The potential of oil palm and forest plantations for carbon sequestration on degraded land in Indonesia

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1 INTRODUCTION

Climate change and global warming are among the most challenging environmental, economic and social issues worldwide. Global temperatures have increased by 0.3-0.6 °C over the past 100 years and are expected to increase by a further 1-3.5 °C by 2100, accompanied by changes in precipitation, storm patterns, and drought frequency and intensity (Santer *et al.* 1996; Kattenberg *et al.* 1996). Global warming, which has been associated with an unprecedented increase in atmospheric greenhouse gas concentrations, is expected to lead to negative impacts on valuable ecosystems, increased intensity and frequency of heat waves, and other climatic-related disasters as well as crop failures and freshwater scarcity.

One of the most prominent anthropogenic-induced greenhouse gases is carbon dioxide (CO_2), contributing to more than 51% of the global warming. The level of atmospheric CO_2 has increased from 280 ppm in 1800 to a present more than 360 ppm. The atmosphere now contains about 760 Pg of carbon (C) as CO_2. The annual global CO_2 emission in the 1990s was 6.3 ±0.4 Pg C yr^{-1} (1 Pg = 10^{15} g). While most was derived from the burning of fossil fuel (IPCC 2001), land-use change, mainly tropical deforestation, also contributed an estimated 1.6 Pg C yr^{-1} (Houghton 1999). However, atmospheric C represents less than 30% of the C in terrestrial ecosystems. Vegetation contains nearly 500 Pg C, while soils contain another 2000 Pg C in form of organic matter and detritus (Schimel 1995; WBGU 1998; IPCC 2000).

Terrestrial ecosystems play an important role in regulating the abundance of atmospheric CO_2. Of the 406 Pg of C emitted during the period 1850 to 1998, 270 Pg C were derived from fossil fuel combustion and cement production, and 136 Pg C were emitted through land-use activities (IPCC 2000). Of these emissions, roughly 110 Pg C were absorbed back into terrestrial ecosystem sinks and about 120 Pg C were absorbed by oceans. The rest (176 Pg C) accumulated in the atmosphere. Thus, it is evident that there is a need to reduce atmospheric CO_2, and other greenhouse gases (GHGs) and that policy measures must take into account the role of terrestrial ecosystems (IPCC 2000).

There are great opportunities in forestry, agriculture, and other sectors for mitigating further increases in the atmospheric C pool. The options vary by social and economic conditions. Slowing or halting deforestation, improved natural forest

management practices, afforestation, and reforestation of degraded forests and wastelands are the most attractive opportunities in the forestry sector (IPCC 2001). All activities leading to the preservation or enhancement of the existing terrestrial C pools, or to the prevention of an increase in atmospheric C pools such as the use of biomass to offset fossil fuel use should be the main focus of GHG mitigation projects. Some practical examples of mitigation strategies include fire or insect control, forest conservation, establishing fast-growing stands, changing silvicultural practices, planting trees in urban areas, ameliorating waste management practices, managing agricultural lands to store more C in soils, improving management of grazing lands, and replanting grasses or trees on cultivated lands (IPCC 2001).

In the case of terrestrial C sinks, a forest ecosystem transforms atmospheric CO_2 into C stock components (trees, roots, other vegetation, litter, and soil organic matter). Even though C stored in forests may ultimately be released through natural or anthropogenic disturbances, forest-C sequestration has been identified as one of the most promising options to reduce the build-up of atmospheric CO_2 (Dixon et al. 1993; Sampson and Sedjo 1997; Marland and Schlamadinger 1999). IPCC (1996) estimated that 700 Mha of forestland might be globally available for C conservation. Of that, 138 Mha might be available for slowed tropical deforestation, 217 Mha for regeneration of tropical forests, and 345 Mha for plantations and agroforestry. By 2050, a cumulative mitigation impact of 60 to 87 Pg C due to improved forest management could be expected, 45 to 72 Pg C of this is likely to occur in the tropics. Towards the end of this time interval, the mitigation impact could approach a maximum rate of 2.2 Pg C/yr (IPCC 2001).

Notwithstanding the debate as to whether global forests are sources or sinks of greenhouse gases (Pelley 2003; Harmon 2001; Metting *et al.* 2001; Schimel *et al.* 2001; Lal and Singh, 2000; Ravindranath *et al.* 1997), managed fast-growing forests may enhance C sequestration (Lee *et al.* 2002; Ney *et al.* 2002; Metting *et al.* 2001; Papadopol 2000). Silvicultural strategies aiming at accelerating the stand growth are likely to increase the rate of C sequestration of the respective forests (Lee *et al.* 2002; Chen *et al.* 2000; Montagnin and Porras 1998).

Plantation of trees and perennial crops on degraded and marginal lands is likely to be an effective way to enhance the build-up of terrestrial C pools. These

plantations promote C sequestration not only in the biomass but also in deep soils. However, there is little information on the potential C sink that could be attained by conversion of degraded lands (such as *Imperata cylindrica* grasslands) into specific tree plantations such as *Acacia mangium* and oil palm.

About 7.5-8.5 million ha of *I. cylindrica* grasslands are distributed on various islands in Indonesia (Garrity *et al.* 1997; Soekardi *et al.* 1993), an area that has been identified to have low economic and ecological values. In line with the extensive expansion of oil palm and forestry plantations (mainly in Sumatra and Kalimantan) planned by the government, conversion of these lands into plantations would be a promising option.

The oil palm as a perennial crop has become important in Indonesia, firstly, as a major source of oils and fats for human food, secondly, as animal feeds, and thirdly, for the manufacture of many domestic products such as cosmetics, soap and detergents. The establishment of large-scale monoculture oil palm plantations in Indonesia began in 1985 over an area of about 600.000 ha. In 1999, the area had expanded to about 3 million ha (Glastra *et al.* 2002; Wakker 2000).

Plantations of fast-growing species have been rapidly increasing in Asia in recent years (Cossalter and Pye-Smith, 2003). *Acacia mangium* is one of the most common fast-growing species in the humid tropics. *Acacia mangium* used to be planted primarily for site rehabilitation; however, due to its rapid growth and tolerance of very poor soils, this species is playing an increasingly important role in efforts to sustain commercial supplies of tree products while reducing pressure on natural forest ecosystems. Its quick growth and dense shade make the tree an effective tool in reforesting *Imperata* grass swards and reducing fire risk (Nitrogen Fixing Tree Association, 1987). It has been reported that this species has a great potential with regard to unproductive and degraded lands such as those infested by *I. cylindrica* (Otsamo 2002; Hardiyanto *et al.* 1999; Otsamo *et al.* 1997).

The main goal of this study is to evaluate the potential C sink that could be achieved by conversion of *I. cylindrica* grasslands into plantations (*Acacia mangium* and oil palm). Furthermore, this study aims at quantifying the C pool and distribution of the plantation systems (*Acacia mangium* and oil palm) and *I. cylindrica* grasslands. The

rate of biomass and C accumulation of the plantations was estimated from a false time series sampling.

Field experiments were conducted on two islands in Indonesia (Sumatra and Kalimantan) between 2002 and 2004. In Sumatra, observation was conducted in the provinces North Sumatra and Jambi and in the province East Kalimantan in Kalimantan.

The thesis consists of seven chapters. Following the introduction in Chapter 1, Chapter 2 provides the site description, and chapters 3, 4 and 5 present the analyses of biomass and C distribution of *I. cylindrica* grassland, *Acacia mangium* and oil palm plantations, respectively. A general discussion on the biomass and C stored in the two plantation systems and *I. cylindrica* grasslands is presented in Chapter 6, and the overall conclusions and recommendations are given in Chapter 7.

2 SITE DESCRIPTION

The study was conducted on the two Indonesian islands of Sumatra and Kalimantan. The sites were selected based on the abundance of the *I. cylindrica* grasslands and the plan for the establishment of plantations in these regions.

2.1 Sumatra

The study was carried out in two provinces of Sumatra, i.e., North Sumatra for the 20- and 30-year-old oil palm plantations and Jambi in south Sumatra for the 3- and 10-year-old oil palm plantations. North Sumatra is located between 0° 04' and 4° 11' north latitude and 97° 53' and 100° 13' east longitude, and Jambi 0° 45' and 2° 25' south latitude and 101° 10' and 104° 55' east longitude (Anonymous 1997).

Altitudes in North Sumatra and Jambi range from 0-250 m asl near the coast to more than 1500 m asl inland. The geomorphology of these regions is flat to undulating near the coast and rolling to mountainous in the upland of the Bukit Barisan mountains. The geomorphology of these regions affects the rainfall pattern, leading to high local variation in rainfall distribution. Based on the Schmidt and Ferguson classification, climate types A to E are found, with annual rainfall ranging from less than 1500 mm to more than 4500 mm. The plots in the study area were all located in climate type A.

The climate of the island of Sumatra is humid tropical, being classified as Af according to the Köppen classification (Köppen 1931) or as humid forest according to the FAO (2001). In the lowlands, the annual average temperatures are 26-27° C. Daily maxima range from 30° C to 36° C and daily minima are around 22° C. However, the more specific climate of the study region is classified according to Köppen as Aafw – a tropical rainy isothermal climate with hot summers (hottest month more than 22°C), without a dry season (mean precipitation in driest month more than 60 mm) and two rainfall maxima (February-April and October-December). Monthly rainfall and temperature distribution of this site are presented in Figure 2.1.

The soils of Sumatra have developed under year-round high temperatures and precipitation and are highly weathered and leached. These soils have low cation-exchange-capacities, high acidity and shallow top-soils. However, in areas with volcanic ash or alluvial deposits, soils of higher fertility are found. Most of the soils in

the lowland areas are fine textured and are well drained and highly weathered (BPN 1993). In some cases, these soils are derived from acid volcanic tuff sediments and have high Al saturation. Kaolinitic clay minerals dominate the clay fraction of the soils.

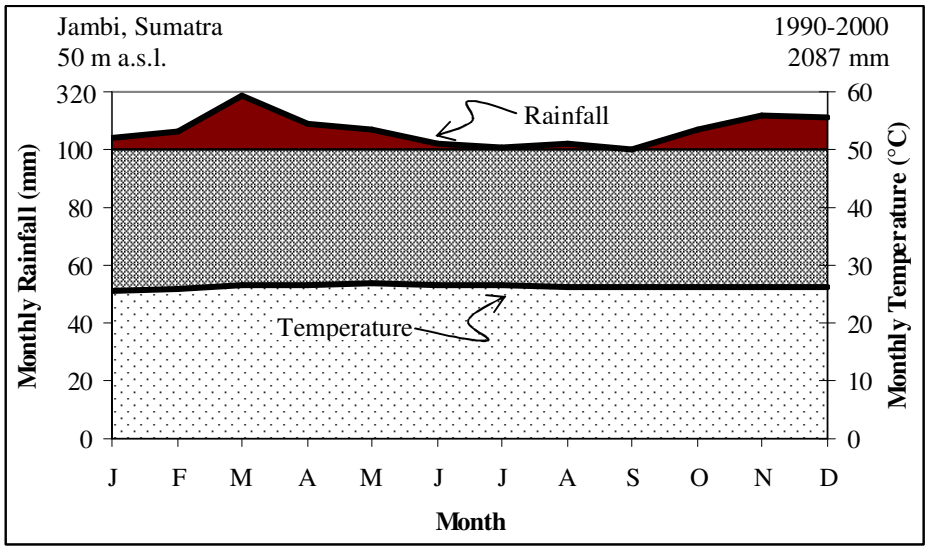

Figure 2.1: Monthly rainfall and temperature curves of study sites in Jambi, south Sumatra

The soils of the study site are Typic Hapludults, characterized by low fertility, clay loam and silty clay texture for the upper and lower soils, respectively. The drainage of the soils is moderately good (slightly slow) to good, the effective soil depth of 50-100 cm and solum depth more than 1 m (PMP-SMART 2001).

2.2 East Kalimantan

East Kalimantan lies between 115°26'28" - 117°36'43" east longitude and 1°28'21" north latitude - 1°08'06" south latitude. Similar to the Sumatra sites, the climate in East Kalimantan is classified as Aafw (Bremen et al., 1990; Ohta *et al.* 1992), i.e., a tropical rainy isothermal climate with hot summers (hottest month more than 22°C), without a dry season (mean precipitation in driest month more than 60 mm) and two rainfall maxima (April-May and December-January). The mean annual rainfall ranges between approximately 2000 mm in the north and 2500 mm in the south (Voss 1982). Mean monthly temperature is 27°C (RePPProT 1987). Highest daytime temperatures of 35°C

and lowest nighttime temperatures of 19°C have been recorded (Voss 1979). Mean monthly temperature and rainfall are depicted in Figure 2.2.

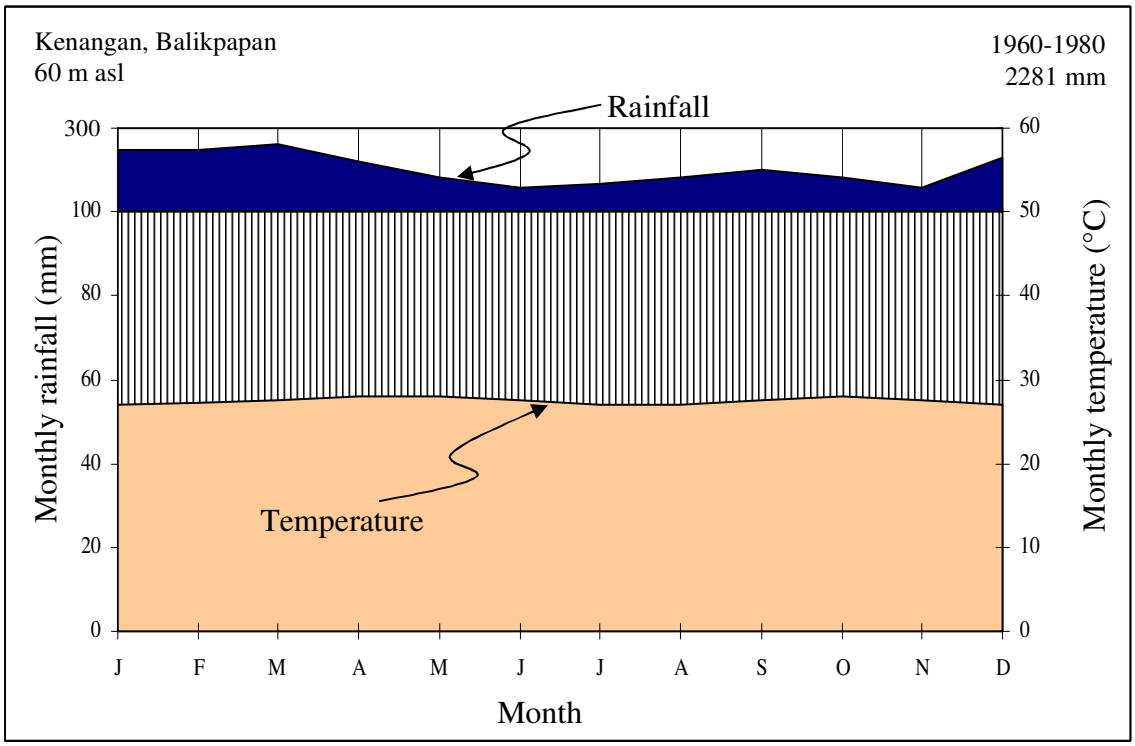

Figure 2.2: Temperature and rainfall curves of East Kalimantan

The eastern part of the province belongs mainly to the physiographic region of the Kutai Valley and Ridge Fold Belt. This region is dominated by systems of high, rugged, strongly folded and faulted mountains, hogbacks and cuestas, piedmont areas, low mountains and rugged hills, and undulating plains (Voss 1982; and Ohta 1992). However, the physiography of the western part of this province is rather smooth with altitude ranging between 50 and 1500 m as1.

The soils in this region have developed from the middle-late Miocene and early Miocene rocks dominate the geology of the province. These rocks have a thickness of approximately 2100 m to 8000 m. The middle-late Miocene rock consists mainly of muddy sandstone and mudstone. Coal layers are also abundant. Early Miocene rocks are largely calcareous mudstones with interbedded limestone, coaly sandstones and occasional tuff beds (Voss 1983; and Ohta *et al.* 1992).

Typic Paleudults and Typic Hapludults are the major soils in the region (Bremen *et al.* 1990 and Ohta *et al.* 1990). However, besides Entisols, Inceptisols and

Spodosols, Aquic Paleudults and Aquic Hapludults can also be found (Bremen *et al.* 1990 and IHM 1989)

The Ultisols have a mixed clay mineralogy consisting of kaolinite, chlorite/vermiculite and oxides of aluminum and iron. Small amounts of mica are reported by Kawana (1976). Sand and silt fractions are dominated by quartz Ruhiyat (1989). Soil properties of the Sumatra and East Kalimantan are presented in Table 2.1.

Table 2.1: Soil properties of top- and subsoil in study sites in Sumatra and East Kalimantan, Indonesia

Parameter	Sumatra		East Kalimantan	
	Topsoil	Subsoil	Topsoil	Subsoil
Soil type (USDA)	Typic Paleudults		Typic Paleudults	
Soil texture (pipette)	SL-SiCL	SC-C	SL-SiCL	CL-C
pH (H_2O)	4.3	4.4	4.3	4.4
Organic C (mg g^{-1}, dry combustion)	15.4	3.9	16.0	6.0
Total N (mg g^{-1}, dry combustion)	1.4	0.4	1.6	0.9
Available P (mg kg^{-1}, Bray II)	5.8	3.4	7.6	2.6

3 *IMPERATA CYLINDRICA* GRASSLANDS: BIOMASS AND CARBON DISTRIBUTION

3.1 Introduction

Low income, inappropriate technology, low input and poor understanding regarding land management have led to huge areas of deforested land in the tropics. In many cases, farmers with land adjacent to forest zones cleared the forests and converted the land into agricultural land to meet their subsistence needs. Due inappropriate land management systems, much of this area has been abandoned and invaded by *I. cylindrica,* the most common weed in the tropics. Today, *I. cylindrica* covers an area of more than 8.5 million ha in Indonesia alone (Garrity *et al*. 1997; Soekardi *et al*. 1993).

Imperata cylindrica is a perennial, rhizomatous grass and reproduces from seed and rhizomes; however, flowering is rare and generally occurs only after human disturbance or stress (Sajise 1972). The plant is stemless, growing in loose to compact tufts with slender, flat, linear-lanceolate leaves from the rhizomes (Hubbard *et al*. 1944). It is a serious pest throughout the tropical and subtropical regions and ranked as the seventh most troublesome weed worldwide (Holm *et al*. 1977). *Imperata cylindrica* has been reported to compete for nutrients, light, and water, and cause physical injury to neighboring plants through rhizomes penetrating the roots of these plants (Boonitee and Ritdhit 1984; Eussen and Soerjani 1975; Jagoe 1938). Furthermore, *I. cylindrica* has low nutritional values due to the high C/N ratio, and high lignin and polyphenol contents (Hartemink and O'Sullivan 2001).

The persistent and aggressive rhizomes of *I. cylindrica* are the main mechanism for survival and local spread, which makes the weed difficult to control. *I. cylindrica* is able to invade areas that will not support other vegetation, as it can tolerate a wide range of soil and climatic conditions (Hubbard *et al*. 1944; Eussen and Wirjahardja 1973).

Shade, repeated herbicide application, and mechanical control have all been used to control *I. cylindrica* (Macdicken *et al*. 1997 Terry *et al*. 1997). Mechanical control is, however, very labor intensive and the use of herbicide (Glyphosate) is costly and open to environmental risks. There is the potential of using *Mucuna* in the fallow