Agriculture, Ecosystems and Environment 211 (2015) 145–154

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

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

Ecological and social drivers of coffee pollination in Santander, Colombia

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ARTICLE INFO

Article history:
Received 30 September 2014
Received in revised form 10 June 2015
Accepted 12 June 2015
Available online xxx

Keywords:
Agroforestry systems
Landscape context
Farm management
Organic and conventional coffee farming
Ecosystem services
Drivers of crop adoption
Pollinators

ABSTRACT

Bees and other insects provide pollination services that are key to determining the fruit set on coffee plantations. These pollination services are influenced by local ecology as well as human factors, both social and economic. To better understand these different factors, we assessed their effect on pollinators and coffee pollination services in Santander, Colombia. We quantified the effect of key ecological drivers on pollinator community composition, such as the method of farm management (either conventional or organic) and the surrounding landscape composition, specifically the proximity to forest.

We found that ambient levels of pollination services provided by the local pollinator fauna (open pollination) accounted for a $10.5 \pm 2.0\%$ increase in final coffee fruit set, and that the various pollinators are affected differently by the differing factors. For example, our findings indicate that conventional farm management, using synthetic inputs, can promote pollinators, especially if they are in close proximity to natural forest fragments. This is particularly true for stingless bees. Honeybee visitation to coffee is also positively influenced by the conventional management of farms. Factors associated with greater numbers of stingless bees on farms include greater shade cover, lower tree densities, smaller numbers and types of trees in bloom, and younger coffee plantations. A forested landscape close to farms appears to enhance these factors, giving increased stability and resilience to the pollinating bees and insects. However we found that organic farms also support diverse pollinator communities, even if distant from forest fragments.

The contribution of honeybees to pollination value (US$129.6/ha of coffee) is greater than that of stingless bees (US$16.5/ha of coffee). Since the method of farm management has a major impact on the numbers and types of pollinators attracted to farms, we have analysed the statistically significant social factors that influence farmers' decisions on whether to adopt organic or conventional practices. These include the availability of technology, the type of landowner (whether married couples or individual owners), the number of years of farmers' formal education, the role of institutions, membership of community organizations, farm size, coffee productivity and the number of coffee plots per farm. It is hoped that the use of our holistic approach, which combines investigation of the social as well as the ecological drivers of pollination, will help provide evidence to underpin the development of best practices for integrating the management of pollination into sustainable agricultural practices.

1. Introduction

Landscapes that are dominated by agriculture are subject to changes resulting from the choice of cropping and from land-use patterns. These changes affect pollinator biodiversity and the provision of pollination services (Kleijn et al., 2011). Market forces and agricultural policy are often the driving factors behind an expansion of crops that were previously only grown over limited areas, and can bring about the introduction of novel crops into the landscape (Haughton et al., 2009).

The integration of pollination management into agricultural practice is essential since pollination by insects can increase the yield of 75% of global crops (Klein et al., 2007). Looking specifically at coffee production, studies have found that pollinators have a positive impact on the *Coffea arabica* L. yield of between 10 and 40% (Klein et al., 2007), despite the fact that the plant has a high degree of self-fertility (Klein et al., 2003a). A wide range of studies have

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http://dx.doi.org/10.1016/j.agee.2015.06.007
0167-8809/

been reviewed (Ngo et al., 2011) to investigate the effect of insects on coffee pollination. They have found that bees are widely recognised for their important role in pollination, especially the highly eusocial tribe Meliponini and the Africanized honey bee. The roles of other insects such as vespid wasps and syrphid flies have not been explored in detail, although species from these groups have been observed visiting coffee flowers.

Several studies have analysed the landscape contexts of coffee farms and have documented increases in bee species richness, visitation frequency, fruit set or berry weight when coffee crops are located in sites close to forest fragments (e.g. De Marco and Coelho, 2004; Klein et al., 2003a; Ricketts, 2004; Roubik, 2002a,b). Other studies in Mexico (Vergara and Badano, 2009) found that the greatest richness of pollinator species and the greatest fruit production were found on more structurally and floristically complex shaded coffee agro-ecosystems. Similarly, it has been stated (Jha and Vandermeer, 2010) that the most important factors predicting bee abundance were related to the diversity of vegetation within the agroforestry system. However, the impact of particular management practices (irrigation, liming, and shading) on pollination services to *Coffea canephora* production were assessed in India (Boreux et al., 2013), where it was found that managing irrigation to produce asynchronous flowering was a more effective tool for securing good pollination than maintaining high shade tree densities as pollinator habitat. Together these studies demonstrate the variety of factors affecting coffee pollinators and that they vary with farm type and location.

Thomas and Kevan (2012) reviewed evidence of the economic impact of pollination services in coffee plantation mosaic habitats and made several relevant policy recommendations. One key finding was that the value of pollination services is influenced directly by the amount of intact forest within 400 m of coffee trees, and that the average pollination value is reduced from US$100/ha to US$74/ha over that distance (Olschewski et al., 2006). They concluded, therefore, that at the global scale, policies such as direct subsidies for forest conservation would positively affect yields.

Further, empirical studies have recently shown the efficacy of pollinators as biocontrol agent vectoring (BVT) against populations of coffee borer, a disease that severely reduces crop yields (Vergara et al., 2014). Special dispensers can be placed at the exit/entrance of hives of managed pollinators (e.g. some honeybees and bumblebees). The dispensers contain specially formulated, naturally-occurring biological control agents that bees carry from their hives to the flowers they visit.

Thus, the two ecosystem services of insect pollination and crop protection combine to improve yields, and it is possible that their promotion at farm level could encourage the adoption of certified management schemes, i.e. practices that encourage farmers to grow coffee crops and manage farms sustainably.

Olschewski et al. (2006) also noted that economic incentives would improve production and advocated policies to support higher prices for certified coffee. Similarly, governmental and trade organizations involved in the import and export of coffee could also potentially influence policies and practices by promoting insect pollination in the process of coffee certification (Thomas and Kevan, 2012).

In addition to the ecological and economic factors noted above, an understanding of the social factors that influence farmers' decisions at the local level is essential since these decisions affect farm management, which ultimately determines pollination services and crop yields (Plieninger et al., 2013). Most research of Arabica coffee has separately analysed either ecological or economic variables and often failed to take into account social factors and their combined effects on coffee pollination systems. If coffee production is to be sustainably managed, then it is important to understand the farm context and what factors drive pollinator biodiversity and pollination services at both the local farm level and on the wider landscape scale, and how these factors interact. The farm scale perspective is particularly important in Colombia and Latin America where smallholder coffee production is predominant, and the adoption of any given agricultural management practice primarily relies on the land owner's decisions.

Focusing on the predominant pollinator groups in the study area, our research aims to quantify the response of pollinators to both farm management (organic vs. conventional) and distance to the nearest forest. Having established these environmental conditions, this study has also attempted to identify the various economic and social factors that influence farmers' decisions regarding management methods. It is hoped that an improved understanding of these factors will allow farmers, in the future, to improve pollination rates, benefiting coffee fruit set and therefore their own livelihoods. We focused on the following questions: (1) What are the effects of both farm management and the surrounding landscape on pollinators and pollination delivery? (2) What is the economic value of pollination services provided by stingless and honeybees? (3) What social drivers affect the provision of pollination services through their influence on both ecological and economic factors?

2. Materials and methods

2.1. Study sites

The study was undertaken in the Santander area, a mountainous region where a high proportion of Colombian specialty coffees are produced. The field work was carried out on 12 farms in Ocamonte, a town located in the south of the region (N6°22′945″, W73°07′552″, at elevations ranging from 1577 m to 1919 m). A balanced two factor design was developed to test the effects of proximity to forest, farm management type, and their interaction. Twelve farms of different smallholders were selected based on both their proximity to a municipal reserve, a secondary forest of ~40 ha size (categories: close <500 m; far 500–1800 m) and crop management type (organic vs. conventional). Forest distance category thresholds were established according to distances reported in previous studies (Klein et al., 2003b; Ricketts, 2004) as well as the spatial distribution and availability of farms in the study site in relation to the forest. Organic farms had been certified by two particular seals corresponding to "Fair Trade" and an additional accreditation granted by a formal agency (e.g. BCS Öko-Garantie) whose branch in Colombia is authorized to certify according to international regulations on organic agriculture. These organic farms are productive without the use of synthetic fertilisers and pesticides. The design of the study attempted to minimize, as far as possible, the effects of bee movement between sites by having a minimum separation distance of 300 m.

2.2. Ecological factors

Measurement of pollinator behaviour on coffee flowers and its effect on fruit production were in accordance with standard field methodologies (Dafni et al., 2005; Table 1). Four healthy coffee plants per site were selected in the centre of a plot per floral episode; bushes comprised flowers that opened during the early hours of the same day of observations, the same genetic variety, and typical production phase (the same age within a plot ranging from 2 to 8 years); it was replicated on all 12 farms. Every day a different full-blooming coffee plant was used for observations. A total of 10,891 flowers were studied on 224 branches of 112 plants during the three floral episodes on 12 farms. We only considered as pollinators those floral visitors that made contact with the sexual