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Biomass production in agroforestry and forestry systems on salt-affected soils in South Asia: Exploration of the GHG balance and economic performance of three case studies

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ABSTRACT

This study explores the greenhouse gas balance and the economic performance (*i.e.* net present value (NPV) and production costs) of agroforestry and forestry systems on salt-affected soils (biosaline (agro) forestry) based on three case studies in South Asia. The economic impact of trading carbon credits generated by biosaline (agro)forestry is also assessed as a potential additional source of income. The greenhouse gas balance shows carbon sequestration over the plantation lifetime of 24 Mg CO_2-eq. ha^{-1} in a rice-*Eucalyptus camaldulensis* agroforestry system on moderately saline soils in coastal Bangladesh (case study 1), 6 Mg CO_2-eq. ha^{-1} in the rice-wheat- *Eucalyptus tereticornis* agroforestry system on sodic/saline-sodic soils in Haryana state, India (case study 2), and 96 Mg CO_2-eq. ha^{-1} in the compact tree (*Acacia nilotica*) plantation on saline-sodic soils in Punjab province of Pakistan. The NPV at a discount rate of 10% is 1.1 k€ ha^{-1} for case study 1, 4.8 k€ ha^{-1} for case study 2, and 2.8 k€ ha^{-1} for case study 3. Carbon sequestration translates into economic values that increase the NPV by 1–12% in case study 1, 0.1–1% in case study 2, and 2–24% in case study 3 depending on the carbon credit price (1–15 € Mg^{-1} CO_2-eq.). The analysis of the three cases indicates that the economic performance strongly depends on the type and severity of salt-affectedness (which affect the type and setup of the agroforestry system, the tree species and the biomass yield), markets for wood products, possibility of trading carbon credits, and discount rate.

1. Introduction

Salt-affected soils are an important category of degraded soils, both with respect to their large global extent and the severe effects that soil salinity and sodicity have on agricultural productivity. Worldwide, approximately one billion hectares of land are salt-affected (Wicke et al., 2011), of which approximately 76 million hectares (Mha) are affected by human-induced salinization and sodification (Oldeman et al., 1991). As a result of inappropriate irrigation management, salinization and sodification of land continue to occur at an estimated rate of between 0.25 and 0.5 Mha each year (FAO, 2000). In South Asia, salt-affected soils and their continuous expansion are a particularly important concern because already scarce land resources are facing rapidly increasing demands for food, feed, and fuel. The large extent of salt-affected soils is all the more problematic given the fact that soil salinity and sodicity greatly reduce agricultural productivity. There are three types of salt-affected soils (saline, sodic, and saline-sodic soils), affecting agricultural productivity by hampering water extraction by plant roots (the osmotic effect), causing cell injury (the specific ion effect) and/or deteriorating the physical properties of the soil (Abrol et al., 1988; Ghassemi et al., 1995; Lamond and Whitney, 1992; US Salinity Laboratory, 1954). In addition, the often co-existing waterlogging (which can be a cause or a result of the soil salinity/sodicity) reduces oxygen availability in the soil, which further slows growth (Barrett-Lennard, 2003).

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0.1. Conventional agriculture on severely salt-affected land is generally not economically viable because agricultural crop yields are low and physical remediation of the salts is often prohibitively expensive for most farmers (Ghaly, 2002; Qadir and Oster, 2004; Qadir et al., 2002). However, forestry and agroforestry systems on salt-affected soils (hereafter referred to as biosaline (agro)forestry systems) may be an alternative land use option. This is because some tree species are less susceptible to soil salinity/sodicity, and their cultivation can help regenerate these soils (Bell, 1999; Lambert and Turner, 2000; Singh et al., 1994). Examples of species tolerant to soil salinity, soil sodicity, or both are *Acacia nilotica (A. nilotica)*, *Eucalyptus camaldulensis (E. camaldulensis)*, *Eucalyptus tereticornis (E. tereticornis)*, and *Prosopis juliflora (P. juliflora)* (Marcar and Crawford, 2004; US National Research Council, 1990). Some tree species have adapted to waterlogging conditions by developing root air channels (aerenchyma) and adventitious (nodal) roots. Examples are *Casuarina obesa*, *Tamarix aphylla* and *E. camaldulensis* (Barrett-Lennard, 2002, 2003).

Although many examples of research on biosaline (agro) forestry systems in South Asia and worldwide exist (*e.g.* Bell (1999), Kaur et al. (2002a), Marcar and Crawford (2004), Masters et al. (2007), Qadir and Oster (2002), Zhang et al. (2004)), only a few studies have evaluated the economic performance of such systems (*e.g.*, Singh et al., 1997, 1994; Stille et al., 2011). These studies focused on sodic soils and found agroforestry systems to be an economically viable land use option. However, little is known about the economic performance of biosaline (agro)forestry on other types of salt-affected soils in South Asia such as saline soils, saline-sodic soils and waterlogged salt-affected soils. These may perform differently from sodic soils as a result of differences in the management systems, particularly the establishment activities and species planted.

With respect to the environmental performance of biosaline agroforestry, previous studies have focused on the ameliorative effects of trees on soil salinity/sodicity and on soil organic carbon content (*e.g.* Kaur et al. (2002b), Lal (2009), Qadir and Oster (2002), Singh et al. (1988), and Wong et al. (2009)), but have not studied other environmental impacts. In particular, the greenhouse gas (GHG) balance of such systems has not been assessed despite their potential to sequester carbon through revegetating degraded sites and the potential economic benefits from trading carbon credits from biosaline (agro)forestry projects. An analysis of both the economic and environmental performance of these systems is important for a better understanding of the economic potential of bioenergy from salt-affected soils (Wicke et al., 2011) and the GHG mitigation potential of biosaline (agro)forestry in South Asia.

The present study was carried out with the main objective to explore the GHG balance of biosaline (agro)forestry on different types of salt-affected soils in South Asia and their economic performance (in terms of the net present value (NPV) and the production costs (COP)). The economic impact of trading carbon credits generated by biosaline (agro)forestry is also estimated as a potential additional source of income. Three case studies were conducted in order to capture the effect of different site conditions (particularly the different types and severity levels of salt-affected soils) and production systems and to explore crucial factors influencing the performance. Each case study analyses a biosaline (agro)forestry system in a different setting: 1) a rice-tree agroforestry plantation on coastal saline soils in Bangladesh, 2) a rice-wheat-tree agroforestry plantation on waterlogged, salt-affected soils in India, and 3) a forestry plantation on saline-sodic soils in Pakistan.

2. Material and methods

2.1. Case studies

Three case studies of biosaline (agro)forestry were assessed, which have climate and soil conditions representative for many salt-affected areas in South Asia: Case study 1 (Bangladesh) has a humid, monsoonal climate and soil salinity is induced by sea water intrusion. Case study 2 (India) and 3 (Pakistan) have a semi-arid monsoonal climate and irrigation-induced soil salinity-sodicity problems. In addition, case study 2 is affected by waterlogging.

Case study 1 is a theoretical case based on a combination of 1) the currently most common agricultural land use in the coastal belt (rice production during the monsoon season) and 2) results from existing coastal reforestation projects. This case was constructed because biosaline agroforestry is not currently common practice in coastal Bangladesh although it may provide financial and environmental benefits to the farmers. Case study 2 and 3 are based on existing agroforestry and forestry plantations in India and Pakistan, respectively. An overview of the three cases and their main characteristics are given in Table 1.

2.1.1. Case study 1: coastal saline soils in Bangladesh

In Bangladesh, 1 Mha of land are salt-affected, mostly in the coastal zone of the Ganges – Brahmaputra River Delta. Sea water intrusion is the main cause of soil and water salinity (Hossain, 2010). Although sea water intrusion is a natural phenomenon at the coast, it is enhanced by overexploitation of freshwater resources and sea level rise. In coastal Bangladesh salinity is seasonal. During the dry season (especially the later part), water levels are low as a result of overexploitation and natural seasonal fluctuations in water levels. Sea water intrusion then reaches further inland, soil water evaporates, and salts build up in the soil. With the monsoonal rains, the (majority of the) salts are washed away again, rendering the soils non-saline or only slightly saline for a few months. In addition to the salinity problem, coastal areas in Bangladesh are often characterized by low soil fertility and affected by droughts in the dry season, when good quality irrigation water is not available or too expensive for small farmers (Haque, 2006). The seasonality of the salinity problem and low soil fertility in coastal Bangladesh allow the cultivation of rice only during the wet season while in non-salt-affected regions two or even three cropping seasons are possible.

The case study examines an agroforestry system that is constructed based on a combination of 1) the currently most common agricultural land use in the coastal belt (rice production during the monsoon season) and 2) results from existing coastal reforestation projects. The location is assumed to be in the coastal zone of Khulna Division, which is one of the areas most affected by sea water intrusion and resulting soil salinity.

Local Aman rice is transplanted during the monsoon (July and August) and harvested in November and December when soil salinity is low. A traditional, manual labour-intensive cultivation is typical in this region and assumed in this study. The rice fields are intersected by tree lines. Assuming a square field of 1 ha, there are two lines, where each line has two rows of trees, and each row accounts for 50 trees. Thus, the tree spacing is 2 m by 2 m, the tree density is 200 trees per hectare, and the tree lines cover 8% of the land. *E. camaldulensis* is a common species in coastal Bangladesh and is known for its salt-tolerance (Marcar and Crawford, 2004). It is assumed to be grown in this agroforestry system. The establishment of the trees at the beginning of the monsoon season includes field levelling, ploughing, holing, fertilizer application, and planting of the six month-old seedlings. Maintenance in the following years includes canopy manipulation and pruning,