1 GENERAL INTRODUCTION

1.1 Introduction

Long before European colonization indigenous groups practiced shifting cultivation, also known as slash-and-burn agriculture, on small plots throughout the Amazon region (Vosti et al., 2002). The eastern Amazon was the first region to be settled by 'outsiders', mainly from the Brazilian northeast and Europe. These settlers used an intensified form of slash-and burn agriculture in a crop rotation scheme, which has been practiced for several generations in this region since. Within this agricultural system, a plot of secondary (or primary depending on the stage of invasion) forest is slashed and after a short drying period burned, to provide the nutrients for a one to two year cropping cycle. Subsequently, the land is left for the fallow vegetation to grow back for a varying number of years, and accumulate the nutrients needed for a next agricultural cycle (Nye and Greenland, 1960; Whitmore, 1998). The strong population growth in Brazil since the 1960's resulted in an increase in pressure on the agricultural land and accelerated the deforestation of primary forest (Fearnside, 1987; Nepstad et al., 1999). The intensification of land use led to shorter fallow periods and the extension of cropping cycles, leaving soils depleted of nutrients and ultimately resulting in the inability of the fallow vegetation to accumulate the nutrients needed for the next cropping cycle (Sanchez, 1976; Uhl, 1987; Uhl and Jordan, 1984). In addition to negative local effects of burning, such as soil fertility depletion and deterioration of soil physical properties, slash and burn agriculture affects global warming by the emissions of greenhouse gasses (Fearnside, 1996; Fearnside, 2000). In an effort to reduce the practice of burning, mulching (chopping and dispersion of the biomass) in combination with zero tillage has been suggested as a sustainable alternative (Denich et al., 2004; Lal, 1981; Thurston, 1997). Mulching is generally thought to have positive effects dry season soil moisture conditions, increase infiltration, reduce erosion, reduce soil temperatures, increase soil organic matter and soil nutrients, and increase crop yields over time (Lal, 1975; Thurston, 1997).

1.2 The SHIFT project framework

The German-Brazilian SHIFT program (Studies of Human Impacts on Forests and Floodplains in the Tropics) financed by the BmBf, CNPq and PPG-7 started in 1989

with the aim to increase the knowledge regarding the structure and key functions of the tropical ecosystem, to develop concise concepts for sustainable land use by recuperation of degraded and abandoned areas, and to improve the scientific assessment of human actions with respect to environmental risks. Under the umbrella of the SHIFT project in Brazil, numerous studies throughout Eastern and Central Amazonia, the Atlantic forests, and the floodplains of the Paraguay River have been developed over the past decade and a half. The common factors connecting all the project areas of research, are nutrient and water flux studies, ecosystem functioning, and socio-economic parameterization of the local population, and the potential uses for management systems. The Eastern Amazonian leg of the program was focused on the functioning and management of secondary forests and fallow vegetation (SHIFT-Capoeira; project code ENV 25).

Within the SHIFT-Capoeira project, various studies on the functioning of the fallow vegetation ecosystem were conducted. Studies of the floristic composition and function of fallow vegetation in the region were performed by Denich (1989), Baar (1997) and Schuster (2001). Fallow regeneration and root zone dynamics were studied by Wiesenmüller (1999), while nitrogen fixation by fallow vegetation and the potentials for natural fallow enrichment were studied by Thielen-Klinge (1997), Paparcikova (1998) and Brienza (1999). Soil biological and physical characteristics were studied by Diekmann (1997) and Maklouf Carvalho et al. (1997). Mackensen et al. (1996) studied the nutrient losses to the atmosphere of the traditional slash and burn system, while Hölscher (1995) and Klinge (1997) studied nutrient transfers to the soils. Social studies of small holding farmer communities were made by Souza-Filho (2004), Hurtiene (1998) and others.

a   b

Figure 1.1 a) Traditional slash and burn agriculture and b) mulching in action

Based on these and other studies, mulch technology was proposed as a sustainable agricultural management tool (Denich, 1996). However, mulching in comparison to traditional burning on crop productivity resulted decline in productivity (Kato et al., 1999; Kato, 1998), which revealed the need for a more integrated optimization approach with changes in the cropping calendar, and enrichment of fallow vegetation (Brienza Jr., 1999). The actual technical implementation of mulch technology was studied by Block (2004), whereas the social and economical feasibility was studied by Hedden-Dunkhorst et al. (2003). Micrometeorology was an integral part of the studies of Klinge (1998), Hölscher (1995), Sommer (2000), Giambelluca et al. (1997; 2000; 2003) and Sá et al. (1996; 1999). A water and nutrient cycling study examining the differences between mulching and burning at a point and plot scale was performed by Sommer (2000).

1.3 Water and nutrient dynamics

Under humid tropical conditions, the pathways and fluxes of nutrients are intimately connected with the pathways and fluxes of water through the (catchment) ecosystem (Bruijnzeel, 1983; Likens and Bormann, 1977). In order to assess the effects of changes in land use on water and nutrient dynamics, a sound understanding of the processes that determine these pathways and fluxes is required (Bonell and Balek, 1993; Bonell and Fritsch, 1997; Bruijnzeel, 1989b; Bruijnzeel, 1991). The various pathways of water through a vegetated hill slope are shown in Figure 1.2. Proctor (1987) summarized the major sources, sinks and pathways of nutrients in water solution in a forested ecosystem with the sketch given in Figure 1.3. For the agroecosystem under study in our experiment, several additions to this sketch were be made. The traditional land preparation gives both a quick release of nutrients from burned vegetation to the soil as well as massive nutrient losses to the atmosphere, whereas mulching and the required use of fertilizers give extra nutrient inputs to the soil (Denich et al., 2004; Lal, 1981; Thurston, 1997).

The studies by Hölscher (1995) and Mackensen (1996) demonstrated that nutrient losses to the atmosphere were several orders of magnitude greater than losses by leaching to drainage water. The anticipated increase in nutrient losses when the vegetation is mulched instead of burned was shown to be minimal due to

immobilization of nutrients by microorganisms and plant uptake (Sommer, 2000). The deep root system of the fallow vegetation was shown to attenuate leaching losses and improve soil fertility.

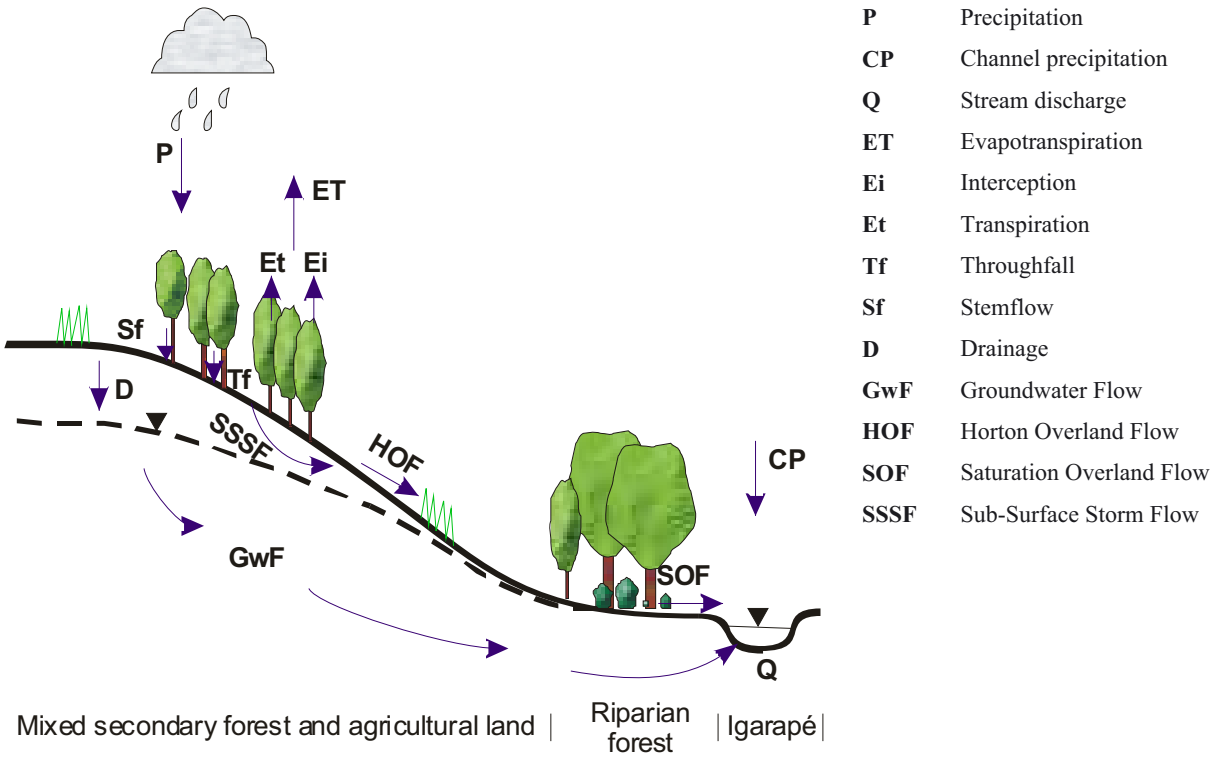

Figure 1.2 Hydrological cycle of a vegetated hill slope (adapted from Waterloo, 1994)

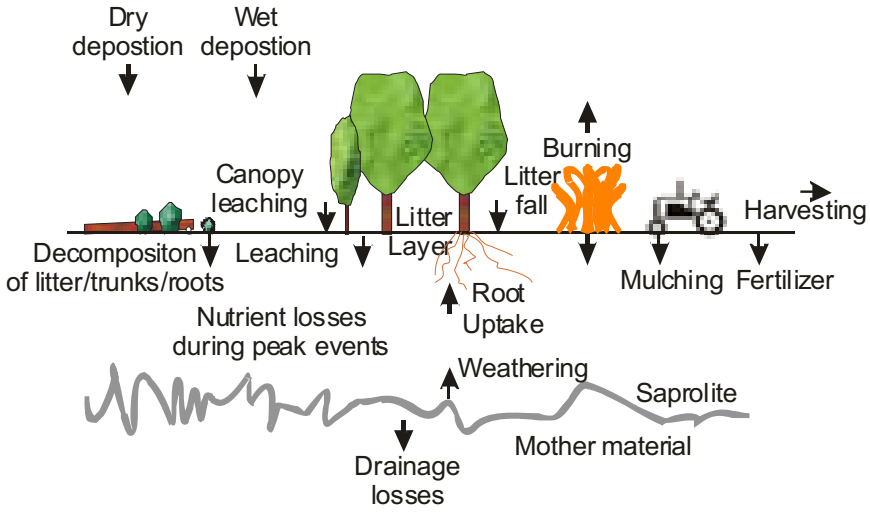

Figure 1.3 Nutrient cycles in an agricultural ecosystem under land preparation with and without burning (modified from Proctor (1987)

To examine the water and nutrient cycle in this study, the small watershed approach (Likens and Bormann, 1977) was followed. This method allows an accurate estimate of the water and nutrient cycle if the watershed conforms to the assumption that the watershed is underlain by an impermeable base, and that the only outflow occurs as streamflow (Bruijnzeel, 1990, Lesack, 1993b).

Following this assumption, the only inputs would be atmospheric and biological (including agriculture), and the only losses atmospheric, biological and geological (Likens and Borman, 1977). Most studies reviewed by Bruijnzeel (1991) and Brinkmann (1983), and more recent studies within our study region (Hölscher, 1995; Sommer 2000; Klinge, 1998) based their ecosystem nutrient loss estimates on shallow to intermediate depth, point to plot-scale measurements of soil water nutrient concentrations. For a complete understanding of the system, incorporation of measurements of groundwater and streamflow under base and peakflow conditions is essential. This study provides a look at the water and nutrient dynamics at a watershed scale in an agricultural ecosystem in the Eastern Amazon region.

1.4 Aims and outline

Based on the knowledge of the previous project phases, the current study is aimed at the integration of this knowledge and at providing an overview of the hydrological and biogeochemical functioning of the smallholder agricultural system in Eastern Amazonia. By analyzing the processes governing water and nutrient movement at the landscape and watershed level, reliable predictions can be made about the physical suitability of fallow management practices in and around the project area. In order to arrive at the overall aim, the specific research objectives were:

- To obtain a closed water balance for a set of experimental watersheds with different fallow clearing techniques by measuring rainfall, actual evapotranspiration, and stream flow
- To obtain a nutrient balance for these watersheds
- To measure and model the main water and nutrient flowpaths in order to reliably establish the extrapolation domain of the obtained results

The general components of the field measurements and the structure of their results are illustrated in Figure 1.4. After the general introduction to the study area in chapter 2,