



Does heterogeneity in crop canopy microclimates matter for pests? Evidence from aerial high-resolution thermography



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ARTICLE INFO

Keywords:

Crop microclimate
Aerial thermal imagery
Microclimate heterogeneity
Potato pests
Spatial metrics
Surface temperature

ABSTRACT

A majority of agricultural pests are influenced by microclimatic conditions that affect their performance and occurrence. Thermal heterogeneity experienced by pests at fine spatial scales is potentially a key to understand pest dynamics, yet its study over entire fields at fine resolution has never been performed. We used aerial infrared thermography to yield high-resolution measurements of crop canopy temperatures in 38 potato fields in the Ecuadorian Andes. In each field, for 30 different plots, we characterized the spatiotemporal heterogeneity of crop canopy temperatures and simultaneously sampled populations of four common leaf-surface dwelling adult pests. We then evaluated the fine-scale thermal heterogeneity implications for pest occurrence and compared a variety of thermal spatial metrics with pest abundance and richness measured in field. We found that the range of temperatures available for pests in crop canopies was independent on scale: pests can access within few centimetres most of the thermal microenvironments recorded at the field level. Also, the availability of thermal microenvironments was dependent on solar radiations: with increasing radiation levels, pests have to travel less distance to reach a variety of thermal environments. At the plot level, we found that the four-studied pests were not clumped into their optimal thermal conditions but rather distributed evenly. Pests having a wide range of favourable microenvironments available within very short distances might be constrained by others factors (resources, enemies). However, we found that pest richness was significantly correlated to both thermal aggregation and diversity index, suggesting that more diverse and distinctly distributed thermal environments in crop fields shelter a higher diversity of pests. As environmental conservation and agronomical management increasingly depend on our ability to understand and predict the responses of species to their environment, we recommend refining global pest distribution predictions using fine-grained microclimatic models to infer accurate responses of organism to climate change. Indeed, fine-scale spatiotemporal heterogeneity of microclimates might provide organisms with more than enough suitable thermal habitats in their actual location to withstand global changes.

1. Introduction

Microclimate effects on ectotherm organisms have long been studied from an ecological perspective (Cloudsley-Thompson, 1962; Willmer, 1982; Frazier et al., 2006; Scheffers et al., 2014; Storlie et al., 2014; Sheldon and Dillon, 2016). The spatiotemporal heterogeneity of microclimates (Woods et al., 2015; Sears et al., 2016) and the biophysics connecting their properties to those of local macroclimates (Holmes and Dingle, 1965; Gates 1980; Kearney et al., 2014) are widely

recognized for shaping organism distribution and physiology (Porter et al., 2002; Roslin et al., 2009; Storlie et al., 2014; Pincebourde et al., 2016). Ectotherm body temperature is strongly altered by changes in the organism's physical environment, inducing a direct relationship between environmental parameters and the metabolism of the organism (Sears and Angilletta, 2015). Solar radiation represents the main heat source and, depending on surface inclination and sun's position, generates a high variability of surface temperatures (Gates, 1980). Accordingly, numerous insect species have developed thermoregulatory

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Table 1

Table of the studied field descriptions. Field area is expressed in squared meters, Phenology and Damage were estimated for the entire field and Cov is the TIR coverage of the field in percentage of the total field area.

| Name | Date | Area | Phenol | Dam | Cov | Name | Date | Area | Phenol | Dam | Cov |
|------|----------|------|--------|-----|------|------|----------|------|--------|-----|------|
| 1 | 14/01/14 | 726 | C | 3 | 31.7 | 20 | 24/01/14 | 1010 | B | 2 | 22.8 |
| 2 | 15/01/14 | 1147 | C | 3 | 20.1 | 21 | 24/01/14 | 1604 | C | 2 | 14.4 |
| 3 | 15/01/14 | 1292 | B | 2 | 17.8 | 22 | 24/01/14 | 958 | A | 1 | 24.1 |
| 4 | 15/01/14 | 1454 | B | 1 | 15.8 | 23 | 24/01/14 | 1118 | C | 2 | 20.6 |
| 5 | 16/01/14 | 2217 | A | 1 | 10.4 | 24 | 27/01/14 | 1136 | B | 1 | 20.3 |
| 6 | 16/01/14 | 1192 | B | 3 | 19.3 | 25 | 27/01/14 | 831 | B | 1 | 27.7 |
| 7 | 16/01/14 | 1188 | A | 1 | 19.4 | 26 | 28/01/14 | 725 | C | 2 | 31.8 |
| 8 | 16/01/14 | 2277 | C | 3 | 10.1 | 27 | 28/01/14 | 982 | A | 3 | 23.5 |
| 9 | 21/01/14 | 705 | C | 3 | 32.7 | 28 | 28/01/14 | 759 | A | 1 | 30.4 |
| 10 | 21/01/14 | 1914 | A | 1 | 12.0 | 29 | 28/01/14 | 818 | A | 1 | 28.2 |
| 11 | 21/01/14 | 850 | C | 2 | 27.1 | 30 | 29/01/14 | 1456 | C | 3 | 15.8 |
| 12 | 22/01/14 | 861 | C | 3 | 26.8 | 31 | 29/01/14 | 1200 | B | 2 | 19.2 |
| 13 | 22/01/14 | 924 | A | 2 | 24.9 | 32 | 29/01/14 | 1597 | A | 1 | 14.4 |
| 14 | 22/01/14 | 1293 | B | 3 | 17.8 | 33 | 29/01/14 | 2016 | B | 2 | 11.4 |
| 15 | 22/01/14 | 1970 | C | 3 | 11.7 | 34 | 31/01/14 | 630 | C | 2 | 36.6 |
| 16 | 23/01/14 | 631 | A | 2 | 36.5 | 35 | 31/01/14 | 2328 | B | 2 | 9.9 |
| 17 | 23/01/14 | 814 | B | 2 | 28.3 | 36 | 31/01/14 | 1778 | B | 2 | 13.0 |
| 18 | 23/01/14 | 881 | C | 3 | 26.2 | 37 | 31/01/14 | 3072 | A | 1 | 7.5 |
| 19 | 23/01/14 | 816 | B | 3 | 28.2 | 38 | 31/01/14 | 921 | A | 2 | 25.0 |

Phenology A = Leaf development, B = Inflorescence and C = Mature stage.

strategies in order to maximise or minimise the amount of radiative heat absorbed according to their thermal needs (Kingsolver, 1985; Roslin et al., 2009; Rojas et al., 2014; Sears and Angilletta, 2015). The relatively small size of most ectotherms (e.g. insect pests) allows them to exploit a great diversity of small-scale variations in climate that are not available to larger animals (Johnston and Bennett, 2008). Moreover, previous studies showed that the temperature variance available to organisms was found to be similar when studied at the landscape, local and micro-scales (Pincebourde et al., 2016). Consequently, it is well acknowledged that quantifying the spatiotemporal heterogeneity of the thermal environment as perceived by small organisms (i.e. at the proper spatiotemporal scale) is of prime importance for understanding their distribution and biological responses in their microhabitats (Potter et al., 2013; Storlie et al., 2014).

Although the spatiotemporal structure of microclimates has been shown to affect insect populations, implications in the context of agricultural pests have been poorly explored. Being ectotherms, agricultural pests respond to the rules of thermal dependency to achieve their optimal performances (Woods et al., 2015; Rebaudo et al., 2016). However, few studies have focused on the potential effects of microclimates on pest distribution at the field scale (e.g. Ferro et al., 1979; Sutherst, 2014). Tompkins et al. (1993) and Suh et al. (2002) showed how agronomical practices and canopy closure influenced the infestation of crop pests and diseases by modifying the components of the inside field microclimates (*Septoria sp* in wheat field and *Trichogramma exiguum* in cotton field, respectively). Also, Willmer et al. (2008) reported how intra-field microclimates constrained the distribution patterns of raspberry beetle (*Byturus tomentosus*). But these studies focused on punctual measurements of microclimatic parameters rather than on a continuous assessment of the spatial heterogeneity of microclimates in the field.

Technical limitations in microclimate measurements have long impeded the exploring to what extent the spatiotemporal heterogeneity in microclimatic conditions can potentially influence crop pest distribution and their damages at the field level (Potter et al., 2013). However, recent developments in thermal infrared camera resolution and mobility (e.g. combined with unmanned aerial vehicle – UAV) now allow characterizing microclimates experienced by tiny insect pests over large areas (Faye et al., 2016b). Here, we used aerial thermal infrared cameras (both fixed on UAV and long perches) to yield accurate estimate of the spatiotemporal heterogeneity of surface temperatures at the field scale and relate this information with the occurrence of 4 major potato

pests and diseases. We sampled 38 potato fields (*Solanum tuberosum* L.) with aerial thermal infrared and visual imagery to obtain, after GIS processing, surface temperatures of crop canopies. The main objectives of this study were to characterize the intra-field spatiotemporal heterogeneity in surface temperatures at a resolution relevant for pests and diseases evolving at the leaf surface, and to assess whether such thermal heterogeneity can be related to pest occurrence in various parts of the field. We hypothesized that 1) the range of temperatures available for pests in crop canopies within the field was mostly independent upon the spatial scale considered, 2) daily variations in solar radiation influence microclimate habitats available for pests, 3) pests would be found at higher densities in their optimal thermal microclimates, and 4) higher diversity of microclimates would allow the co-occurrence of more pest species (that have different thermal needs) within the same field.

2. Materials and methods

2.1. Data acquisition

2.1.1. Study area

Measurements were carried out during the last 2 weeks of January 2014 in 38 potato fields located 115 km south from the equatorial line (01°01'36"S, 78°32'16"W) at 2850 ± 135 m.a.s.l. in the Cotopaxi province of Ecuador. In the region, potato crop, that represents a foremost agronomical income, is confronted to massive pest threats (Dangles et al., 2008). The low seasonality occurring in this region (less than 1 K mean monthly temperature variations along the year) allows potato crops to be planted and harvested all year round, making convenient the study of crops at different growth stages at the same time (Faye et al., 2014). Therefore, pests and diseases, have favourable conditions in terms of both climate and food resource (Dangles et al., 2008). The 38 studied fields provided a balanced sample of potato crop phenology from leaf development to mature stage (Table 1). They were planted with 1-m spaced rows (± 0.16) and with 0.5-m spaced plants (± 0.06) within each row. To ensure comparability, we chose fields presenting homogenous farmers' practices in terms of irrigation, pesticide and fungicide applications. Indeed, fields were not irrigated at least within the last 3 days before sampling and pesticide and fungicide applications were not performed during the last 5 weeks before sampling. Pesticide and fungicide applications were considered homogeneous between farmers (personal observations, Pumisacho and Sherwood, 2002). Fields' size ranged from 630 to 3072 m² (average of

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