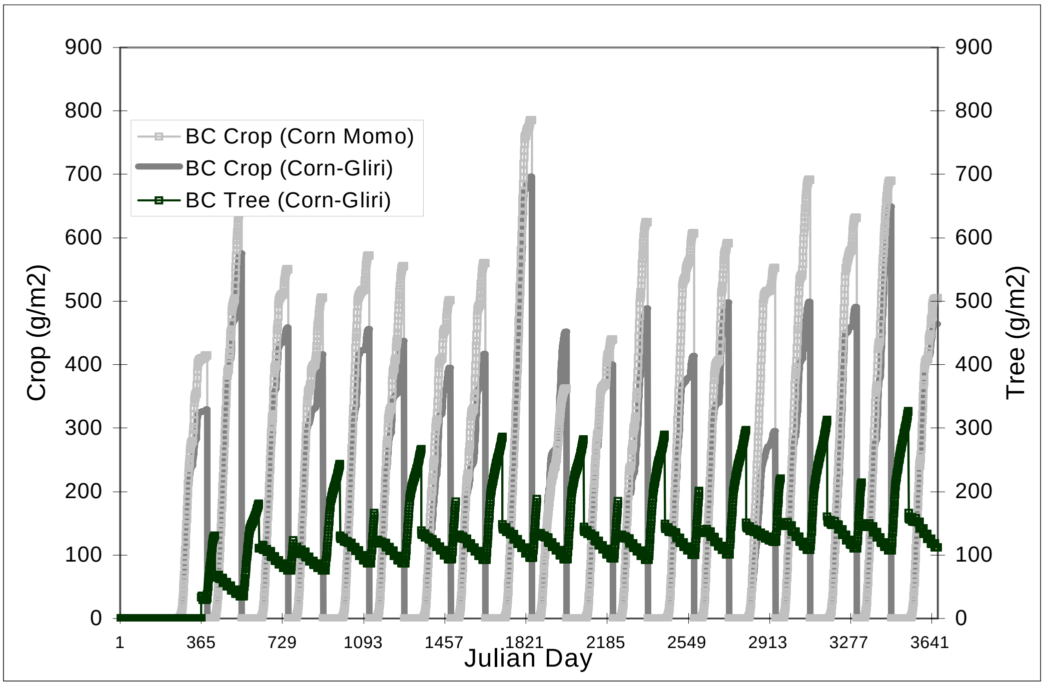

Figure 4-30. Simulated ten-year daily crop and tree Carbon content.

Table 4-7. Carbon stocks of corn-*Gliricidia* cropping system

Year	Season	JD	BC SOMInit g/m2	BC Crop g/m2	BC Tree g/m2	BC HarvestedC	BC HarvestedT cum	BC TotalRespired cum	BC TRespforFix cum	BC SOM cum	BC TimeAvg CStock g/m2	BC Sequestered
1	1	183	16876	0	0	0	0	174.49	0	16706	16797	-78.79
	2	392	16876	329	33	0.23521	0	377.67	0.95	16611	16769	-107.02
2	3	548	16876	575	35	0.42912	0	619.37	15.14	16631	16797	-78.93
	4	757	16876	458	75	0.32969	0	990.92	47.99	16589	16803	-73.33
3	5	913	16876	417	75	0.31006	0	1,224.52	59.73	16516	16798	-77.67
	6	1122	16876	456	87	0.32939	12.89	1,596.93	85.72	16493	16789	-86.9
4	7	1278	16876	438	86	0.32539	12.89	1,845.33	102.86	16432	16780	-96.26
	8	1487	16876	395	93	0.29113	40.67	2,215.70	132.85	16396	16763	-113.42
5	9	1643	16876	417	92	0.31207	40.67	2,472.36	153.48	16339	16749	-127.38
	10	1852	16876	696	95	0.50598	80.5	2,849.68	189.02	16406	16741	-134.81
6	11	2008	16876	452	93	0.34643	80.5	3,083.46	201.83	16300	16730	-145.91
	12	2217	16876	400	95	0.28823	111.54	3,429.93	229.8	16274	16714	-162.07
7	13	2373	16876	488	92	0.37173	111.54	3,661.00	248.01	16217	16700	-176.02
	14	2582	16876	414	100	0.30013	145.96	3,990.22	277.26	16190	16682	-193.87
8	15	2738	16876	498	100	0.37054	145.96	4,219.26	295.34	16150	16669	-206.58
	16	2947	16876	295	121	0.21376	179.25	4,562.81	326.86	16087	16649	-227.5
9	17	3103	16876	499	108	0.36999	179.25	4,795.44	344.91	16070	16635	-240.68
	18	3312	16876	491	110	0.35485	208.24	5,134.79	372.58	16074	16619	-256.94
10	19	3468	16876	649	107	0.49188	208.24	5,360.99	390.94	16052	16608	-267.57
	20	3677	16876	464	112	0.33891	242.11	5,700.03	421.13	16033	16594	-282

Table 4-7. Carbon stocks and biomass: corn monocropping system

Year	Season	JD	BC SOMInit g/m2	BC Crop g/m2	BC HarvestedC	BC Respiration	BC SOM g/m2	BC TimeAvg CStock g/m2	BC Sequestered
1	1	183	16,876	0	0		16739	16806	-70
	2	392	16,876	415	0.2969		16708	16817	-60
2	3	548	16,876	647	0.4861		16692	16835	-41
	4	757	16,876	550	0.3991		16609	16812	-64
3	5	913	16,876	505	0.3761		16544	16798	-78
	6	1122	16,876	572	0.4164		16481	16765	-111
4	7	1278	16,876	555	0.4176		16421	16746	-130
	8	1487	16,876	501	0.3690		16329	16706	-170
5	9	1643	16,876	560	0.4177		16285	16683	-193
	10	1852	16,876	785	0.5735		16274	16652	-224
6	11	2008	16,876	362	0.2709		16137	16625	-251
	12	2217	16,876	440	0.3232		16054	16583	-293
7	13	2373	16,876	625	0.4737		16030	16559	-317
	14	2582	16,876	607	0.4416		15969	16522	-354
8	15	2738	16,876	592	0.4416		15920	16499	-377
	16	2947	16,876	553	0.3981		15848	16463	-413
9	17	3103	16,876	691	0.5156		15831	16441	-435
	18	3312	16,876	632	0.4600		15765	16408	-469
10	19	3468	16,876	690	0.5136		15742	16386	-490
	20	3677	16,876	505	0.3705		15636	16352	-524

highest value among the different C outflows with 7, 678 gm m^{-2}.

Overall, the total amount of C loss from the system was 15,657 gm m^{-2}. Similar to corn monocropping, the C balance again showed a decrease in soil C during the simulation. The SOM C-stock was reduced by about 5.12% from its initial value (16,876 to 16,033 gm m^{-2} or 167 to 160 Mg ha^{-1}). While this value was lower compared to corn monocropping, the general trend showed a declining soil C stock (Figure 4-27).

On the other hand, the time-average C stock for 10 years lower than the initial soil C (16,139 and 16,876 gm m^{-2}, respectively). Therefore, C sequestration under this system also has a negative value (-283 gm m^{-2}) which meant that there was a net emission of C. While the predicted value was lower than that of corn monocropping, the results showed that it has a low potential for carbon sequestration.

One of the many contributions of the tree component in agroforestry is its potential to store carbon. Carbon fixation through agroforestry is a function of biomass accumulation and storage. The higher the biomass accumulation the greater is the potential to sequester carbon. Carbon storage under *Gliricidia* during the simulation averaged only about 300 gm m^{-2} or 3.0 Mg ha^{-1}, which was rather low compared to other agroforestry practices. For example, an improved fallow system in Cebu, Philippines was estimated to store 16 Mg $ha^{-1}$and sequester 5.3 Mg ha^{-1} yr^{-1} (Lasco and Suson, 1999). Zamora (1999) estimated that a Narra-Cacao multistory system stores about 170.69 Mg ha^{-1}. On the other hand, a grassland area in the Philippines has been found to store about 10.79 Mg ha^{-1}. The are several reasons, which could explain the low carbon stock and sequestration potential in hedgerow intercropping. First, biomass production of the hedgerow depends on tree density. In a typical hedgerow intercropping system with a 5-m hedgerow interval, trees occupied only 20% of the area. In the present study, total zone width was 7.5m, which further reduced the area occupied by the hedges. This greatly diminished the system's potential to produce adequate biomass for C storage. Secondly, the hedges were regularly pruned suppressing the growth of the biomass. This practice also prevented long-term C storage and when the harvested biomass decomposed, C was released in the process.

The overall carbon stocks in hedgerow system could increase if contributions from tree roots can be estimated and inputted in the model. As previously mentioned, considerable amount of C can be contributed by crop and tree roots. In the study by Hairiah and Sitompul (2000), tree roots from *Gliricidia*/*Peltophorum* hedgerow mix was estimated to contribute 37% of total C input into the soil. Estrella (1999) observed that 30% of *Gliricidia* hedgerow biomass was stored in the roots and has the potential to store about 2.83 t C ha^{-1}. Lai (1989) also reported that high amount of soil organic carbon in alley cropping was attributed to greater root biomass of the tree.

The tree C-content increased through time while the crop C-content for both systems continue to fluctuate (**Figure 4-30**).

Trade-off between Biophysical Suitability, Profitability, and C-stocks

Cropping Systems' Sustainability Evaluation

1. Biophysical Suitability

a. Runoff

Corn-*Gliricidia* Cropping System (CGCS) received an annual average of 23285 mm, while Corn Monocropping System (CMS) received 21979 mm effective rainfall for the period of 10 years. The total runoff produced from cumulative effective rainfall for CGCS and CMS, was 5275mm and 8388mm, respectively. This means that while CGCS received more effective rainfall, CMS produced more runoff. Twenty two percent (22%) of total rainfall received in CGCS, went out of the system through runoff, compared to 36% for the CMS system. Refer to **Table 4-8.**

Table 4-8. Comparison of effective rainfall, runoff and % runoff for two cropping systems.

Year	Corn-Monocropping System			Corn-Gliricidia System		
	Effective Rainfall (mm)	Runoff (mm)	%	Effective Rainfall (mm)	Runoff (mm)	%
1	2272	955	42.01	2458	733	29.82
2	3405	1887	55.41	2489	810	32.56
3	2090	882	42.18	2367	724	30.59
4	1993	618	31.02	2228	403	18.11
5	2203	786	35.69	2491	522	20.97
6	2048	1024	50.00	2327	701	30.13
7	1952	192	9.85	2157	163	7.55
8	1655	334	20.18	1933	130	6.74
9	2152	789	36.66	2369	473	19.97
10	2208	921	41.73	2468	614	24.89
Total	21979	8388		23285	5275	
Mean	2198	839	36.47	2329	527	22.13

For CGCS, there were 67 rainfall events that produced more than 10 mm of runoff, and all of these events were erosive. On the other hand for CMS, there were 110 rainfall events with more than 10 mm runoff recorded. However, only 74 events were erosive. Refer **to Table 4-9** for details.

Table 4-9. Frequencies of runoff, erosive rainfall events and soil erosion for different cropping systems.

Year	Corn-Monocropping System			Corn-Gliricidia Cropping System		
	Runoff Freq. (>10mm)	Erosive Rainfall Events Freq.	1-Ton Erosions Freq.	Runoff Freq. (>10mm)	Erosive Rainfall Events Freq.	1-Ton Erosions Freq.
1	27	25	5	10	10	5
2	14	8	2	9	9	2
3	11	7	1	8	8	0
4	9	5	1	7	7	0
5	11	6	3	7	7	0
6	11	9	3	9	9	0
7	2	2	1	2	2	0
8	5	0	0	3	3	0
9	9	5	2	6	6	0
10	11	7	3	6	6	2
Total	110	74	21	67	67	9
Mean	11	7.4		6.7	6.7	

As expected, the CMS system was inferior to CGCS system in terms of filtering water runoff.

b. Soil loss

CGCS system lost a total 37.38 tons/ha surface soil over the period of ten years while CMS system lost 60.09 tons/ha over the same period. Both systems passed through the acceptable soil erosion rate of 10tons/ha/year except in years 1 and 10 for CMS and year 1 for CGCS system. For both systems, highest erosion rate was observed during the initial year when crop failure occurred during the first cropping season. This confirmed that soil loss is directly proportional to the soil surface cover, as indicated in the Rose sedimentation equation. (Refer to **Table 4-10**).

With the management option used for CMS system, more soil degradation was expected. However, since the kind of soil used for this simulation is exceptionally good, we observed an even tolerable resource depletion rate. Soil erosion rate directly influenced two biophysical suitability indicators used in this study namely: soil organic matter and soil depth.

Table 4-10. Comparison of effective rainfall, runoff and erosion, CMS and CGCS.

Year	Corn-Monocropping System			Corn-Gliricidia Cropping System		
	Effective Rainfall mm	Runoff mm	Erosion t/ha	Effective Rainfall mm	Runoff mm	Erosion t/ha
1	2272	955	14.50	2458	733	11.56
2	3405	1887	5.17	2489	810	5.66
3	2090	882	3.52	2367	724	7.54
4	1993	618	3.43	2228	403	1.16
5	2203	786	7.43	2491	522	1.20
6	2048	1024	6.33	2327	701	2.99
7	1952	192	2.86	2157	163	0.09
8	1655	334	0.13	1933	130	0.62
9	2152	789	6.55	2369	473	0.98
10	2208	921	10.17	2468	614	5.58
Total	21979	8388	60.09	23285	5275	37.38
Mean	2198	839	6.01	2329	527	3.74

c. Soil organic matter

Soil organic matter declined by 5% for CGCS system over the period of 10 years, while SOM decline for CMS system was 7% over the same period. SOM decline was primarily due to the removal or depletion of soil surface through soil erosion by surface runoff. (Refer to **Table 4-11**).

Table 4-11. Comparison of soil organic matter content, CMS and CGCS.

Year	Corn-Monocropping System				Corn-Gliricidia Cropping System			
	Initial SOM g/m2	Current SOM g/m2	Cum. SOM Decline %	Non-Cum SOM Decline %	Initial SOM g/m2	Current SOM g/m2	Cum. SOM Decline %	Non-Cum SOM Decline %
1	33752	33446	0.91	0.91	33752	33317	1.29	1.29
2	33752	33301	1.34	0.43	33752	33220	1.58	0.29
3	33752	33025	2.16	0.82	33752	33009	2.20	0.63
4	33752	32749	2.97	0.82	33752	32828	2.74	0.54
5	33752	32559	3.53	0.56	33752	32745	2.98	0.24
6	33752	32191	4.62	1.09	33752	32574	3.49	0.51
7	33752	31999	5.19	0.57	33752	32407	3.99	0.50
8	33752	31767	5.88	0.69	33752	32236	4.49	0.50
9	33752	31596	6.39	0.51	33752	32143	4.77	0.28
10	33752	31378	7.04	0.65	33752	32086	4.94	0.17
Total				7.04				4.94
Mean				0.70				0.49

d. Soil depth

Soil depth was reduced by 37 millimeters in the CGCS system compared to 60 millimeters for CMS system over the period of 10 years. (Refer to **Table 4-12**).

Table 4-12. Comparison of runoff, erosion and soil depth, CMS and CGCS.

Year	Corn-Monocropping System				Corn-Gliricidia System			
	Effective Rainfall mm	Runoff mm	Erosion t/ha	Soil Depth CMS	Effective Rainfall mm	Runoff mm	Erosion t/ha	Soil Depth CMS
1	2272	955	14.50	0.14	2458	733	11.56	0.12
2	3405	1887	5.17	0.05	2489	810	5.66	0.06
3	2090	882	3.52	0.04	2367	724	7.54	0.08
4	1993	618	3.43	0.03	2228	403	1.16	0.01
5	2203	786	7.43	0.07	2491	522	1.20	0.01
6	2048	1024	6.33	0.06	2327	701	2.99	0.03
7	1952	192	2.86	0.03	2157	163	0.09	0.00
8	1655	334	0.13	0.00	1933	130	0.62	0.01
9	2152	789	6.55	0.07	2369	473	0.98	0.01
10	2208	921	10.17	0.10	2468	614	5.58	0.06
Total	21979	8388	60.09	0.60	23285	5275	37.38	0.37
Mean	2198	839	6.01	0.06	2329	527	3.74	0.04

Soil erosion rate was tolerable for 10 years in both systems, while the decline in soil organic matter and soil depth were, likewise, tolerable in both systems.

e. Crop and tree biomass

Except for year 6, the crop biomass produced by CMS is almost always higher than the CGCS. (Refer to **Figure 4-31**).

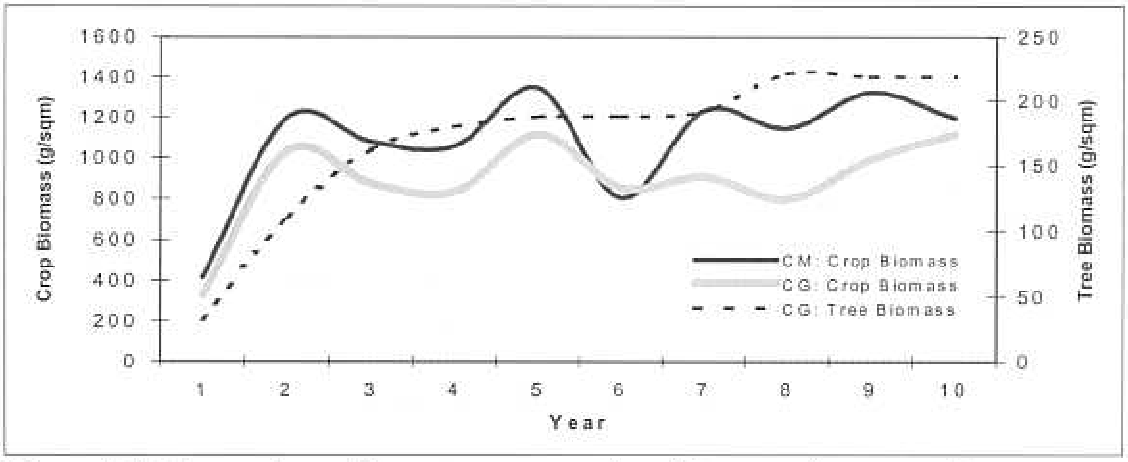

Figure 4-32. Comparison of long term crop and tree biomass of two cropping systems.

2. Economic Viability

f. crop yield

The average grain yield of CGCS system was lower than the CMS system for a period of 10 years. The lower average annual yield obtained from the CGCS system was due to reduced area attributed to hedgerow (20%) and, at the same time, the tree-crop above-ground competition for light and the below ground competition for water and nutrients. (Refer to **Figure 4-32**).

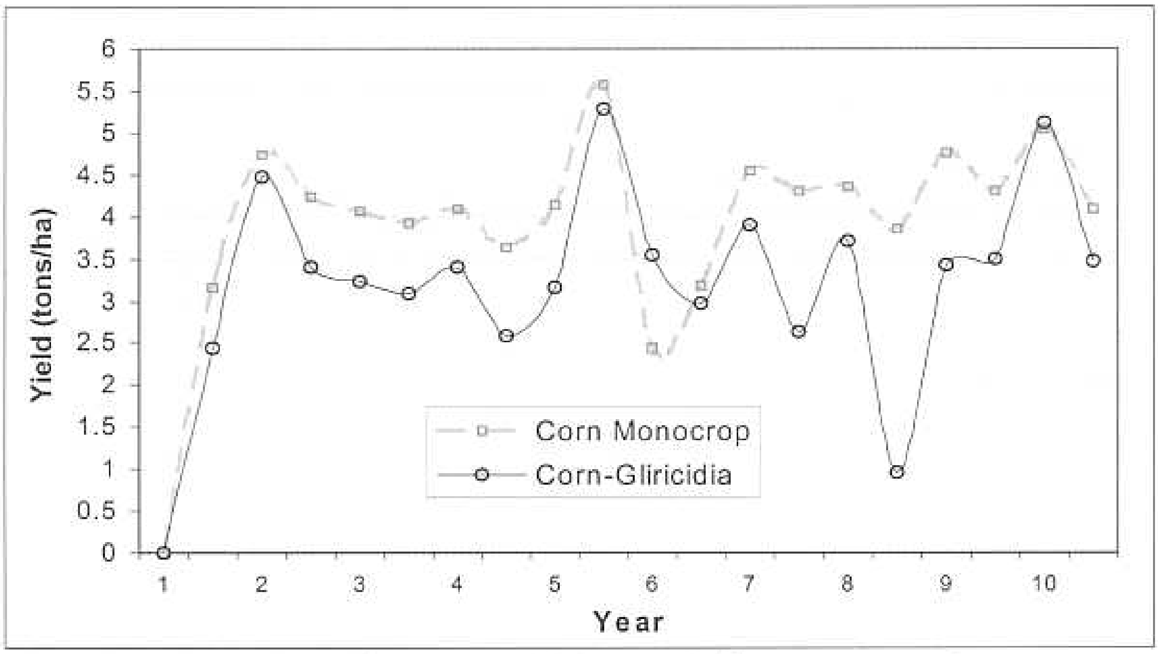

Figure 4-32 Comparison of long term yield (ten-year) of corn monocropping System and corn-Gliricidia cropping system.

g. Net return

The results of net return simulation shows that the CMS is more profitable than the CGCS. (Refer to **Figure 4-33**). There are several reasons for this observation such as: (1) CGCS has lesser cropped are than the CMS, (2) the cost of nutrients lost from CMS was not quantified and deducted from the overall cost, and (3) the value of the pruning applied as mulch to the CGMS was not valuated.

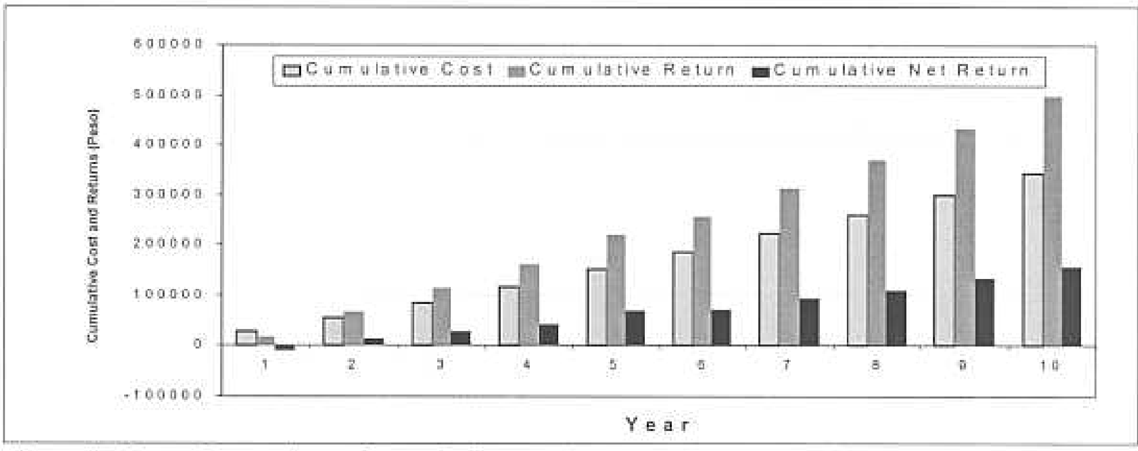

Figure 4-33. Comparison of cumulative total costs and net returns for CMS.

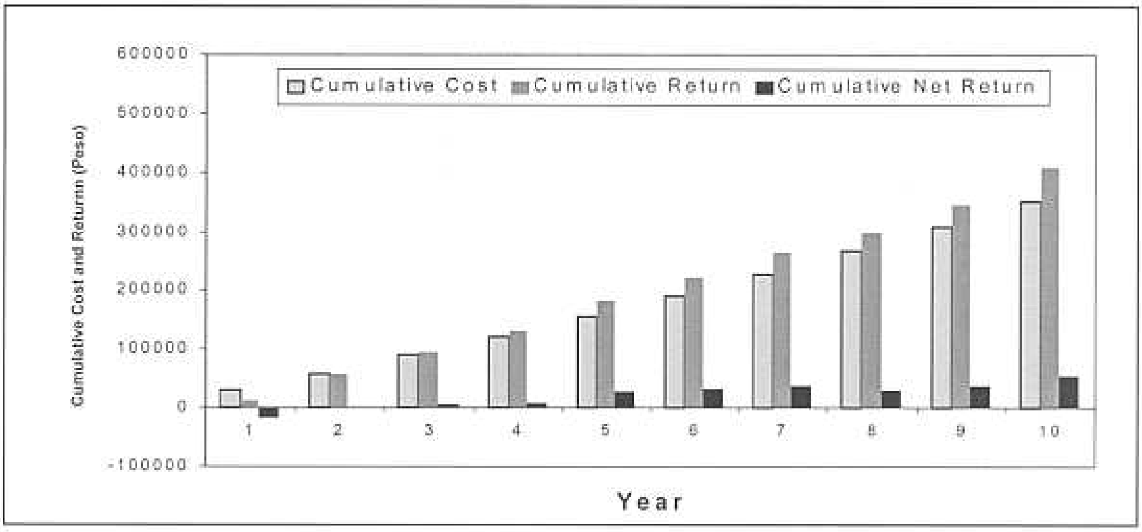

Figure 4-33. Comparison of cumulative total costs and net returns for CGCS.

3. Carbon Stocks

h. Carbon sequestration

Sequestration of atmospheric carbon showed negative emission for both systems. The total carbon emission from CGCS system was 550 g/m2 for the period of 10 years, while it was 1014 g/m2 for CMS system. Therefore, both systems were not sustainable in terms of carbon sequestration. (Refer to **Figure 4-34**).

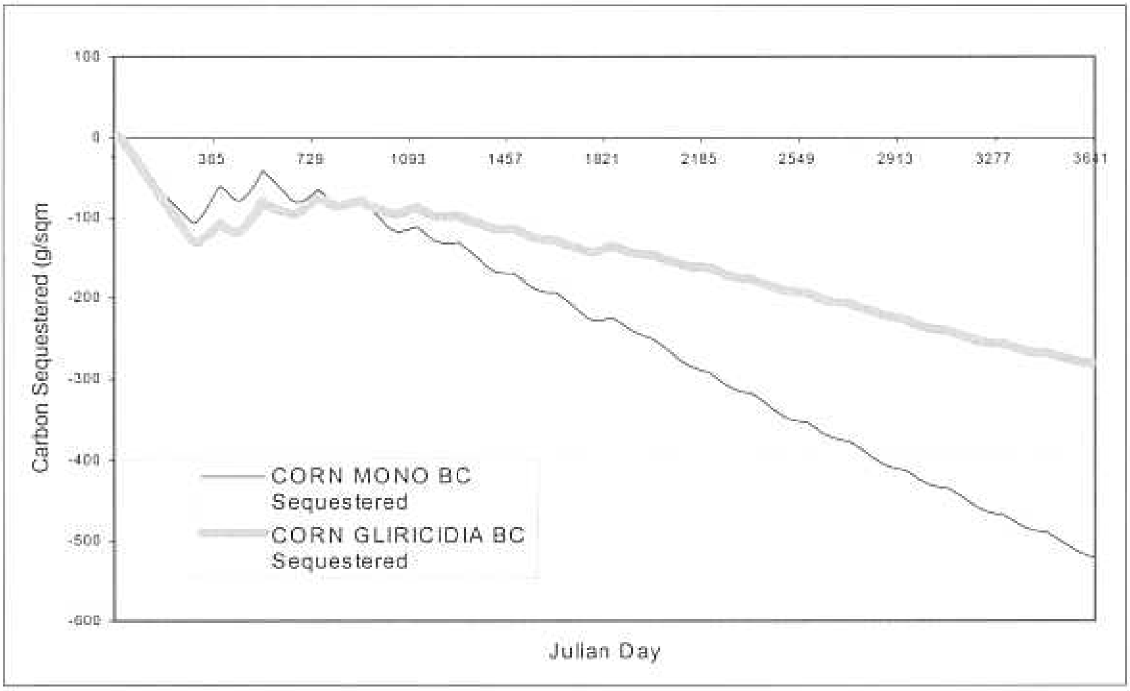

Figure 4-34. Simulated harvested carbon.

Setting sustainability evaluation criteria

Using the simple generic test of sustainability, the two systems modeled were subjected to long term sustainability evaluation.

Sustainability Indicators	Criteria	Corn Monocropping	Corn – Gliricidia
Biophysical suitability		XXX	X
Runoff	Less or equal to 20% of effective rainfall	Ok	Ok
Soil erosion	< 10 tons/ha/yr	Ok	Ok
Soil organic matter loss	< 2.5% of system total	Ok	?
Soil depth loss	< 10 mm/ha/yr	Ok	Ok
Yield trend	Non-negative	Ok	Ok
Economic viability		X	XXX
Yield trend	Non-negative	Ok	?
Net return/ trend	Non-negative	Ok	X
Carbon stocks		XXX	XX
Carbon sequestration	Non-negative	XX	X
System Sustainable?		**Needs Further Analysis**	**Needs Further Analysis**

Legend: Ok = acceptable; X, XX, and XXX = unacceptable at different degrees; ? = dubious result.

Based on the simulation results, it appears that CMS is less unsustainable or more sustainable than CGCS in terms of biophysical suitability and economic viability. But in general, both are unsustainable.

However, it is safer to say that the result of this simulation study is not yet enough to determine the sustainability of selected cropping systems, hence inconclusive. There are many factors that were not given proper attention due to some project limitations (e.g., time constraints, unavailability of specific secondary data required by the model.).

Sustainability determination of the selected cropping systems, therefore needs further analysis.

SUMMARY AND CONCLUSION

To test the model in providing simulation outputs from which indicators of cropping systems sustainability can be derived, study focused on the following factors namely: (1) rainfall, (2) soil erosion, (3) crop yield, (4) cost and return, and (5) carbon stocks. The simulation model was parameterized by modifying the default values of the input parameters which are related to or could directly influence the above-mentioned factors.

The study considered only two predominantly common cropping systems. However, the choice of the systems to be studied was secondary only to the major aim of this project which is to parameterize the WaNuLCAS model using the local datasets.

The simulation model far exceeded the expectations of the project researchers as it provided very detailed output information that helped understand the complex soil-tree-crop relationship at the plot level. As the model is not a ‘black box’, it was easily modified, to some extent, to meet the specific technical output requirements for the analysis.

While most of the team members are still on the model ‘familiarization stage’, the project can now release the observations incurred during the duration of the project implementation. A series of sensitivity analysis followed a long period of model familiarization among team members.

The data gap or differences observed between the model-simulated daily rainfall and the observed or actual rainfall is not attributed to volume but on its daily distribution. As daily rainfall was among the observed critical parameters, a recommendation to refine the built-in model’s rainfall generator was emphasized.

The simulated soil losses and related outputs that were produced using the Rose modified soil erosion and sedimentation equation, are of acceptable magnitude. Refinement of the erosion sector, however, is deemed necessary. Further study and output analysis are required, particularly on the subsurface water lateral movement portion which affects the total water runoff.

The unusually high crop yield observed for both systems is attributed to the modification made to the length of the vegetative and generative stages which has direct and significant effects to the crop growth and development. The longer vegetative period and growth duration allowed the crop to grow and develop further.

High grain yield produced high net returns. There is a direct relationship between yield and return. The lower net return in the corn-*Gliricidia* system compared to the corn monocropping system is primarily due to reduced cropped area and higher labor and hedgerow-associated expenses. The profitability sector, likewise, requires further refinement and review as it presently does not include input costs such as land preparation, which has a large contribution to the total farming costs.

Both systems registered negative carbon sequestration values over the entire simulation period. In the case of corn-*Gliricidia* system, too frequent pruning of the hedgerow resulted to none or almost zero carbon sequestration.

The basic methodology used to evaluate the sustainability of the cropping system in terms of biophysical suitability and economic viability is able to satisfy a number of expectations and objectives. However, tradeoff analysis should be emphasized since sustainability and miltifaceted and mltidimensional.

The simulation model, WaNuLCAS is a good model to derive sustainability indicators and to evaluate the sustainability procedure or analysis.

ACCOMPLISHMENTS

Objective 1	To assess the long term implications for soil properties, nutrient, water and organic matter balance for selected land use alternatives for upland agriculture and agroforestry, to estimate the possible trade-offs between profitability, sustainability and carbon sequestration.
Accomplishments:	The long-term implication of ten-year corn-corn and corn-*Gliricidia* cropping systems on selected biophysical properties, as sustainability indicators, was assessed. However, very limited scenario-building procedures were done to determine the best possible tradeoffs between biophysical suitability, economic viability and carbon stocks or carbon sequestration. However, still the project gained sufficient techniques and model exposure and familiarization, which can be used to address agroforestry-based issues in the near future.
Objective 2	To test a generic method for deriving sustainability, profitability and carbon stock indicators from a comprehensive tree-soil-crop interaction model.
Accomplishments:	A generic procedure for determining sustainability was conducted for the two cropping systems using the WaNuLCAS simulation model. Soil-tree-crop interaction was studied and better understood using the model, which has a very active, visual graphical display capability and a tabular interface. The model proved to be very useful in providing better understanding of the complex soil-tree-crop interaction, which involves a multitude of critical parameters or factors governing their very site-specific behavior.

Accomplishments and lessons learned gained through suggested methodology procedure

Step 1 Identify typical representatives of the generic land use classes (as developed for global ASB comparisons) in Northern Mindanao;

Identification was not done using ASB guidelines, but through field visitations and group discussions with local farmers. Two cropping systems were identified: 1) corn monocropping system and 2) corn-*Gliricidia* cropping systems.

Step 2 Parameterize the WaNuLCAS model for climate, soil, tree and crop parameters using secondary data to represent selected typical land use options and, if necessary, collect primary data;

Parameterization involved secondary data collection, input data generation, sensitivity analysis and curve-fitting.

Step 3 Parameterize the WaNuLCAS model for labour requirements and prices to allow profitability analysis;

Basic profitability analysis using four economic viability indicators such as NPV, IRR, payback period and cost and return analysis were employed.

Step 4 Further develop the soil loss module in WaNuLCAS in cooperation with ICRAF to reflect soil and water conservation functions;

Refinement of the existing soil erosion and sedimentation sector was done, mostly at the local level, with little collaboration with ICRAF.

Step 5 Meet to discuss progress in model development and data collection;

Meeting between WaNuLCAS project-based ICRAF-SEA staff and SEARCA-UPLB staff to level off expectations and to clarify project procedures did not materialize due to inability to arange a common schedule for both groups. One staff from SEARCA was sent to ICRAF-Bogor for detailed consultations with ICRAF WaNuLCAS staff.

Step 6 Make model run, summarize results and derive performance indicators (e.g. sustainability, stability) for the main land use categories

Sustainability evaluation of selected cropping systems was performed using the generic procedure and the simulated results of the model.

IMPLICATIONS

1. Based on the findings of the research team, the model is complex enough and highly sensitive. This implies that it can further be simplified and fine-tuned to a specific application with higher reliability of results.

2. The research team's valuable experience in manipulating the model can provide an initial impetus to explore variant models that may take into account other plant growth variables like solar intensity, effect of nutrient competition, soil ecology, etc.

3. The model is highly applicable at the plot level. However, considering the generic nature of the key variables the model attempts to investigate rainfall, soil erosion, crop yield and carbon stocks upscaling the model to the watershed level could be a good prospect for further study in the future. Upscaling could be done outside the model using other research analytical tool like geographic information system (GIS).

4. Despite the marginal time spent by the research team to really scrutinize the extent use and functioning of the model, yet a number of add-on dimensions and innovations were implemented (e.g. rainfall generator, and Rose erosion model). This means that if given more time and financial resources to gather primary data, much could have been done that would have led to a more improved and responsive model.

5. The key variables used in the study (e.g. dynamics of soil erosion, rainfall and others) have not been exhaustively examined. This suggests that more studies on these aspects should be pursued as they significantly affect crop production.

RECOMMENDATIONS

Climate

When using the model's type 2 rainfall, coefficient variation (CV) requirement should not be limited to only one value. This recommendation was arrived at since the monthly rainfall distribution has different means, standard deviation and CVs.

Soil Erosion

For more precise utilization of the Rose erosion model, modification and refinement of the equation, particularly the cover factor portion, should be done. This is because the surface cover affects event runoff and erosion.

Profitability

a. Private vs. Social Price

If private price actually refers to farm gate price and social price refers to price at the market place, then it may be better to simply use the term farm gate price. The term social price for the purpose of the model is not appropriate. Social price in economic jargon may actually refer to efficiency prices. It was suggested that the reference point be the farm gate price. If the price information available is at the community market, then appropriate adjustments for costs such as transportation costs and margin of trader should be used to get the farm gate price.

b. Hired vs. family labor

The amount of hired labor used should be separated from family labor. Though it is possible to estimate the opportunity cost associated with family labor, for decision-making purposes, farmers may treat family labor differently from hired labor. There is cash outlay involved when hired labor is utilized while this is not true for family labor. The opportunity cost associated with family labor, in some instances, may be treated as equal to zero if the farmer does not have alternative uses for his labor.

c. Monetizing non-market inputs

To be able to determine the value of the non-marketed inputs to production such as enhanced soil fertility (e.g. due to the introduction of *Gliricidia* into the cropping system), it will be important to determine the total value of production (price times quantity of production) and the value of the other inputs. The difference between the total value of production and the value of the inputs is the value of the non-marketed input.

d. Financial indicators

i. Payback period

This is one indicator that may be included in the model. Considering that the benefits from investments in soil fertility is realized only over time, it will be important to determine how long it will take to at least break even. It can be calculated as the number of years of operations required for the NPV of net benefits to equal the NPV of investment cost. Given this computation, it will be able to discriminate amongst fast-paying and slow-paying projects.

Sustainability criterion:

At least, the investments should be realized within the life of the investment.

ii. Internal rate of return

This is the rate of discount at which the benefits are equal to zero. It is the discount rate that makes the present value of costs and benefits equal to zero. This is computed by trial and error but most spreadsheet software have the facility to compute this efficiently.

Sustainability criterion: as long as the IRR is at least equal to the opportunity cost of capital (the next best alternative investment), then it can be said that it is worth investing in the project.

iii. Net present value

This can be interpreted as the present value of the net income or benefit stream generated by an investment. It is the present value of the stream of net revenues accruing to the individual or firm for whom the project is being undertaken.

$$NPV = \sum \frac{B_t - C_t}{(1+i)^t}$$

where NPV is the Net Present Value
Bt is the benefit arising in year t
Ct is the cost arising in year t
i is the discount rate
n is the life of the project

Developing the Livestock Sector of the Model

Parameterization of WaNuLCAS model for livestock-related parameters, including those that interact with crops, using: (1) secondary data, and (2) validation of secondary data for site- specificity

Materials balance will be established for sample animals, typical weight, dry matter (DM) basis to determine biomass intake, waste output (DM manure/urine) and biogas generation (metane or CH4). Quantities will also be valued in monetary terms, using market prices and best available estimates.

Tabular representation of data needed for the analysis of livestock sector.

	Large ruminants	Small ruminants	Non-ruminants
Feed (DM/day/yr)			
Manure (DM/day/yr)			
Biogas (CH4/day/yr)			
Work output (hp/day/yr)			
Product outputs (milk, eggs, hide)			

Appendix A

RESEARCH AGREEMENT

Purpose

This agreement confirms the terms and conditions in SEA Regional Center for Graduate Study and Research in Agriculture and project implementation team will undertake research work for the Regional Technical Assistance (RETA) project grant 5711 from the Asian Development Bank under the Alternatives to Slash and Burn (ASB) programme. The RETA 5711 is executed by the International Centre for Research in Agroforestry (ICRAF) through its Southeast Asian Regional Research Programme.

The research team will hereinafter be called the *Grantee*.

Under this agreement, the Forestry and Environment Research Division of the Philippine Council for Agriculture, Forestry, and Natural Resources Research and Development (PCARRD) will provide assistance to ICRAF in monitoring research activities undertaken by the Grantee.

Research will be undertaken as specified in the proposal entitled '*Assessment of Sustainability Criteria and Carbon Stocks for Selected Land Use Options for Philippine Uplands*'.

Term

The term of this Agreement will be from the date of signing by all parties until submission of an acceptable research report (in English) by the Grantee on or before April 30, 2000.

Research

The *objective* of the research are as follows:

i. Assess the longer term implications for soil properties, nutrient, water and organic matter balance of a range of land use alternatives for upland agriculture and agroforestry, to estimate the possible trade-offs between profitability, sustainability and carbon sequestration;

ii. To test a generic method for deriving sustainability, profitability and carbon stock indicators form a comprehensive tree-soil-crop interaction model.

The *scope* of this research grant will comprise the compilation and review of relevant secondary data, the collection of primary data as necessary in mutually agreed sites in North Mindanao.

Methods:

i) Identify typical representatives of the generic land use classes (as developed for global ASB comparisons) in Northern Mindanao;

ii) Parameterize the WaNuLCAS model for climate, soil, tree and crop parameters using secondary data to represent typical forms of a range of land use options; if necessary collect primary data;

iii) Parameterize the WaNuLCAS model for labour requirements and prices to allow profitability analysis;

iv) Further develop the soil loss module in WaNuLCAS in cooperation with ICRAF to reflect soil and water conservation functions;

v) Meet to discusss progress in model development and data collection;

vi) Make model run, summarize results and derive performance indicators (e.g. sustainability, stability) for the main land use categories

Financial Assistance

Total cost
The total cost of the financial assistance is US$ 11,000 (Eleven Thousand US Dollars). The funds will be used exclusively to finance expenditures for the research to be undertaken in accordance with the appended Research Budget.

Payment
ICRAF will effect payment (s) according to the following schedule:

1) 2/3 on signing of the Research Agreement by all parties
2) 1/3 on submission of an acceptable Research Report by the Grantee together with receipts for expenditures, which is to be done on or before April 30, 2000

Financial report
The Grantee will submit to ICRAF a statement of accounts showing use of ICRAF's funds together with copies of invoices or other evidence in respect of all payments made for the research. This statement will be submitted to ICRAF upon completion of the research.

Responsibilities of the Grantee

1. The Grantee will be responsible for all aspects of research implementation, as well as technical and financial administration.

2. The Grantee will maintain records adequate to show the use of funds and the progress of the research, and will enable ICRAF's representative to be informed of all aspects of the research, including any relevant records and documents.

3. Upon completion of the research the Grantee will prepare and submit to ICRAF, no later than April 30, 2000, a final report describing the results of the research and the use of funds.
4. The Grantee will make available to ICRAF the results of its research, and for the purpose of copyright, all reports prepared will be in joint ownership of ICRAF and the Grantee. Further, the Grantee will credit the ASB-Philippine Consortium, ICRAF, and the Asian Development Bank if any information derived from the research is published elsewhere.

5. The Grantee will make available all relevant information related to progress of the research to the Forestry and Environment Research Division of the Philippine Council for Agriculture, Forestry, and Natural Resources Research and Development (PCARRD).

General Provisions

1. The Grantee will indemnify ICRAF against, and hold ICRAF harmless from all losses, claims, liabilities, damages, demands, actions or proceedings whatsoever arising out or in connection with the Grantee's performance of its duties under this Agreement.

2. ICRAF undertakes no responsibility in respect of life, accident, travel, or any insurance coverage of the Grantee's research personnel in carrying out research activities.

Termination

ICRAF may at any time suspend or terminate this Agreement, after consultation with the Grantee, if any circumstances arise which interfere with or threaten to interfere with the successful carrying out of the research. Further, the Grantee may at any time in writing request ICRAF to terminate this Agreement if such circumstances as above described arise. In the event of any such termination or suspension, ICRAF and the Grantee shall consult with each other concerning the appropriate steps to be taken and any further action which may be necessary or desirable to take with respect to the research.

Key Personnel

For ICRAF, the personnel responsible for the implementation of this Agreement will be Dr. Thomas P. Tomich, Principal Economist or any officer(s) as is (are) duly designated by ICRAF;

For the *Grantee*, the personnel responsible for the implementation of this Agreement will be Dr. Percy E. Sajise and the project team. Each will participate fully in the necessary data collection, analysis, and report writing as specified in the Proposal.

___________	___________
Date	Date
SGD.	SGD.
Dr. Thomas P. Tomich Principal Economist ICRAF Southeast Asian Regional Research Programme	**Dr. Percy E. Sajise** Director SEAMEO-SEARCA

Cc: Dr. Dennis P. Garrity, Regional Coordinator, ICRAF SEA Regional Research Programme
Dr. Meine van Noordwijk, Principal Soil Scientist, ICRAF SEA Regional Research Program
Dr. Segundino Foronda, Director Forestry and Environment Research Division, Philippine Council for Agriculture, Forestry, and Natural Resource Research and Development (PCARRD) FINAD ICRAF SEA Regional Research Program

Appendix B

"Assessment of Sustainability Criteria and Carbon Stocks for Selected Land use Options for Philippine Uplands"

Proposal for subcontract from ICRAF to SEARCA as part of the ADB RETA 5711 project.

Objectives

1) Assess the long term implications for soil properties, nutrient, water and organic matter balance of a range of land use alternatives for upland agriculture and agroforestry, to estimate the possible trade-offs between profitability, sustainability and carbon sequestration.

2) To test a generic method for deriving sustainability, profitability and carbon stock indicators from a comprehensive tree-soil-crop interaction model.

Methods

The following steps will be taken:

1. Identify typical representatives of the generic land use classes (as developed for global ASB comparisons) in Northern Mindanao,
2. Parameterize the WaNuLCAS model for climate, soil, tree and crop parameters using secondary data to represent typical forms of a range of land use options; if necessary collect primary data,
3. Parameterize the WaNulCAS model for labour requirements and prices to allow profitability analysis,
4. Further develop the soil loss module in WaNuLCAS in cooperation with ICRAF to reflect soil and water conservation functions,
5. Meeting to discuss progress in model development and data collection,
6. Make model runs, summarize results and derive sustainability indicators for the main land use categories, and
7. Report-writing.

Role of partners

1. SEARCA (Dr. Felino P. Lansigan and Allan E. Dela Cruz)
- overall responsibility for all steps

2. UPLB Soils department (Dr. Ed Paningbatan)
- link with ongoing research on filter functions at landscape level; definition of land use systems, parameters for soil (and climate) properties

3. ICRAF S.E.Asia (Meine van Noordwijk, Betha Lusiana)
- participate in discussions to specify land use systems,
- backstopping on use of the WaNuLCAS model,
- partnership in developing an improved soil movement module for WaNuLCAS.

Budget (In US$)

Personnel	
Research Assistant (7-8 months)	5 000.00
Senior staff time	2 000.00
Travel Expenses	1 000.00
Miscellaneous (supplies and communication)	2 000.00
Administrative Cost (10%)	1 000.00
Total	**11,000.00**

WaNuLCAS, a model of water nutrient and light capture in agroforestry systems

WaNuLCAS was developed to represent tree-soil-crop interactions in a wide range of agroforestry systems where trees and crops overlap in space and/or time (simultaneous and sequential agroforestry). The model is based on above and below ground architecture of tree and crop, elementary tree and crop physiology and soil science. It can be used for exploring positive and negative interactions for different combinations of trees, crops, soil, climate and management by the farmer.

WaNuLCAS makes use of the STELLA modelling environment and thus allows users to modify parameters between simulations and add model structure and relations of specific interest. It can be used for teaching as well as research.

What's inside WaNuLCAS?

The model conceived as four layers of soil exploited by roots of two components (a crop and a tree). A simple vertical water balance is maintained on the basis of precipitation entering the top layer and drainage leaving the bottom layer. Water leaching downwards carries nutrients, based on the current average concentration in soil solution. Each layer of soil has its own potential uptake of water and nutrient; actual uptake is based on a comparison of the summed potential uptake from all layers and the current 'demand' as determined by the plant biomass. Plant growth is limited by light supply as well as the minimum of relative nutrient and relative water uptake. The two plants interact primarily via the belowground resources and also by shading.

WORLD AGROFORESTRY CENTRE (ICRAF)
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