Agriculture, Ecosystems and Environment 254 (2018) 1–9

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

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

Research paper

The significance of climate in the pollinator dynamics of a tropical agroforestry system

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ARTICLE INFO

Keywords:
Pollination
Biodiversity
Rainfall
Agroforestry
Ceratopogonidae
Agroecology

ABSTRACT

Even though many globally important tropical agroforestry crops are partially or completely dependent on insect pollination, the conditions influencing pollinator abundance in these systems are often incompletely understood. This is particularly the case for cocoa midges (Diptera: Ceratopogonidae), which are essential for cocoa pollination and thus yield, but agro-ecological management frequently neglects them. We report the first assessment of cocoa midge population dynamics from two Caribbean countries across a full year, and relate this to seasonal climate variables.

We used static suction traps along transects to sample insects monthly, from six cocoa farms across three Caribbean islands, with a particular focus on known pollinators of cocoa. A total of over 87,000 insects were captured, including more than 1800 cocoa midges. Midges were present in all months of the survey and on all sites, but typically comprised less than 2% of the total insects caught. At least twelve different species of cocoa midges were identified from this survey. The previous month's rainfall positively predicted cocoa midge absolute abundance and further analysis also revealed a relationship between rainfall and relative midge abundance. In particular, during drought periods, midge numbers were very low, consistent with their larval ecology. Humidity and mean daily maximum and minimum temperatures did not relate to midge abundance. Rainfall negatively influenced the Shannon-Weaver index. The findings highlight the possible threat of droughts to cocoa pollination services and the importance of proactive farm management to support them.

1. Introduction

Extensive research has been carried out on factors impacting pollinator distribution and abundance in semi-natural and agricultural systems in temperate regions over recent decades (Vanbergen and The Insect Pollinators Initiative, 2013; Rader et al., 2016). Far less work, in comparison, has taken place in study systems located in the tropics, especially the Caribbean islands. More information is needed about pollination in the tropics, as these areas are likely to be affected severely by climate change (Intergovernmental Panel on Climate Change, 2014), which may impact negatively on ecosystem services and lead to reduced yields (Settele et al., 2016) and therefore impact incomes and livelihoods.

One system of particular interest in this respect is cocoa (*Theobroma cacao* L.): a major tropical agroforestry crop with rising demand worldwide and of high value to growers, who are often resource-poor smallholders. Yields of this crop depend upon successful transfer of pollen between flowers; pollinator exclusion in some cultivars has been found to decrease fruit set to zero (Bos et al., 2007). Recent studies have shown significant pollination limitation in several regions (Groeneveld

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https://doi.org/10.1016/j.agee.2017.11.013
Received 23 June 2017; Received in revised form 3 November 2017; Accepted 14 November 2017
Available online 21 November 2017

Table 1
Information about the sites studied.

Farm (reference)	Location	Approx. elevation (m asl)	Government/Private	Size (ha) (approx.)	Trapping dates	System
La Reunion, Trinidad (LR)	10° 35′ 30″ N 61° 18′ 15″ W	22	Government	200	February 2013 – February 2014	Mixed varieties of cocoa (mostly TSH), some intercropping with banana
Gran Couva, Trinidad (GC)	10° 25′ 17″ N 61° 20′ 8″ W	76	Private	7	February 2013 – February 2014	Cocoa intercropped with mixed fruit trees; TSH varieties
L'Eau, Tobago (LE)	11° 12′ 54″ N 60° 37′ 54″ E	10	Private	2	March 2014 – February 2015	Rehabilitated estate with TSH and fruit trees.
Providence, Tobago (PR)	11° 12′ 11″ N 60° 43′ 53″ W	124	Private	1.2	March 2014 – February 2015	Farm under restoration, mostly TSH and some ICS accessions.
Highgate/Orange River, Jamaica (OR)	18° 13′ 59″ N 76° 52′ 55″ W	136	Government	111	November 2013 – November 2014	Cocoa intercropped with mixed fruit trees; varieties ICS1, 60, 95, PA150, TSH, IMC67
Boscobel, Jamaica (FP)	18° 22′ 53″ N 76° 58′ 17″ W	176	Private	44	November 2013 – November 2014	Cocoa intercropped with coconuts; varieties ICS1, 60, 95

et al., 2010; Forbes and Northfield, 2017). Pollination is achieved primarily by midges (Diptera: Ceratopogonidae) (Billes, 1941; Posnette, 1944) with other small Diptera such as Cecidomyiidae and similar insects making possible secondary contributions (Salazar-Díaz and Torres-Coto, 2017). Cocoa flowers are relatively small (10 mm long), with a specialized morphology that restricts which insects can pollinate them successfully. As a consequence, relatively few taxa can be effective pollinators, and evidence indicates that Ceratopogonidae are most effective at carrying sufficient pollen to ensure successful pollination (Toledo-Hernández et al., 2017).

Cocoa often forms part of a diverse agroforestry system, and as such, the potential to support invertebrate and vertebrate biodiversity on cocoa farms is considerable (Bisseleua et al., 2009). However, published surveys of biodiversity, and particularly midge diversity, from cocoa plantations in the Caribbean – where cocoa farms are often medium-sized and grown alongside shade and fruit trees – are rare compared with those from other parts of world (Winder, 1978; Frimpong et al., 2009, 2011; Deheuvels et al., 2014). Consequently, there is much still unknown about the abundance and species composition of cocoa pollinators in this region. It is currently very difficult to predict the impact of global change on pollination services in cocoa plantations generally, and in the Caribbean in particular. It has previously been hypothesized that rainfall, due to its impact on soil and vegetation moisture, is an important factor affecting cocoa pollination (Entwistle, 1958; Toledo-Hernández et al., 2017), because Ceratopogonidae larvae develop primarily in moist, decomposing vegetable matter such as cocoa pods and leaf litter (Winder, 1978; Adjaloo et al., 2013). This has not yet been tested in the Caribbean despite the fact that Caribbean countries are expected to experience decreased rainfall in future (Intergovernmental Panel on Climate Change, 2014).

Understanding the link between on-farm conditions and cocoa midge abundance is key to targeting farm management to ensure continuing pollination services and support yields. As cocoa suffers a pollination deficit (Groeneveld et al., 2010), there is increasing interest in targeting management to increase cocoa pollinator abundance globally.

This study sought to determine the abundance and species diversity of cocoa midges on three islands in the Caribbean (Trinidad, Tobago and Jamaica), evaluating their phenology in relation to the seasons. This enables consideration of the interaction between climate and farm management in safeguarding future pollination services in this important system. In particular, we studied the relationship between various climatic factors (rainfall, humidity and mean maximum/minimum daily temperatures) and adult midge populations from six farms. We also explored the relationship between climate and variability in overall invertebrate diversity within and between these locations. Our specific hypotheses were as follows:

1. Rainfall over the previous month is a significant predictor of absolute and relative cocoa midge (Ceratopogonidae) abundance.
2. Rainfall is a weaker predictor of Cecidomyiidae (secondary pollinator) abundance (because they do not normally reproduce in moist, rotting vegetable material).
3. Humidity is a positive predictor of insect and specifically Ceratopogonidae abundance.
4. There is a weak or absent link between temperature and Ceratopogonidae and Cecidomyiidae abundance (because temperature is relatively seasonally uniform in the Caribbean).

2. Materials and methods

2.1. Sites

We sampled from four sites in Trinidad and Tobago (two on Trinidad from February 2013 to January 2014, two on Tobago from March 2014 to February 2015) and two sites in Jamaica from October 2013 to September 2014, with details of locations, cocoa cultivars