Agriculture, Ecosystems and Environment 245 (2017) 32–42

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

journal homepage: www.elsevier.com/locate/agee

Research paper

Evaluating the effect of shade trees on provision of ecosystem services in intensively managed coffee plantations

Louise Meylan[a,b], Christian Gary[c], Clémentine Allinne[a,b], Jorge Ortiz[d], Louise Jackson[e], Bruno Rapidel[a,b,*]

[a] CIRAD, UMR System, 34060, Montpellier, France
[b] CATIE, 30501, Turrialba, Costa Rica
[c] INRA, UMR System, 34060, Montpellier, France
[d] CoopeLlanoBonito, Llano Bonito de León Cortés, Costa Rica
[e] University of California–Davis, One Shields Ave., Davis, CA, 95616, USA

ARTICLE INFO

Keywords:
Coffee
Agroforestry
Ecosystem services
Tradeoff
N fixation
Yield components

ABSTRACT

Intensively managed cropping systems with emphasis on productivity of the main crop can benefit from additional ecosystem services brought by integration of trees in the system − but potential drawbacks must also be accounted for. In an on-farm study, we used a variety of plant, soil and water- related variables to assess the effect of *Erythrina* spp. and *Musa* spp. on the provision of ecosystem services in productive, high-quality *Coffea arabica* plantations in Costa Rica. We found 1) no significant effect of shade trees on coffee production overall; 2) evidence that shade trees do affect flowering and subsequent cherry development, with effects strongly dependent on climate and annual variations in coffee plant physiology; 3) Erythrina shade trees significantly increased soil litter and relative infiltration rate of water in the soil, both linked to soil conservation and decrease in erosion; 4) even in highly fertilized environments, Erythrina trees do fix N which was taken up by adjacent coffee plants. The lack of significant negative effect of shade trees on overall coffee yield and the observation of the provision of other useful services was not unexpected, because of 1) the low density of shade trees in the study site (100–350 trees/ha pruned twice a year on average) and 2) the sensitivity of coffee yields to other interacting effects such as climate, pests and diseases and physiological variations in the plant. Pending further long-term research into the factors affecting coffee yield, we find shade trees provide sufficient ecosystem services to justify their integration in even intensively managed plantations.

1. Introduction

The search for new methods of improving sustainability of agriculture has led to renewed interest in the age-old practice of integrating trees in the agro-ecosystem. This practice, commonly known as agroforestry, is based on the principle that trees bring increased benefit to the cropping system into which they are integrated (Cannell et al., 1996). Trees in cropping systems can be used for a wide variety of purposes, from production of timber and other produce, to regulation or support of various ecosystem functions such as pest control or nitrogen cycling (Torquebiau, 2000). However, trees can also inhibit such ecosystem services, for example through competition with the main crop for light, water and nutrients (Van Noordwijk et al., 2015), or provide dis-services, such as creating more favorable conditions for pests or diseases (Zhang et al., 2007). The integration of trees in the cropping system, and the modalities of tree management, must therefore be carefully examined in terms of their impact on the ecosystem services concerned.

Coffea arabica is a perennial plant originally grown under a dense forest canopy in Eastern Africa. Widely grown in Asia, Africa and Latin America today, coffee plantations traditionally require some degree of shade cover. However, in the right climate, more productive dwarf or hybrid varieties such as Caturra or Bourbon can grow in unshaded coffee monocultures (Steiman et al., 2011).

Some downsides of coffee monocultures include decrease in the longevity of coffee plants (Chaves et al., 2012) as well as increased soil erosion (Lin, 2010). Exactly how many shade trees should be in a coffee plantation, and in what conditions, is still a question for which most coffee farmers seek an answer. Surveyed literature broadly concurs on the fact that since complete canopy cover decreases coffee production (Estivariz-Coca and Muschler, 1998), it is not desirable in commercial coffee plantations, yet low to moderate shade is more beneficial than no

* Corresponding author at: CIRAD, UMR System, Montpellier SupAgro, Bat 27, 2, place P. Viala, 34060, Montpellier, France.
E-mail address: bruno.rapidel@cirad.fr (B. Rapidel).

http://dx.doi.org/10.1016/j.agee.2017.05.005
Received 15 July 2016; Received in revised form 4 March 2017; Accepted 5 May 2017
Available online 16 May 2017

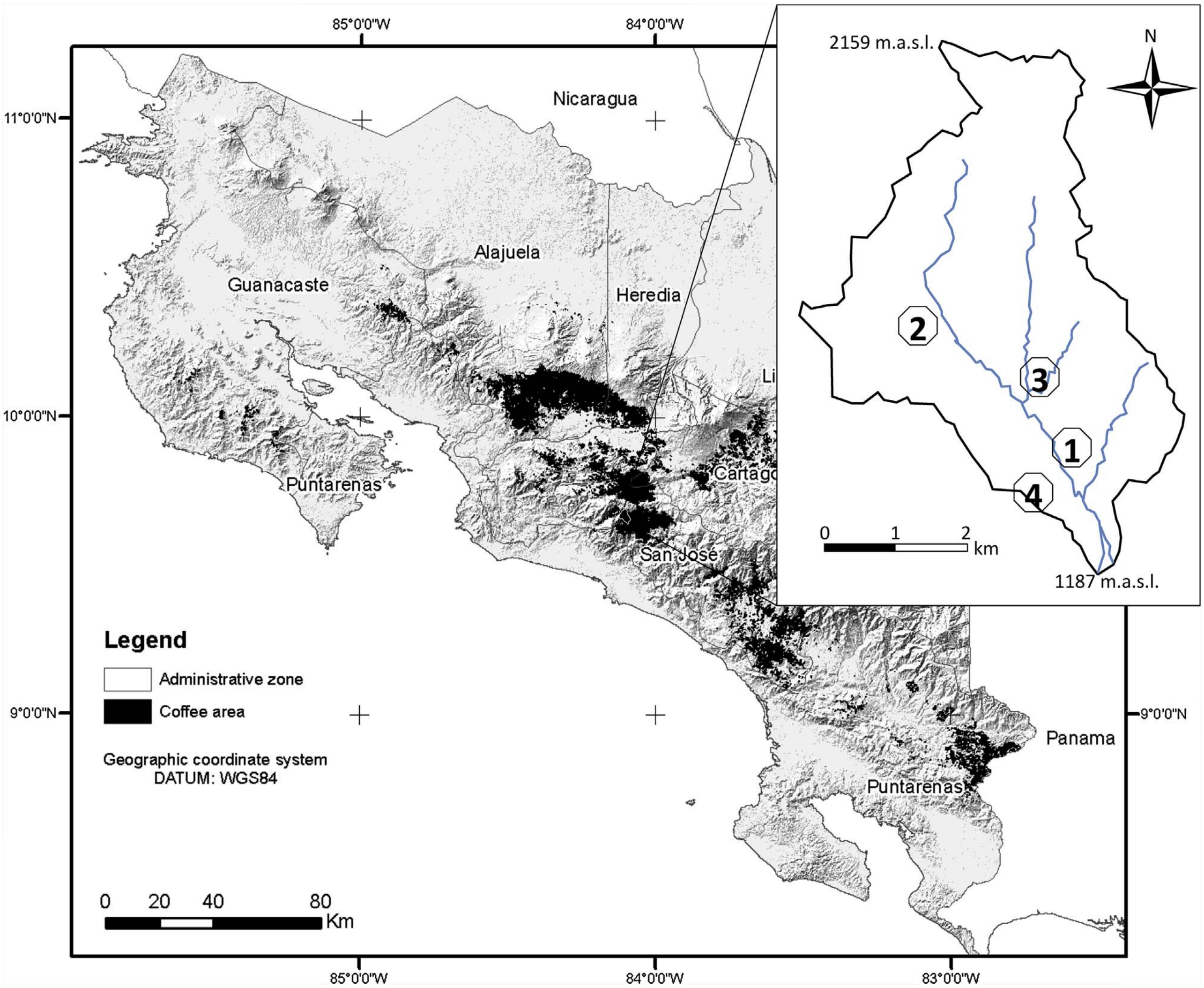

Fig. 1. Location of study sites in Llano Bonito watershed.

shade at all (Detlefsen-Rivera, 1988). Estimates of the ideal shade cover in the Americas vary between 15 and 65% canopy cover, depending on local environmental conditions, climate, management, and shade tree species used (Beer et al., 1998; Soto-Pinto et al., 2000; Staver et al., 2001; Campanha et al., 2005). Complex effects on potential attacks by pests and diseases must also be considered; Avelino et al. (2007) found that the effect of shade cover on fungus attacks in Costa Rican highland coffee plantations was dependent on rainfall and humidity conditions, themselves partly determined by slope orientation. In the same vein, Allinne et al. (2016) found that the physical characteristics of the environment, topoclimate and soil characteristics, are the main drivers of injury profiles and of resulting yield losses. Cropping practices and pest and disease management first need to be adapted to these physical characteristics. There still remains a significant gap of information in order to fully understand the effect of trees in a shade tree-coffee agroforestry system across the wide variety of environments and climates in which coffee is grown (van Oijen et al., 2010).

Evaluating the effect of shade trees on the performance of the agroecosystem as a whole requires understanding the effects of trees on multiple ecosystem services. In highly productive systems, a primary concern of the coffee farmer is the effect of shade on coffee biomass production and coffee yield, the main provisioning service. Shaded coffee plants can have similar rates of photosynthesis but lower bean production, since lower light levels affect development of reproductive organs and may reduce flowering (Campanha et al., 2005). Cerdán et al. (2012) showed that coffee yield can be broken down into several yield components; the effect of shade can be examined on each of these. In addition to annual yields, shade trees also help production by preventing dieback (death of producing branches or shoots from excessive production) (Chaves et al., 2012), therefore favoring long-term cherry production.

In Costa Rica, *Erythrina poeppigiana* (subsequently referred to as Erythrina trees in what follows) is a popular species for providing shade in coffee plantations (Budowski and Russo, 1997). As a leguminous species, it fixes N by capturing atmospheric N_2 in the form of organic compounds in root nodules (Nygren and Ramírez, 1995). Upon decomposition, mineralized N may become available for other plants to use as well (Chesney and Nygren, 2002). This has been shown to provide additional N supply in coffee plantation, a supporting service (Salas et al., 2001). Nevertheless, in heavily fertilized cropping systems it is uncertain if Erythrina still accomplishes this energy-demanding function due to high amounts of N already present in the system. Erythrina trees also provide services common to other trees such as improvement of soil structure and increase in organic matter by leaf fall and decomposition of pruning residues (Beer, 1993; Lin and Richards, 2007; Tully et al., 2012).

Bananas (*Musa* spp.) is also frequently used as shade in coffee plantations across Central America. It may produce additional income, better distributed through the year, as compared to the income generated from coffee. In Costa Rica, these banana plants are seldom used for income generation, and are mostly grown for self consumption and to provide quickly-established, easy-to-manage, shade for coffee