# Soil erosion as an indicator of agricultural sustainability in tropical watersheds

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**Abstract**
A systems approach was utilised for operationalisation of the concept of agricultural sustainability. The process was prerequisite to deriving case- and site- specific sustainability indicators for agriculture-based tropical watersheds. The breakdown into functional units can be crucial for quantitative measurements of the degree of sustainability or could simply be valuable in developing alternatives to unsustainable farming practices. The most prominent indicator or measure of agricultural sustainability as determined from a causal loop diagram is the degree of erosion and runoff, which has also been identified by local stakeholders as the main driver of land degradation in their watershed area.

**Key Words**
Adaptive management, agriculture sustainability, erosion, systems analysis, socio-economics, tropical.

## Introduction

A universal framework for the assessment of agricultural sustainability can be elusive due to location specific conditions as well as differences in data availability. Moreover, outcome and results of sustainability studies are usually not transferable to other sites due to a wide range of spatial and temporal variables. A systems approach is a promising method being promoted to natural resource managers to deal mainly with the complexities of agri-environmental and socio-economic parameters as well as to address the issue of insufficiently available data (Grant *et al*., 1997). This study is an attempt to employ systems analysis in determining indicators for agricultural sustainability. Specifically, this exercise focuses mainly on the conceptual modelling of what constitutes agricultural sustainability in a mostly agriculture-based tropical watershed. The breakdown of the important factors (variables) and their structure (interactions, feedback loops and delays) are crucial in the operationalisation for a case and site specific meaning of agricultural sustainability. The derived conceptual model may then be utilised as a basis for identifying key variables and eventually the corresponding sustainability indicators where quantitative measurements can be implemented. Hence, the operationalisation for a case and site specific meaning of agricultural sustainability and its breakdown into functional units are the main objectives of this study. A whole systems model which holistically describes an agriculture-based watershed with the relationships and linkages of the different variables will be established. And finally, sustainability indicators that can be used for evaluating agricultural sustainability will be identified.

## Method

Preliminary logistics for this research were established during the project implementation of the Australian Centre for International Agricultural Research (ACIAR 2005) project LWR/2001/003, “Integrated watershed management for sustainable soil and water resources management of the Inabanga watershed, Bohol island, Philippines”. The results and findings of that project formed the basis for applying the so-called “systems approach” to gain a holistic view of the current situation for the Bohol study area.

### *Concept mapping*

A conceptual diagram was established, Figure 1, showing the complex interrelationships of factors (collective variables) potentially affecting sustainability in an agriculture-based watershed. Considering the collective variables, it is apparent that a key variable influencing agricultural sustainability is the ‘Farming System’ component. This is supported by the work of Ikerd (1993), which stated that sustainability depends on the nature of the whole farming system. An emphasis is also directed towards interventions that are practically attainable by local communities, who are the farmers themselves, hence encouraging participatory initiatives. As illustrated (Figure 1), the farming system dictates the type of land use that would develop across the watershed and also influences the infrastructure that would support it. Farm productivity is in turn, also a result of a suitable farming system in a given landscape with certain land qualities (climate, slope, soil type, *etc.*). Ultimately the farming system determines the degree of soil erosion and runoff which may threaten environmental quality.

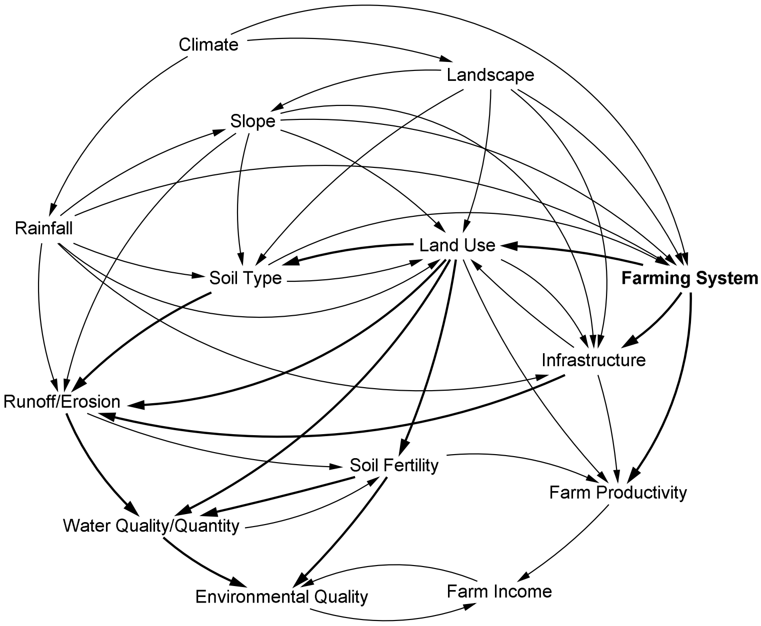


**Figure 1. Interrelationships of variables potentially affecting the sustainability in an agriculture-based watershed.**

*Participatory approach*

Participatory initiatives utilised as this approach promoted wider involvement and ownership. Consequently stakeholders were better prepared to adapt ideas and experiences (Kobus 2005; Magnuszewski *et al.,* 2005). Consultation of stakeholders' perception of agricultural sustainability was carried out using techniques in adaptive management, to explore and derive sustainable management options for the agriculture-based watershed systems. Implementing an adaptive environmental assessment and management (AEAM) process (Grayson *et al.,* 1994), achievable management actions that could address the perceived sustainability concept were tabulated (Table 1). Based on the stakeholders' insights, agricultural sustainability is attained when: (1) productivity is maintained in the long run, (2) resources are preserved, and (3) financial income of farmers is guaranteed. These management actions are predominantly in agreement with the ecological and economic arguments presented by von Wiren-Lehr (2001).

*Causal loop diagram*

Causal loop diagramming (CLD) is an effective method to generate conceptual models facilitating the interpretation of the system's structure, *i.e.* which variables are involved and how they are linked (Sendzimir *et al.,* 2007). Figure 2 shows a CLD which traces the interactions among factors of the farming system including socio-economic parameters, with the aim of addressing the highlighted stakeholders' sustainability goals from Table 1. In developing the CLD (Figure 2), it was considered that the number of farm families contributes to the amount of farm activities in the watershed, which consequently controls the farming area for the different combinations of cropping systems common in the study area. Non-farm commitments or employment are factors that can reduce farm activities. In general there is a direct correlation between farm area / crop diversity and security of income. The greater the farm area allocated to a number of different or combinations of cropping systems, the more potential for higher production, which can ultimately transform into a higher income for the farm families. This is true as long as standing crops are not significantly affected by natural calamities or major infestations occurring in the area. Also, favourable market conditions will always influence the financial income of farmers from produce. On the other hand, increasing farm area allocated for any of the cropping systems mentioned would imply more erosion and runoff within the watershed. This can be mitigated by employing erosion and runoff control measures into the cropping systems of choice or adopting only cropping systems that practice conservation techniques. Such control measures will also consume space within the farm area or essentially limit the choice of cropping systems to the farmers. Moreover, control measures will also involve additional farm inputs and thus incur extra expense at the outset. Selection of appropriate cropping systems or combinations thereof for a given farm area would be a function of local biophysical and socio-economic factors. Erosion and runoff will eventually contribute to further environmental problems like soil fertility and water quality/quantity issues, that will significantly result in negative feedback to crop production and eventually affect farmer's income in the long run. Other considerable environmental concerns that are affected by the choice and setting-up of the cropping systems include depletion of soil nutrients, increase in water requirements, and destruction of natural ecosystems.

**Table 1. Management actions as perceived by the stakeholders to achieve agricultural sustainability and its corresponding long-term goals (participatory inputs).**

| Management action | Perceived sustainability goal |
|---|---|
| **Significant reduction of soil erosion** | Resource preservation |
| Reforestation and/or vegetative cover on open areas | |
| Ploughing along the contours on sloping lands | |
| Alternative cropping for corn/cassava cultivation | |
| Alley cropping to minimise runoff on sloping lands | |
| Use of vegetative strips to stabilise slopes | |
| Higher planting densities | |
| Maintenance of cover crops on bare areas | |
| Other Sloping Agricultural Land Technology (SALT) activities | |
| **Minimise nutrient loss from top soil** | Resource preservation & Productivity maintenance |
| Crop rotation for high nutrient-depleting crops | |
| Use of legumes for nutrient replenishment to soil | |
| Utilisation of crop residues | |
| Growing of cover crops for organic matter residues | |
| Application of organic fertiliser | |
| **Improved cropping strategies** | Productivity maintenance |
| Inter-cropping with cash crops | |
| Allocation of different crops in a farm (diversifying) | |
| Multi-story farming and/or agro-forestry | |
| **Management of water quantity and quality** | Resource preservation & Productivity maintenance |
| Irrigation on serviceable areas | |
| Construction of small farm reservoir | |
| Responsible use and disposal of chemicals and pesticides | |
| Road bank and stream bed stabilisation | |
| **Provision of support services** | Guarantee of farm income |
| Road access | |
| Efficient agricultural extension services | |
| Irrigation services | |
| Availability of farm inputs | |
| Loans and funding support | |
| Marketing assistance | |
| **Sustained farm family income** | Guarantee of farm income |
| Engage in other income generating activities (non-farm) | |

## Conclusions

As a result of the systems approach presented above, an operational meaning based on case and site specific conditions was derived for agricultural sustainability. It is determined by an appropriate combination of cropping systems employing suitable erosion and runoff interventions that could help preserve soil and water resources while sustaining agricultural productivity and consequently ensuring financial income of farmers. Therefore, the primary indicator or measure of agricultural sustainability in this case, would be determined by the degree of erosion and runoff as it is the main driver towards land degradation. The breakdown into functional units can be crucial for quantitative measurements of the degree of sustainability or may simply be valuable in developing alternatives to unsustainable farming practices.

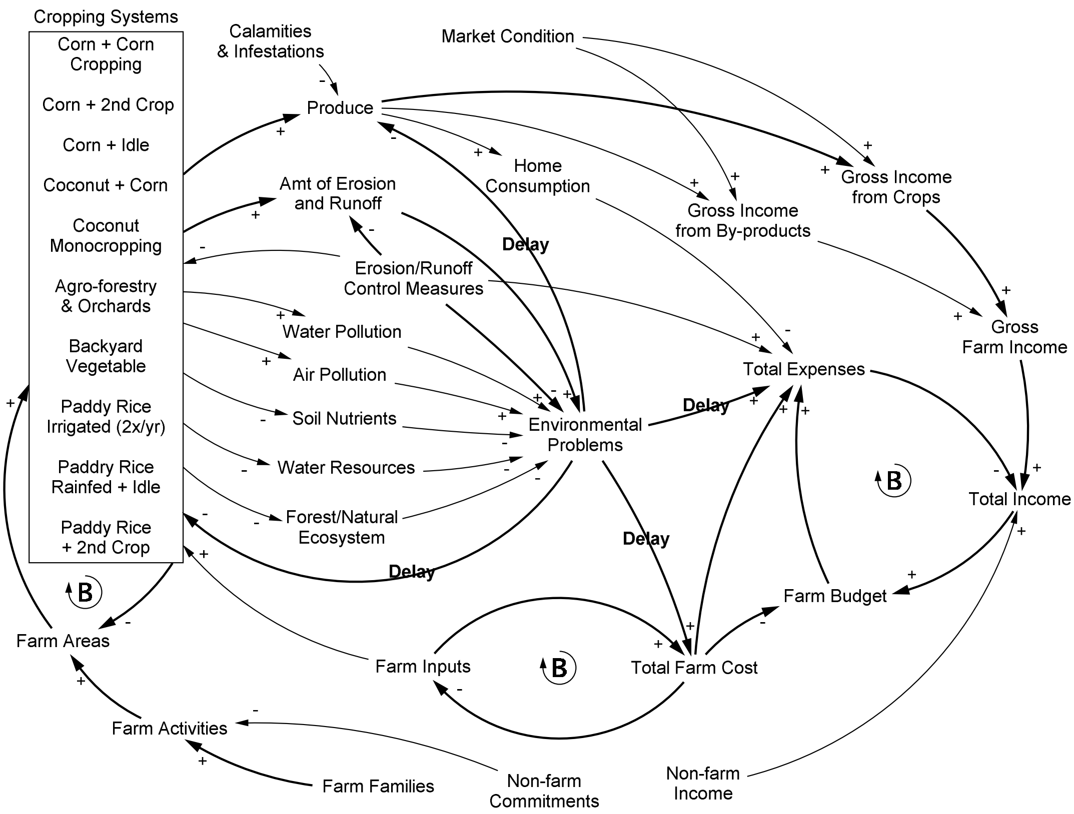


**Figure 2. Causal loop diagram of farming system variables addressing agricultural sustainability goals. Darker arrows signify dominant routes or loops. Coiling arrows with a "B" symbolise balancing loops in the system.**

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