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A bioeconomic analysis of the potential of Indonesian agroforests as carbon sinks

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ABSTRACT

Agroforests managed by smallholders have been shown to provide biodiversity, carbon-storage and rural-livelihood services. Consequently, these systems are being promoted as an effective way of rehabilitating millions of hectares of degraded, formerly forested land in many tropical countries. Current conditions at the forest margins in these countries, however, make it easier to clear unprotected forests than restore degraded lands through agroforestry. The result is large-scale deforestation that causes substantial losses of biodiversity and stored soil and biomass carbon. Agroforests will only be an attractive activity if they are financially viable and socially acceptable. In this study we investigate the financial viability of agroforestry systems as carbon sinks when carbon-credit payments are available. A meta-modelling framework is adopted, comprising an econometric-production model of a land parcel in Sumatra, Indonesia. The model is used within a dynamic-programming algorithm to determine optimal management of the system in terms of three decision variables: tree/crop area, tree-rotation length, and wood harvest. Results show the influence of soil-carbon stocks and discount rates on optimal strategies and reveal interesting implications for joint management of agriculture and carbon as well as for the possible restoration of degraded land.

1. Introduction

Large-scale deforestation and land degradation cause substantial losses of stored soil and biomass carbon which contribute to climate change (Sampson and Scholes, 2000; Fearnside, 2001). Agroforestry systems[1] can contribute to climate mitigation by sequestering atmospheric carbon, while helping to maintain productivity and meet local cultural requirements (Smith and Scherr, 2003; Makundi and Sathaye, 2004). Albrecht and Kandji (2003), for example, estimate the carbon sequestration potential of agroforests to be between 12 and 228 $\mathrm{Mg\,ha^{-1}}$ (with a median value of 95 $\mathrm{Mg\,ha^{-1}}$) with between 585 and 1215 million ha of the earth's area suitable for agroforestry. Oelbermann et al. (2004) emphasise that the capacity to sequester carbon varies globally and estimate the biomass-carbon sequestration potential of agroforestry to be approximately 2.1×10^9 Mg C year^{-1} in tropical biomes and 1.9×10^9 Mg C year^{-1} in temperate biomes. However, much of the land in the tropics is managed by semi-subsistence farmers and shifting cultivators, so their willingness to participate in carbon-sequestration projects may be an important factor to consider when designing reforestation programs (de Jong et al., 2000).

The economics of agroforestry systems in the presence of incentives to sequester carbon has been studied by authors

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[1] Agroforestry systems are agricultural lands where trees have been introduced and judiciously managed together with crops and/or animals (Albrecht and Kandji, 2003).

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such as de Jong et al. (2000, 2004), Shively et al. (2004), Cacho et al. (2003, 2004), and Seeberg-Elverfeldt et al. (2008) among others. The effects of management, technologies and risk on tree-based systems have been studied through bioeconomic modelling by Grist and Menz (1996), Nelson et al. (1998) and Predo and Francisco (2008) among others. We contribute to this literature by focusing on the financial viability of smallholder agroforestry systems in the presence of carbon payments, subject to constraints of soil and biomass carbon dynamics over the long term. Two articles of the Kyoto Protocol provide the policy context for the analysis presented here: Article 3.3 (Land-use, Land-use Change and Forestry) and Article 12 (the Clean Development Mechanism). These articles are designed to give incentives to developed countries to invest in greenhouse-gas mitigation activities in developing countries to help meet their Kyoto emission limitations (UNFCCC, 1997). Allowable activities include terrestrial carbon sinks such as small-scale forestry and agroforestry.

The uptake of land-based activities involving carbon sinks within the CDM has been low relative to energy efficiency projects, representing less than 1% of registered Certified Emission Reductions (CERs) by early 2009 (Kossoy and Ambrosi, 2010). Reasons for the low uptake of projects involving sinks under the CDM include the complexity of rules for certification (Henman and Hamburg, 2008), uncertainty about permanence of the carbon sequestered, and concerns over accuracy of monitoring (Capoor and Ambrosi, 2009). In the case of projects that involve smallholders, other barriers include risk to food security, high capital costs combined with lack of access to credit, and missing or poorly defined property rights (Lipper and Cavatassi, 2004). There is evidence, in cases where markets for agricultural output, labour, credit, or land are absent, or where the transaction costs are excessive, that households' accommodate these constraints by linking their production and consumption decisions to meet their multiple objectives of food security, income and leisure (de Janvry et al., 1991; Holden, 1993; Vosti et al., 2002).

While we acknowledge that the smallholders of our study area may not be able to maximise profit due to production constraints, financial viability is a necessary condition to make a production system attractive, and profit is an important component in the objective function of farmers (Tomich et al., 1998: 59). Furthermore, investor-driven projects, such as those funded by the Biocarbon Fund (World Bank, 2002) and the Global Environment Facility (GEF, 2000) are subject to acceptability restrictions. These include secure land tenure; local government and policy support; infrastructural and technical support; linkages to input and output markets; the enhancement of tree management skills; and transparent and equitable relationships between project partners (Smith and Scherr, 2003; Roshetko et al., 2007). Such projects would provide the enabling conditions for smallholders to adopt agroforestry based on profit motives and they give legitimacy to our approach. Milder et al. (2010) provide examples of carbon-sequestration projects that have been successful at enhancing local livelihoods because they have been both profitable and socially acceptable.

This study is conceptually based on a production possibility frontier (PPF) representing the tradeoffs facing landholders with fixed resources and technologies to produce bundles of products from two land uses, trees (Y_1) and crops (Y_2) (Fig. 1). The optimal combination of Y_1 and Y_2 is determined by the price ratio p_1/p_2. If the present value of crop outputs exceeds the present value of tree outputs, the optimal point is likely to be located closer to the vertical axis (point E_1) reflecting the current situation in much of south-east Asia where slash-and-burn practices and shifting cultivation are widespread (Wise and Cacho, 2008). If the external environmental benefits provided by trees are internalised through direct payments for sequestered carbon the price ratio (p_1/p_2) will increase and landholders are more likely to plant a larger area of their land to trees (point E_2, Fig. 1).

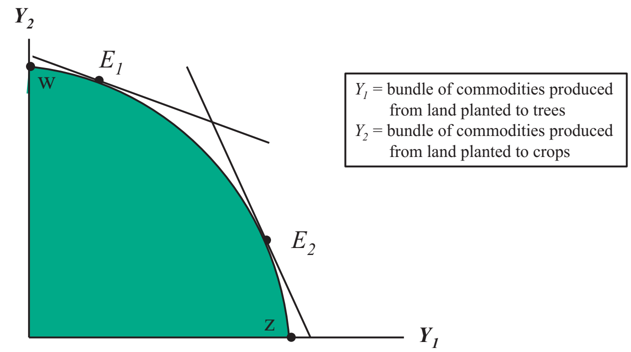

Fig. 1 – Pareto efficient production possibilities of landholders when (1) not receiving payments for positive environmental externalities and (2) when positive external effects are internalised through carbon-sequestration payments.

This paper builds on the study of Wise and Cacho (2008), who found that the planting decisions that maximise profit are driven by soil quality. In degraded soils, it pays to plant trees to improve soil quality when carbon payments exist. But as soil quality improves, there is a point where it becomes optimal to switch from trees to crops and to not participate in carbon trading. In this study, we identify profit-maximising land-management strategies for cases where nitrogen-fixing trees provide an alternative to inorganic fertilisers. We assume that soil fertility can only be improved through nitrogen-fixation of plants and the addition of organic matter. This represents a system that is sustainable and does not require purchased fertiliser.

2. Study area: Jambi Province, Sumatra

The Jambi Province of southern Sumatra, Indonesia, provides our case study. Jambi is situated in the humid tropics and is largely covered by Sumatra's broad 'peneplain' agro-ecological zone. It is almost flat land, less than 100 m above sea level, and is divided into a lowlands area (10%) made up of river levees and floodplains with fertile alluvial soils; and an uplands area (90%) with a gently undulating landscape (slopes of 5–17%) (Tomich et al., 2001).

This region is one of the alternatives to slash-and-burn (ASB) benchmark sites and represents the equatorial rain-forests of south-east Asia where primary forests are being