Watershed services of smallholder agriculture in the Eastern Amazon

Ricardo de O. Figueiredo [a*], Jan Börner [b], and Eric A. Davidson [c]

[a] Embrapa Meio Ambiente, Rodovia SP-340, Km 127.5, Jaguariúna, SP, 13820-000, Brazil. Phone: +55 (19) 3311-2778, Fax: +55 (19) 3311-2640. E-mail: ricfig@cnpma.embrapa.br

[b] Center for International Forestry Research (CIFOR), Rua do Russel 450/601, Rio de Janeiro, RJ, Brazil. E-mail: j.borner@cgiar.org

[c] The Woods Hole Research Center, 149 Woods Hole Road, Falmouth, MA 02540-1644, USA. E-mail: edavidson@whrc.org

* Corresponding Author

ABSTRACT

Several hydrobiogeochemical research activities have been conducted in the Eastern Amazon, contributing to the understanding of how changes in forests and agro-ecosystems affect ecosystem service provision. Findings have demonstrate that good agricultural practices and the presence of natural secondary vegetation favored by smallholder farm management are important factors for hydrobiogeochemical cycling, aquatic ecosystem conservation, soil conservation, and mitigation of trace gases emissions from biomass burning in Amazonian small catchments. Two challenges for watershed service management arise in this context. First, low population densities and the relatively flat landscape mean that a critical mass of downstream beneficiaries of such services - a prerequisite for public intervention - is more difficult to identify than in more densely populated mountainous areas. Second, although watershed service providers (farmers) are also to considerable extent service beneficiaries, conflicts over land and cultural heterogeneities among settlers inhibit local collective action to safeguard stream water quality. Including smallholders in carbon payment schemes that compensate for the maintenance of riverbank vegetation would appear as a cost-effective means to secure watershed services as co-benefits of forest-based climate change mitigation.

Keywords: Stream water quality, hydrobiogeochemical, good agricultural practices, watershed management, payments for ecosystem services.

1. Introduction

Agricultural frontiers in the Brazilian Amazonia are expanding into the forest, compromising terrestrial and aquatic ecosystem structure and function, including fluxes of nutrients, carbon and water in small catchments. These first and second order streams comprise 80% of the total riverine habitat throughout this region (McClain and Elsenbeer, 2001). Several hydrobiogeochemical research activities have been conducted in the Eastern Amazon, contributing to the understanding of how changes in forests and agro-ecosystems affect ecosystem service provision.

Water cycling, besides carbon storage and biodiversity maintenance, is an important environmental service provided by the conservation of the Amazonian forests. The magnitude and value of these services are poorly quantified (Fearnside, 2005). Among other urgent policy actions, Fearnside (2001) suggested to fortify family agriculture contrary to the current policy focus on large landholders. In this sense, among other measures, it is suggested that consideration should be given to the possibility of payments for environmental services as a source of support.

In the Eastern Amazon in Brazil, the use of fire for land preparation is still a widespread practice in many traditional agricultural systems. Reducing the use of fire could be an important step towards sustainable smallholder agriculture and conservative practices, such as mulching in combination with zero tillage have shown promising results in experiments (Sommer, 2001). Innovative policy programs, such as payments for environmental services could help to promote the introduction of this and other alternatives to slash-and-burn agriculture by compensating farmers for additional watershed services, including forest conservation. The development of payments for watershed services schemes currently hinges on a better understanding of the biophysical determinants of hydrological service provision, especially in the Amazon region.

2. Hydrobiogeochemical Aspects

Large scale agriculture, such as cattle ranching and row crops, tends to radically change the natural characteristics of small rivers and streams, whereas small holder agriculture, characterized by secondary forest mosaic landscapes, has a less disturbing effect on small rivers and streams, especially when slash-and-burn land preparation practices are avoided. Research has demonstrated that good agricultural practices and the presence of natural secondary vegetation favored by smallholder farm management are important factors for hydrobiogeochemical cycling, aquatic ecosystem conservation, soil conservation, and mitigation of trace gases emissions from biomass burning in Amazonian small catchments (Davidson et al., 2008). In Table 1 we present a calculation for two different systems in eastern Amazonia which shows that the GWP (Greenhouse Warming Potential) CO_2 (dioxide carbon) equivalents from soil emissions, fertilizer use, and diesel fuel use in the chop-and-mulch system were not trivial, but they were nearly six times smaller than the total GWP CO_2 equivalents of slash-and-burn system extensively used by smallholder farming in the region

Other biogeochemical catchment studies more specifically related to water resources have shown pasture stream channels were deeper and had a lower cover of sandy bottom habitat and a higher cover of aquatic grass habitat than the forest streams, as well as lower concentrations of dissolved oxygen and nitrate (NO_3^-) and higher concentrations of dissolved iron (Fe^{2+}) and phosphate (PO_4^{3-}) (Neill et al., 2006). The stream chemistry of these two pairs of forest and pasture watersheds can be checked in Table 2.

In a related article the authors suggest that some links among deforestation, soil biogeochemistry and the amount of nitrogen (N) and phosphorus (P) reaching small streams have the potential to influence the structure of these aquatic ecosystems (Neill et al., 2001). The authors point out that lower ratios of inorganic and total dissolved N:P in pasture streams suggest a switch from P limitation in forest streams to N limitation in pasture streams. In addition periphyton bioassays in these forest and pasture streams confirmed that N limited algal growth in pasture streams where light was available. Figure 1 serves as an illustration of the dimension and environmental aspects of these studied streams.

Whereas the overland flow production is negligible in Amazon forests, overland flow represents a significant pathway for additional loss of phosphorus and other elements from pastures to the streams (Biggs et al., 2006). A photograph (Figure 2) of a pasture hillslope in this study area illustrates the importance of this component of the hydrological cycle in the catchment, where we can see the cattle trail conveying the water of the overland flow. In the same region Ballester et al., (2003), testing the effects of the landscape characteristics on river water chemistry, performed a multiple linear regression analysis and estimated a threefold increase of phosphate concentration in stream water due to an increase of 10% in the pasture area of a river basin.

Identifying the sources and mechanisms of solute contribution to Amazonian streams is necessary for understanding nutrient cycling processes in mature tropical forests and the long-term effects of land use change in the region. Regarding this objective Markewitz et al. (2001) observed in a particular watershed, where forest clearing and burning 30 years previously enriched the soils in cations, an increase of leaching of cations during the wet season which increased the input of these elements into the streams.

In contrast to pasture streams, where crops were grown near the stream, increases in steam concentrations of nitrate, sodium, chloride, and turbidity have been observed to increase with increasing crop cover area (Figueiredo et al., 2010). In this evaluation land use change affected water chemistry and other measures of streamwater quality in the eastern Amazon catchments. Box plots graphs in Figure 3 illustrate upstream-downstream trends for pH, nitrate (as Ln NO_3^--N), and dissolved oxygen (DO) in three streams (IG54, IG7 and IGP). Upstream-downstream trends in pH are decreasing for IG54 while pH increases downstream in IG7 and IGP, being attributed to impacts in the headwaters of IG54. On the other hand nitrate upstream-downstream declines were associated with decreasing percent forest area, while agricultural inputs are suspected of promoting the observed nitrate spike and dissolved oxygen collapse in station 4 of the IG54.

The benefits of smallholder production systems in term of watershed services are strongly related to the amount of secondary forests available in the landscape. Secondary forests may become increasingly important as moderators of hydrologic cycles in the Amazon Basin as agricultural lands are abandoned and often later cleared again for agriculture (Vieira et al. 2003). In catchments primarily occupied by smallholders, large areas of secondary forest, together with good agriculture practices that avoid slash-and-burn land preparation, resulted in the conservation of almost natural stream characteristics (Figueiredo, 2009).

In a watershed study (drainage areas < 30 ha), in the eastern Amazonia, Wickel (2004) observed that, in a catchment where fire is used to prepare land to small crops or pasture renovation compared to a catchment mainly occupied by secondary forests or chop-and-mulching to agriculture management, there are additional nutrients losses from soils to streamwater. In Table 3 we observe the mean chemical composition of baseflow streamwater of this two different type of watersheds according to land preparation and ratio of concentrations in baseflow to the concentration in rain. This approach demonstrates larger losses of potassium, calcium, magnesium, sulfate, and nitrate from slash-and-burn agriculture watershed soils compared to chop-and-mulching watershed soils losses to streamwater.

Larger catchment output of calcium was also in the study of Barroso (2011) analysing streamwater chemistry in nine watersheds in the eastern Amazonia. In Figure 4 we can see larger concentrations due to slash-and-burn agriculture in the M4, M5 and M6 watersheds.

Even stream fish communities studies in the eastern Amazonia have shown that agricultural catchments dominated by smallholder farmers can bear a reasonable stream fish diversity. After nine monthly collections Corrêa (2007) identified forty-three fish species in three streams of such agricultural catchments, while Brejão (2011) in seven streams of the same agriculture region registered seventy-three species distributed in six orders, twenty six families and sixty three genera (Figure 5).

Moreover, a few of these studies have surveyed sustainable indicators that can be measured in Amazon soils and streams, using rapid field measurements that would allow their use by environmental regulatory agencies. Turbidity, temperature, pH, and dissolved oxygen appear to be the simplest and most indicative parameters for detecting effects of land-use change on water quality in this region (Figueiredo et al., 2010). These measurements could be used as indicators for the payment of watershed services in this region. But further steps are needed specially those related to the values of these environmental services.

It can be conclude from the studies shown above and other studies that the small-holder agriculture, when not using fire for land management and when preserving large areas of forest (secondary or mature forests), including riparian zones, can help to mitigate impacts to water quality in small stream in the Amazonia. This opens a discussion of the possibility of paying for watershed services to the smallholders who use conservative agriculture practices in the region, or even compensating large-scale farmers in some way for the same environmental service.

3. Challenges of Setting up Payments for Ecosystem Services Schemes in the Amazon

As for the hydrobiogeochemical aspects previously discussed we can infer that, if we want to assure streamwater quality in the Amazonian small catchments, we need to help producers make the transition from the traditional slash-and-burn agricultural practices that currently prevail in the Amazon frontier toward more diversified and sustainable agricultural and extractive practices. Payments for Environmental Services (PES) could be an effective tool for this purpose (Carvalho et al., 2004). In a watershed study in the Peruvian Amazonian, McClain and Cossío (2003) state that resource management efforts should move quickly to implement programs that reinforce good practices of local people, further educate local people on the ecosystem services provided by riparian areas, and strengthen the institutional framework for maintaining these practices into the future.

A fundamental precondition for PES to be feasible is that ecosystem service beneficiaries are willing to pay for at least the costs of setting up and running a given PES scheme. In the case of watershed services, these beneficiaries are typically spatially clustered downstream water users. Many other ecosystem services, such as carbon capture and species habitat provision result in benefits to the society as a whole. In the context of the Amazon, two important challenges arise for PES implementers:

1. *Identifying beneficiaries:* Low population densities and the relatively flat landscape mean that a critical mass of downstream beneficiaries of such services - a prerequisite for public intervention - is more difficult to identify than in more densely populated mountainous areas.

2. *Promoting local collective action:* Second, although watershed service providers (farmers) are also to considerable extent service beneficiaries, conflicts over land and cultural heterogeneities among settlers inhibit local collective action to safeguard stream water quality.

With regard to the first challenge, a crucial bottleneck is thus to identify a sufficiently large group of service beneficiaries. Experiences from PES schemes around the world show that watershed services can often piggyback in PES schemes that address other more globally valued ecosystem services, such as carbon capture and habitat conservation. Mechanism that link several services are called bundling or layering (Wunder and Wertz-Kanounnikoff, 2009). Economic analyses of conservation opportunity costs of smallholders in the eastern Brazilian Amazon suggest that the costs of setting aside an additional hectare of secondary deforestation lie between roughly R$ 10-20 per ton of CO_2 (Figure 6). This is slightly higher than cost-estimates for the retirement of extensive pastures (Bowman et al., 2012; Nepstad et al., 2009; Wunder et al., 2008).

For many reasons, including transport infrastructure quality and land tenure security, however, PES schemes may be more competitively established in the eastern Amazon setting than at today's agricultural frontiers, where the transaction costs of implementing local interventions tend to be high. Based on the existing Brazilian Forest Law carbon payment schemes in the Brazilian Amazon could be optimized in terms of watershed service provision, e.g. through higher rewards for the conservation and restoration of riparian vegetation.

With regard to the second challenge, everywhere in the Amazon the need is evident for the analysis community conflicts generated by smallholder's own economics needs and interests versus the environment aspects of fulfilling legal requirements. Plans for sustainable development must come together with environmental education components and perception and with economic return for the poor agriculture communities as well as dialogue between conflicting interest groups in target watersheds. The perception of voluntary groups and institutions that work in support these rural people is that dialogue and mutual confidence are essential for the success of such development plans. Plus a considerable amount of work has also to be done to identify who the stakeholders are in this development process (Grimble & Wellard, 1997).

4. Outlook and Conclusions

We show that there is a: 1. clear differences in water quality indicators between traditionally and fire-free managed watershed; 2. clear difference between smallholder versus large-scale producer managed watershed.

Watershed services alone, however, are unlikely to evoke sufficient local demand for establishing PES schemes in most Amazonian settings. Optimizing carbon payment schemes, for example, in the context of currently mushrooming REDD+ schemes in the region could represent an opportunity to improve watershed service provision through ecosystem services bundling.

The high degree of dependence of the local population on stream water resources may, nonetheless, also justify public interventions purely based on replacement cost criteria. The potential costs of establishing and maintaining decentralized water treatment facilities as natural watershed services degrade are likely higher than investments in promoting improved community watershed management schemes.

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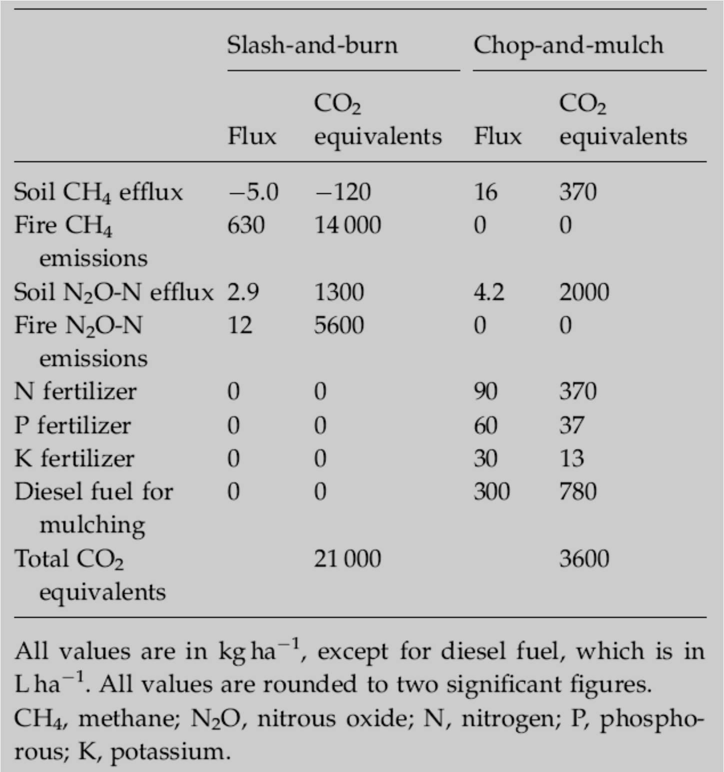
Table 1

Comparison of greenhouse warming potentials (GWP) for a 100-year time frame of emissions from slash-and-burn and chop-and-mulch cropping systems over approximately a 2-year cycle.



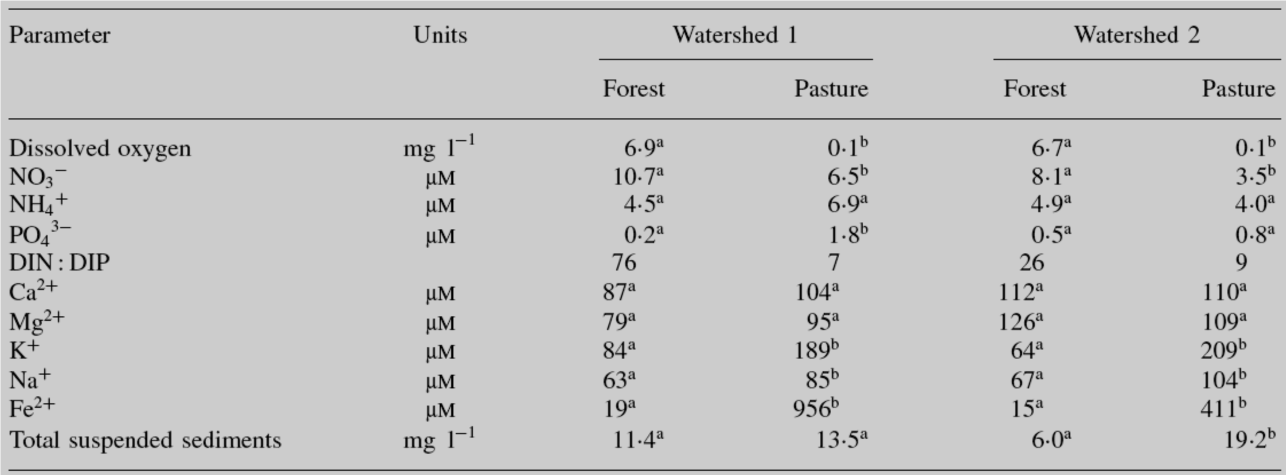
	Slash-and-burn		Chop-and-mulch	
	Flux	CO_2 equivalents	Flux	CO_2 equivalents
Soil CH_4 efflux	−5.0	−120	16	370
Fire CH_4 emissions	630	14 000	0	0
Soil N_2O-N efflux	2.9	1300	4.2	2000
Fire N_2O-N emissions	12	5600	0	0
N fertilizer	0	0	90	370
P fertilizer	0	0	60	37
K fertilizer	0	0	30	13
Diesel fuel for mulching	0	0	300	780
Total CO_2 equivalents		21 000		3600

All values are in kg ha^{-1}, except for diesel fuel, which is in L ha^{-1}. All values are rounded to two significant figures. CH_4, methane; N_2O, nitrous oxide; N, nitrogen; P, phosphorous; K, potassium.

Source: Davidson, E.A. et al (2008). An integrated greenhouse gas assessment of an alternative to slash-and-burn agriculture in eastern Amazonia. Global Change Biology 14, pp.1003.

Table 2

Nutrient, cation and total suspended sediment concentrations in forest and pasture streams at Nova Vida Ranch,Rondônia, Brazil, during the period of low flows in August to September of 1998 and 1999. Different superscripts indicate that forest and pasture means within each stream pair were significantly different (t-test, $p < 0.05$)



Parameter	Units	Watershed 1		Watershed 2	
		Forest	Pasture	Forest	Pasture
Dissolved oxygen	mg l^{-1}	6·9^{a}	0·1^{b}	6·7^{a}	0·1^{b}
NO_3^-	µM	10·7^{a}	6·5^{b}	8·1^{a}	3·5^{b}
NH_4^+	µM	4·5^{a}	6·9^{a}	4·9^{a}	4·0^{a}
PO_4^{3-}	µM	0·2^{a}	1·8^{b}	0·5^{a}	0·8^{a}
DIN : DIP		76	7	26	9
Ca^{2+}	µM	87^{a}	104^{a}	112^{a}	110^{a}
Mg^{2+}	µM	79^{a}	95^{a}	126^{a}	109^{a}
K^+	µM	84^{a}	189^{b}	64^{a}	209^{b}
Na^+	µM	63^{a}	85^{b}	67^{a}	104^{b}
Fe^{2+}	µM	19^{a}	956^{b}	15^{a}	411^{b}
Total suspended sediments	mg l^{-1}	11·4^{a}	13·5^{a}	6·0^{a}	19·2^{b}

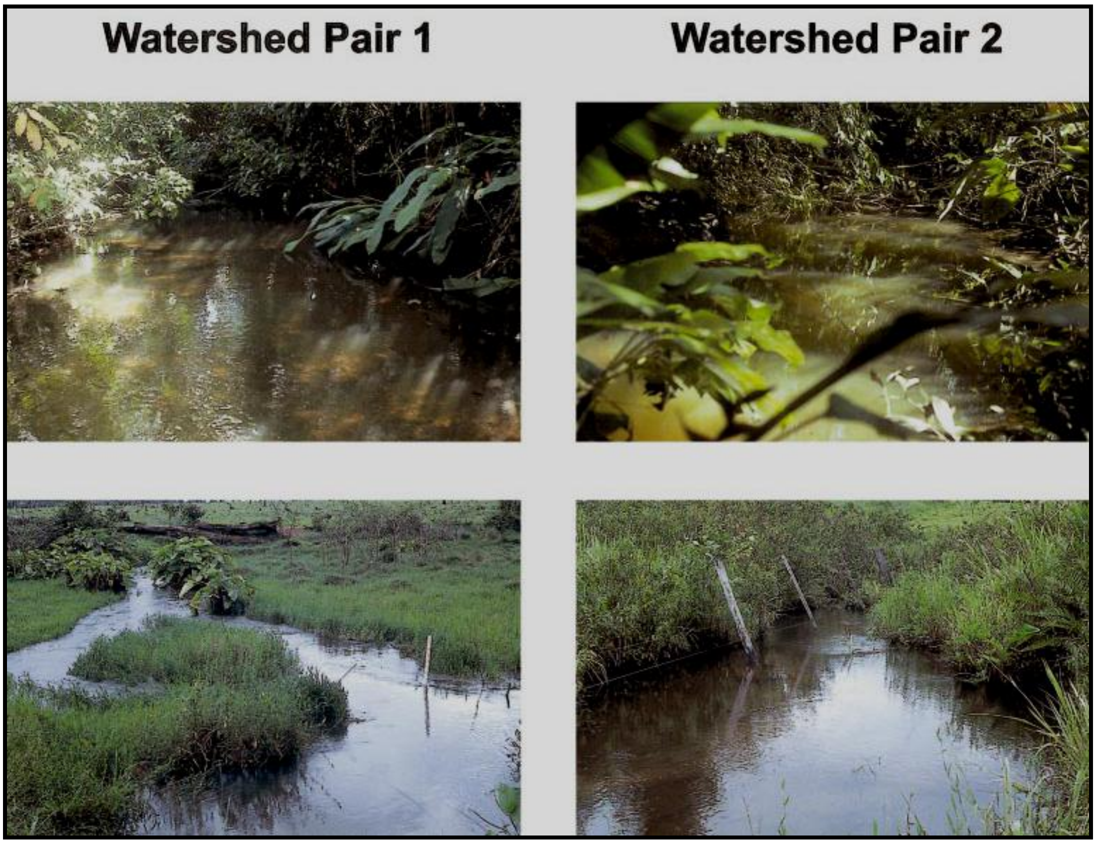
Source: Neill, C. et al (2006). Deforestation alters the hydraulic and biogeochemical characteristics of small lowland Amazonian streams. Hydrological Processes 20, pp.2570.

Table 3

Mean chemical composition (in mg L^{-1}) of baseflow water of the two watersheds, and ratio of concentrations in baseflow to the concentration in rain (Q/P ratio). WS1= 25.5 ha chop-and-mulching agriculture watershed; WS2= 28.6 ha slash-and-burn agriculture watershed.

	Na^+	**K^+**	**Ca^{2+}**	**Mg^{2+}**	**SO_4^{2-}**	**PO_4^{3-}**	**NO_3^-**	**Cl^-**
WS 1								
Mean	1.45	0.09	0.16	0.20	0.41	0.03	0.02	2.63
WS1/Rain	**2.37**	**0.56**	**1.31**	**3.34**	**2.32**	**0.75**	**1.74**	**2.51**
WS 2								
Mean	1.40	0.20	0.61	0.29	0.81	0.02	0.04	2.58
WS2/Rain	**2.30**	**1.21**	**4.99**	**4.83**	**4.65**	**0.57**	**4.47**	**2.46**

Modified from Wickel, B., 2004. Water and nutrient dynamics of a humid tropical watershed in Eastern Amazonia. University of Bonn, Ecology and Development Series 21. pp. 96.



Source: Neill, C. et al. (2001). Deforestation for pasture alters nitrogen and phosphorus in small Amazonian streams. Ecological Applications 11, pp. 1819.

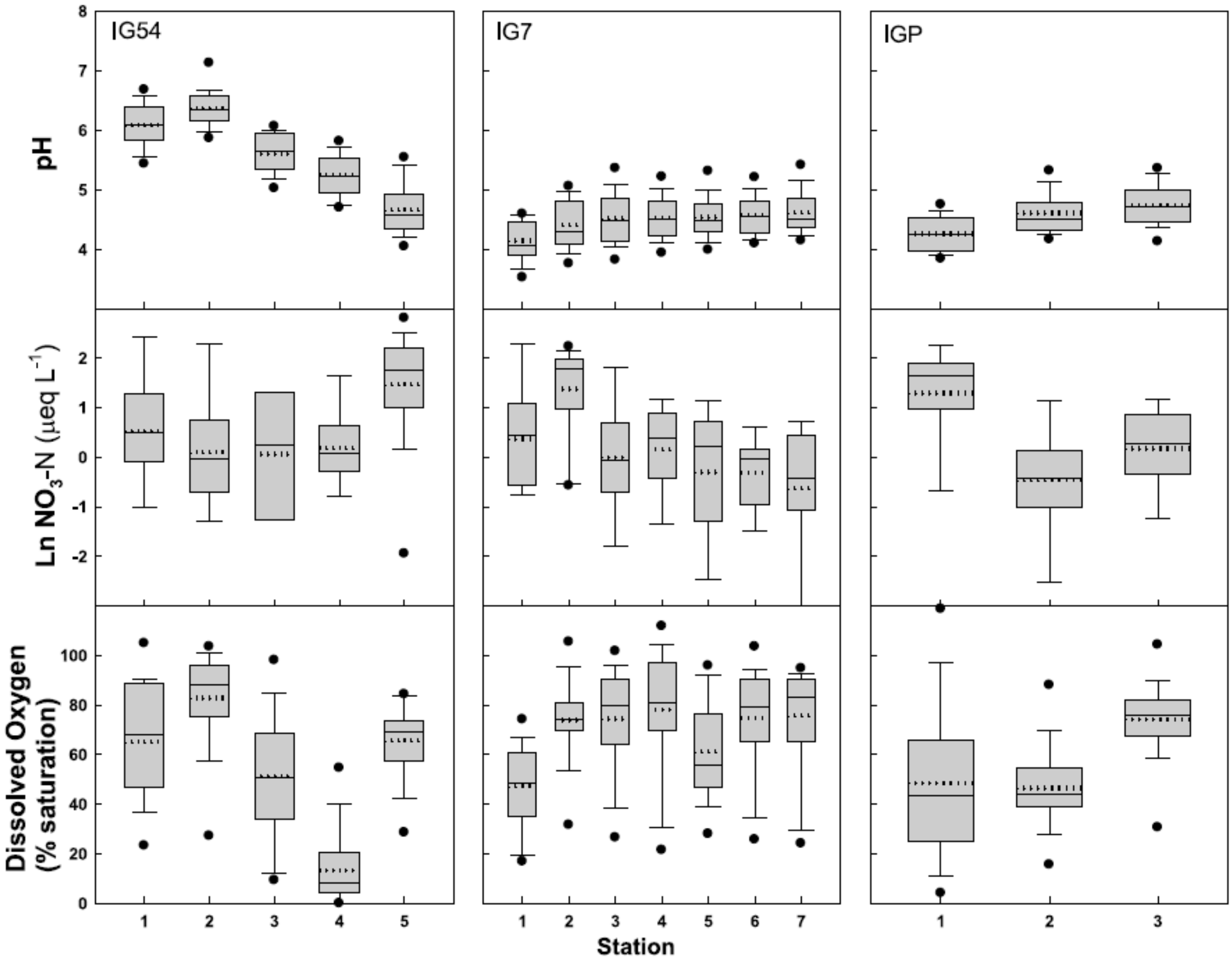
Figure 1

Photos of (top) forest and (bottom) pasture studied streams.

Source: Biggs, T.W., Dunne, T, Muraoka, T. et al., 2006. Transport of water, solutes and nutrients from a pasture hillslope, southwestern Brazilian Amazon. Hydrological Processes 20, pp. 2530.

Figure 2

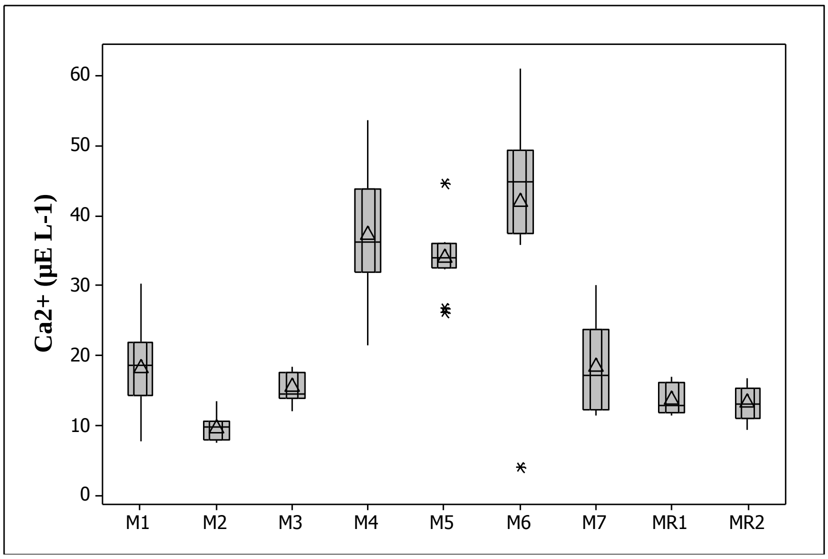
Photograph of a pasture hillslope as viewed from the overland flow sampling location, with runoff at the end of an 11-mm rainstorm. In the photo we can see the cattle trail conveying the water.



Source: Figueiredo, R.O. et al., 2010. Land-use effects on the chemical attributes of low-order streams in the eastern Amazon. Journal of Geophysical Research 115, G04004, pp.9.

Figure 3

Upstream-downstream trends for pH, nitrate (Ln NO_3^--N), and dissolved oxygen (DO) in three streams of eastern Amazonia (IG54, IG7, and IGP). Lower and upper boundaries of the box are 25th and 75th percentile, dots are 5th and 95th, solid line is median, and dotted line is mean for samples that were collected monthly from April 2003 to October 2005.



Source: Barroso, D.F.R., 2011. Fluxos hidrogeoquímicos em águas fluviais de microbacias do Nordeste paraense e a sua relação com o uso da terra. Universidade Federal do Pará, Belém, pp.68.

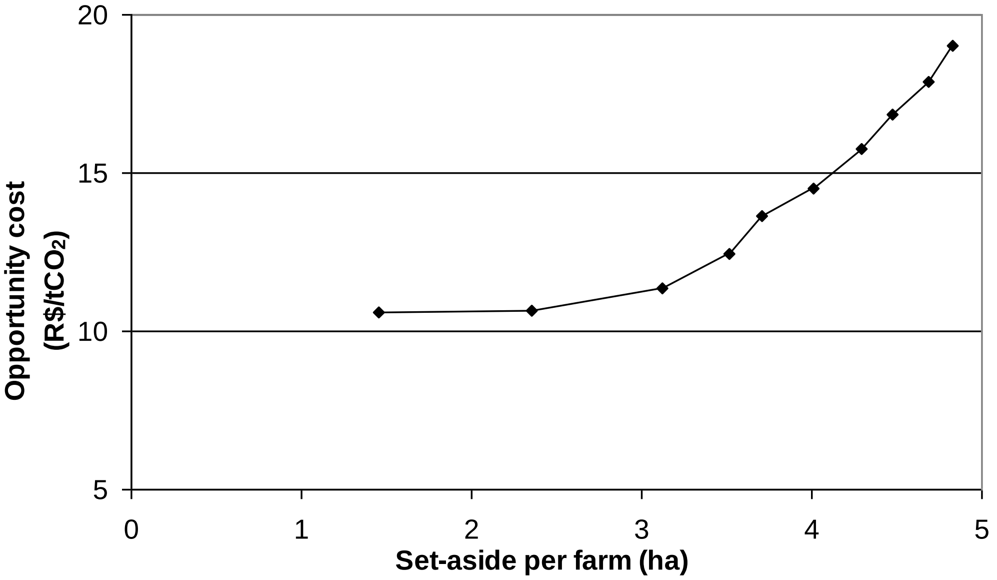
Figure 4

Box plot graph of calcium (Ca^{2+}) concentrations along one year period (n=12) in streamwater at nine catchments in the Marapanim River Basin, eastern Amazonia.

Source: Gabriel Lourenço Brejão files.

Figure 5

Two of the seventy-three species registered by Brejão (2011) in seven streams of the same agriculture region.



Source: Modified from Börner, J. et al., 2007. Ecosystem services, agriculture, and rural poverty in the Eastern Brazilian Amazon: Interrelationships and policy prescriptions. Ecological Economics 64, pp.362.

Figure 6

Opportunity costs per unit of avoided CO2 emission in smallholder systems in the eastern Brazilian Amazon.