Neotropical Entomology
https://doi.org/10.1007/s13744-021-00872-4

ECOLOGY, BEHAVIOR AND BIONOMICS

Can Occurrence and Distribution of Ground Beetles (Carabidae) Be Influenced by the Coffee Farming System in the Mount Elgon Region of Uganda?

Anthony Raphael Ijala[1] · Samuel Kyamanywa[1] · Scola Cherukut[1] · Christopher Sebatta[1] · Thomas Hilger[2] · Jeninah Karungi[1]

Received: 23 May 2020 / Accepted: 19 March 2021

Abstract

The Mount Elgon region of Uganda has coffee farmlands distributed along the slopes of the mountain, in a mosaic of differing crop combinations, and semi-natural vegetation. Thus, there are parcels of varying microclimate that create disparities in occurrence of key insect functional groups. The study quantified the occurrence of Carabidae in 72 coffee farmlands categorized by altitude: low (1400–1499 m.a.s.l), mid (1500–1679 m.a.s.l), and high (1680–2100 m.a.s.l); and farming system: coffee monocrop, coffee+annual crops, coffee+banana, and coffee+banana+shade trees. The results revealed highly significant effects of altitude, farming systems, and the interaction of the two on occurrence of three Carabidae genera (*Anisodactylus*, *Chlaenius*, and *Harpalus*.). The abundance of *Harpalus* spp. was higher at lower altitudes in coffee monocropped farming systems; *Anisodactylus* spp. were more abundant at higher altitudes in coffee+annual crop systems; and *Chlaenius* spp. were highest in the coffee+banana+shade tree system at mid altitudes. The belowground microclimate parameters of soil moisture, pH, EC; and the aboveground diversity of semi-natural vegetation explained some of the differences in occurrence of the different Carabidae genera. This distinctiveness in preference of different genera in the same family hinders collective recommendations but looks to a more pragmatic strategy in nurturing diversity on a holistic scale.

Keywords Semi-natural vegetation · soil chemical properties · ecological service · microenvironments

Introduction

Ground beetles (Coleoptera: Carabidae) are usually diverse and highly abundant in nature and agroecosystems and offer crop protection services as biological control agents of insect pests (LaRochelle 1990; Kromp 1999; Sunderland 2002; French et al. 2004; Menalled et al. 2007; Leslie et al. 2009; Traugott et al. 2012; Evans 2016; Adhikari and Menalled 2018). Carabidae with relevance to agroecosystems are of particular genera; they have specific preferences, and characteristic appendages in their morphology, which enables them to climb and fly on top of plants for insect searches (Chiverton 1987; Lovei and Sunderland 1996; Snyder and Ives 2001). Carabidae are well documented as generalist predators of insect pests in major cropping systems (Lovei and Sunderland 1996; Ogunrinde and Afolabi 2007), especially of aphid species (Edwards et al. 1979; Chiverton 1987; Loughridge and Luff 1983; Ogunrinde and Afolabi 2007). Important and common Carabidae genera in the agroecologies which have been reported in the insect control, notably *Harpalus* spp., *Chlaenius* spp., *Anisodactylus* spp., *Bembidion* spp., and *Pterostichus* spp. (Edwards et al. 1979; Loughridge and Luff 1983; Kromp 1999; Tooley and Brust 2002; Milius et al. 2006).

These Carabidae are reported to have common associations with particular habitats such as field edges, marginal lands, dry grasslands, pastures, and mulched layers (Thiele 1977; Desender and Bosmans 1998; Merivee et al. 2004, 2006; Milius et al. 2006; Ogunrinde and Afolabi 2007; Koivula

Edited by Simão Dias Vasconcelos

✉ Anthony Raphael Ijala
tonyijala209@gmail.com; t_ijala@yahoo.co.uk;
aijala@caes.mak.ac.ug

[1] Dept of Agricultural Production, School of Agricultural Sciences, Makerere Univ, Kampala, Uganda

[2] Institute of Agricultural Sciences in the Tropics (Hans-Ruthenberg-Institute, Agronomy in the Tropics and Subtropics), Stuttgart, Germany

Published online: 23 April 2021

2011; Sadej et al. 2012; Goulet 2003). The Mount Elgon region of Uganda has coffee farmlands distributed along the slopes of the mountain (1400–2300 m above sea level) in a mosaic of differing crop combinations and semi-natural vegetation. The varying altitude and cropping/vegetation intensity create parcels of microclimate that may affect insect functional groups differently. Indeed, altitude has been reported to moderate soil properties and vegetative physical presence causing direct and/or indirect impacts on Carabidae aggregations (Siemann 1998; Yüksek et al. 2013; Park et al. 2015; Nietupski et al. 2015; Twardowski et al. 2017). The parameters of soil that have been reported to influence Carabidae populations are soil acidity, soil salts, and soil moisture (Goulet 2003; Sadej et al. 2012).

Conversely, farming systems with unique styles of vegetative inclusions such as intercropping, agroforestry, hedgerows, road reserves, fallows, tree strips, contour tillage, and minimum tillage are also reported to modify belowground microclimates leading to variable Carabidae occupations (Welsh 1990; Siemann 1998; Desender and Bosmans 1998; Holland and Luff 2000; Szyszko et al. 2000; Aviron et al. 2005; Skalski et al. 2011; Liu et al. 2015; Nietupski et al. 2015; Twardowski et al. 2017; Li et al. 2017).

The unique biophysical parcels in the coffee farmland mosaics of the Mt. Elegon region were found to have distinct effects on soil macrofauna (Karungi et al. 2018); and the Hymenopteran complex associated with the coffee berry borer (Ijala et al. 2019); with specific recommendations that can promote conservation efforts. Studies on the occurrence and specific preferences of the Carabidae genera therefore could add to the generated information for the Mt. Elgon region and provide insights that will boost biological control measures in the Coffee farmlands as a whole. The study tested two hypotheses: (i) There is higher occurrence of Carabidae in coffee systems that are less disturbed by annual cropping; (ii) Soil properties are more important than semi-natural vegetation diversity in determining Carabiadae occurrence in the coffee farmlands of the Mt. Elgon region.

Materials and methods

Study site description

The study was carried out in Eastern Uganda, on the slopes of Mount Elgon, from 1400 to 2100 meters above sea level. Two districts, Kapchorwa, on the slopes and Sironko on the slopes were included in the study. The area is highly productive for Arabica coffee (Kapchorwa District Local Government 2011) and lies within 1°8′43″N–1°23′04″N and 34°22′26″E–34°26′29″E; with a bimodal rainfall pattern, attaining annual precipitation range of 1200–2200 mm (National Environmental Management Authority 2010). The average annual minimum and maximum temperature of the area stands at 13.2°C and 23.2°C, respectively (Buginyanya local weather station). The soils have been described as Nitisols (International Union of Soil Science 2007), developed on basaltic outflows (De Bauw et al. 2016). The farmlands are majorly mixed cropping system/agroforestry which includes perennial plantations of coffee trees, banana, and shade trees; regularly teamed with seasonal crops that majorly include *Zea mays*, *Solanum tuberosum*, *Phaseolus vulgaris,* and *Arachis hypogaea* in a matrix of semi-natural vegetation (Karungi et al. 2018; Ijala et al. 2019).

Research design

The study was designed with two independent factors, i.e., altitude and farming system. The altitude was the major factor, and was categorized at three levels: low (1400–1499 m.a.s.l), mid (1500–1679 m.a.s.l), and high (1680–2100 m.a.s.l) following the procedures of Karungi et al. (2018). The farming system, the second factor was nested in altitude and had four categories: coffee monocrop, coffee+annual (coffee + one or two of the seasonal crops as practiced in the area), coffee+banana, and coffee+banana+shade trees that were replicated three times. We used transect walks to establish 72 study sites, each with an area of about 4000 m^2 denoted by GIS 3.2/ GPS points following the guidelines of Ijala et al. (2019), Diekotter et al. (2010). So, for each district, in each of the three demarcated altitudinal levels, four farming systems were selected, replicated three times (2 districts × 3 altitude levels × 4 farming systems × 3 replications = 72).

Data collection

Abundance of Carabidae

In each field, ten pitfall traps were established in a zig-zag pattern below the canopies of the plants, spaced at least 10m apart for monthly monitoring of Carabids following the guidelines of Dauber et al. (2005), Qodri et al. (2016), Mwambala et al. (2019), Allema et al. (2019). This was a longitudinal study over a period of 2 years. As such, every month a total of 720 pitfall traps (2 districts × 3 altitude levels × 4 farming system × 3 replicates × 10 traps each) were processed. The pitfall traps were made of 500-ml plastic cups (diameter 85 mm) filled with approximately 170 ml of ethanol-glycerine solution (2:1) and a detergent was added in, to reduce surface tension. Rain covers (metallic sheets, 250 mm) were placed approximately 10 cm above each trap to prevent flooding by rain following the guidelines of Dauber et al. (2005), Liu et al. (2015), Baranová et al. (2018), Allema et al. (2019). The trapped insects were collected into 300 ml bottles containing 70% ethanol. All the bottles were precisely labeled by farm code, farming system, altitude, and dataset. The insects were then sorted using an insect dichotomous key into major groups such as beetles, ants, centipedes, and millipedes. The majority of the insects collected in good condition were beetles compared to the rest which existed in pieces of body parts. The beetles were further sorted into distinct groupings using their external morphological features. These proceeded for identification into family, subfamily, genera, and species level using comparative morphological identification keys at Kenya National Museum in Nairobi following the guidelines of a Lindroth (1974) handbook. Thirteen representatives of these samples were sent to the CABI Plantwise diagnostic and advisory services in the UK where they were confirmed using the morphological identification and sequencing results (inquiry No CABI 002-18). These were analyzed using the database held by BOLD (Barcode of Life Data System (Databases/ BOLDSYSTEM) and the European Molecular Biology Laboratory (EMBL) database via the European Bioinformatics Institute (EBI), using the FASTA algorithm with the 'ENA Sequence Invertebrate' database, and NCBI GenBank 'Others' database using the BLAST algorithm. Only 4 of the 13 representative Coleoptera were confirmed to belong to the family Carabidae. Of the remaining 9; 2 were identified as Nitidulidae, 3 as Scarabaeidae, 1 as Rhopalidae, and 3 were not clearly identified. All the representatives of the thirteen (subsamples) were deposited at CABI with the inquiry No CABI 002-18. The four which were confirmed as Carabidae family were identified to genus and/or species (*Anisodactylus australis*, Per, *Anisodactylus* sp.; *Harpalus crotognathoides* Gat, *Harpalus asemus* Bas.; *Chlaenius discopictus*, Frm and *Chlaenius* sp). These were deposited at the Kenya National Museum (Reference NMK/SIZ-IC 103). In the bulk of the analysis, it is only data of the three identified Carabidae genera that was used. Information on the trap collections is summarized in Table 1.

Ambient and soil microclimate and soil properties

The data on the microclimatic conditions for each farm was recorded at midday on sampling days (light in foot-candles, the temperature in ^{0}C; and percentage relative humidity) taken along the diagonal and recorded at three points. A thermo-hygrometer pen (Model 3402, Spectrum Technologies, Inc. 2009) was used for relative humidity ± 3% and temperature ± 0.6 °C; and foot candle meter (Model 3413F, Spectrum Technologies, Inc. 2011) for light intensity ± 5% following the techniques of (Dunning 2009; Jonsson et al. 2014; Karungi et al. 2018; Ijala et al. 2019). These were later used in regressions to establish relationships with Carabidae occurrence. Mean microclimate parameters, designated as above ground microclimate for the studied farmlands are shown in the supplementary material (S1) submitted with the manuscript.

The data on soil properties were obtained in-situ at each farm level that is soil temperature (± 1°C), soil moisture (± 3% VWC), and soil electrical conductivity (EC) ± 5% from 0 to 5 dS/m using Prochecksensor (GS3 model) and soil pH using a pH meter following the technology of Wadsworth (2015). All the measurements were taken from a soil depth of 0 – 15 cm. The soil organic matter was determined from a composite sample using laboratory procedures (Wakley & Black method) following Okalebo et al. (2002). A checklist was used to collect data on soil management practices and categorized as 1 = organic-intensive, 2 = inorganic-intensive, and 3 = no management. The data on soil variables were used in correlations and regression with Carabidae occurrence following Karungi et al. (2018). Mean soil microclimate parameters designated as belowground microclimate parameters for the studied farmlands are shown in Table S2 supplementary material.

Table 1 Insect groups, total number of insects, and percentage trap collections using pitfall traps

Insect group	Insect total numbers	% trap collection
Carabidae	9780	54.4
Nitidulidae	1078	6.1
Scarabaeidae	2451	13.6
Rhopalidae	987	5.4
Un-identified Coleoptera	3693	20.5
Grand total	**17989**	**100**

Semi-natural vegetation parameters

To establish abundance and diversity of the semi-natural vegetation in the coffee fields and hedgerows, fields and field margins 5 m into the surrounding area of the perimeter of the study fields were recorded. The inventory showed that semi-natural vegetation comprised of plants in the families: Boraginaceae, Fabaceae, Lauraceae, Anacardiaceae, Meliaceae, Proteaceae, Verbenaceae, Euphorbiaceae, Myrtaceae, Moraceae, Caricaceae, Pinaceae, Asteraceae, Oxalidaceae, Commelinaceae, Solanaceae, Cannabaceae, Amaranthaceae, and Poaceae.

Data on abundance was collected using counts within 1 by 1m quadrants for weeds and grasses; expanded to bigger demarcations or individual counts in case of shrubs and trees following Wilson (2007). Species total counts were established for each study site as a discrete variable. Shannon's diversity indices were derived by calculations following Shannon and Weaver (1949). The diversity of the semi-natural vegetation of the studied farmlands is shown in Table 2.

Data analysis

Data on Carabidae counts were analyzed using the generalized linear mixed models (GLMM) of GenStat 13 computer

Table 2 Diversity Indices (Shannon's *H*, Shannon's *E*), and abundance of semi-natural vegetation (mean number of plant species/ ha) in different farming systems at different altitudinal levels

Altitude	Farming system	Shannon's *H*	Shannon's *E*	Mean no. of species/ha
Low	Coffee monocrop	1.785	0.790	9.5
	Coffee+annual	1.895	0.840	9.5
	Coffee+banana	1.815	0.770	10.5
	Coffee+banana+ shade tree	1.700	0.575	19.5
Mid	Coffee monocrop	1.930	0.740	12.0
	Coffee +annual	1.930	0.855	10.0
	Coffee+banana	1.740	0.770	10.0
	Coffee+banana+ shade tree	1.845	0.665	17.0
High	Coffee monocrop	2.100	0.880	11.0
	Coffee+annual	1.925	0.825	10.5
	Coffee+banana	1.855	0.845	9.0
	Coffee+banana+ shade tree	1.820	0.760	11.0

software. The Poisson distribution with a logarithm link was used with the farm as a random factor with a dispersion of 1 for fixed factors. The Wald tests were generated for tables and back-transformed means were used in the figures. Mean separations were done using Fischer's protected LSD at 5%.

The soil properties, above ground microclimate, and semi-natural vegetation species parameters were used as predictors while transformed numbers of Carabidae were the response variables in the general linear regression. The automatic selection of potentially important predictors was done using a stepwise regression procedure of a generalized linear regression model. In the testing criteria, fixed critical *F*-values (Test Criterion) were used which are not based on the actual *F*-distribution. Typically, criterion values of 4.0 were selected in the stepwise methods. The Change Model was used to add the predictors and the worst predictors were dropped off from the model (O'Neill 2010; Gallagher et al. 2011).

Results

The effect of altitude and farming system on Carabidae occurrence

The analysis revealed a highly significant effect of altitude, farming system, and their interaction on occurrence of the Carabidae genera; *Anisodactylus* spp., *Chlaenius* spp., and *Harpalus* spp. (Table 3). *Harpalus* spp. occurred in all studied farmlands but had a marked abundance in the coffee monocrop system at low altitudes (Fig. 1a). *Anisodactylus* spp. were more abundant at high altitude and in the coffee+ annual crop system (Fig. 1c). *Chlaenius* spp. had a patchy occurrence and was not recorded at low altitude in the coffee monocrop, and the coffee+banana+shade trees system, but showed a distinct higher abundance at mid altitudes in the coffee+banana+shade trees system (Fig. 1b). Collectively, the coffee+banana+shade tree system had the highest Carabidae abundance; however, this was not significantly different from the coffee monocrop (Fig S1).

The relationship between Carabidae occurrence and above- and belowground microclimate parameters, and diversity of semi-natural vegetation

Linear regression of potentially important predictors for Carabidae abundance indicated specific significant relationships. Soil moisture, pH, and soil EC were the studied soil properties and formed the belowground microclimate. For *Anisodactylus* spp., the only significant relationship was with soil moisture, which was positive (Table 4). On the other hand, *Harpalus* spp. had a negative relationship with soil

Table 3 The *F*-statistics, Wald statistics, and numerator degree of freedom for the occurrence of Carabidae genera in different farming systems at different altitudinal levels

Fixed term	Wald statistic	n.d.f.	*F* statistic
***Anisodactylus* spp.**			
Altitude	9707.93	2	4853.97***
Farming system	1696.85	3	565.62***
Altitude farming system	2598.26	6	433.04***
***Chlaenius* spp.**			
Altitude	385.00	2	192.5***
Farming system	1547.03	3	515.68***
Altitude farming system	112.72	6	18.79***
***Harpalus* spp.**			
Altitude	10253.53	2	5126.77***
Farming system	10029.75	3	3343.25***
Altitude farming system	6703.860	6	1117.31***

Values with *** sig. at $P < 0.001$

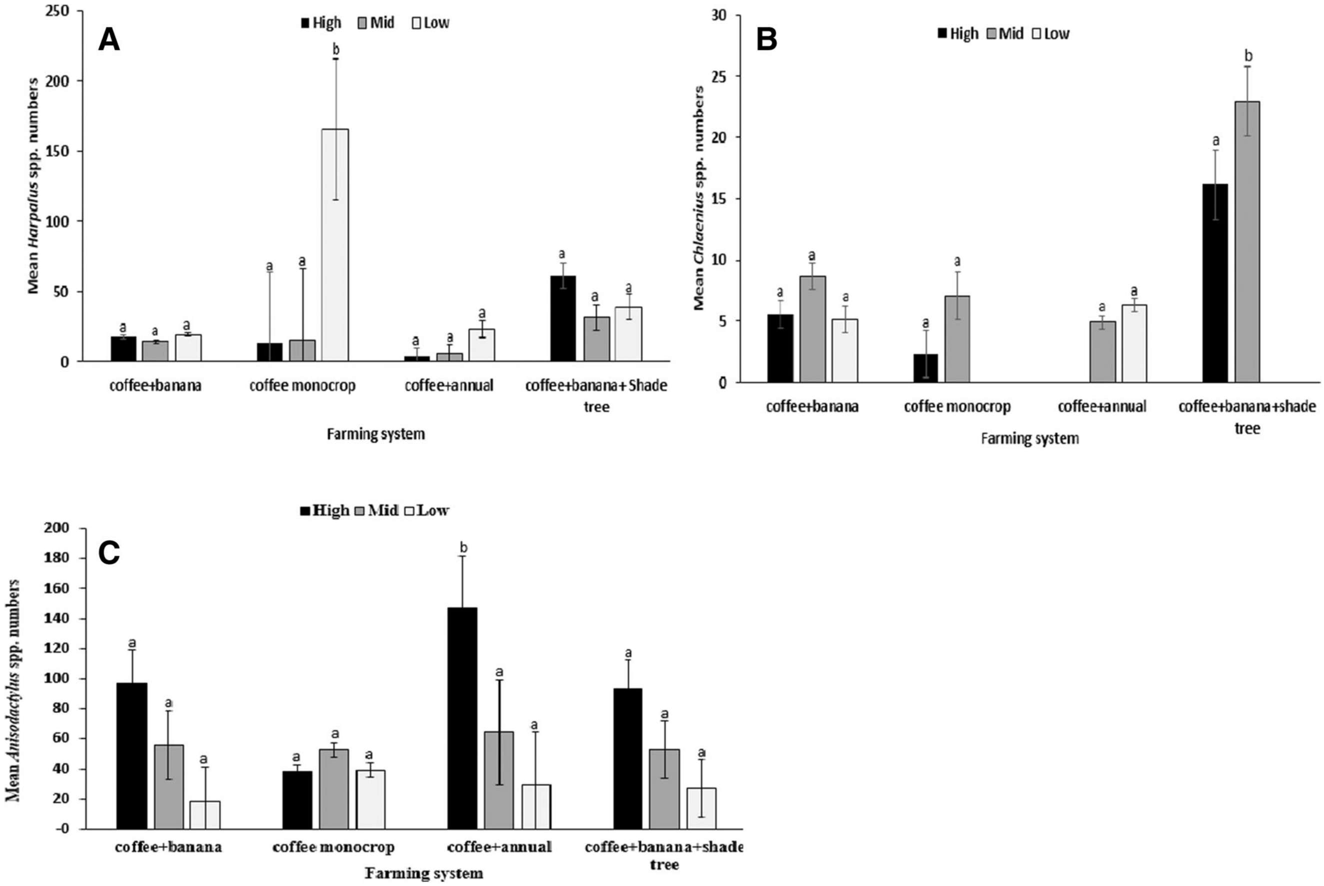

Fig. 1 Mean numbers + SE of Carabidae in different farming systems at different altitudes. **A** *Harpalus* spp. **B** *Chlaenius* spp. **C** *Anisodactylus* spp. b highly significant at $P < 0.001$; a not significant at $P < 0.001$

moisture, and a positive relationship with soil EC (Table 4a). *Chlaenius* spp. had a significant relationship with soil pH, which was negative; and a marginal negative relationship with soil EC (Table 4).

Uniquely, ambient temperature, relative humidity, and light intensity that formed the aboveground microclimate were not significant predictors of Carabidae abundance for any genera in this study (Table 4). With regard to the relationship with semi-natural vegetation, *Chlaenius* spp. was the only Carabidae genera that showed a significant relationship with semi-natural vegetation diversity, which was positive (Table 5).

Discussion

Altitude- and farming system-driven soil microclimate as a predictor of Carabidae occurrence

The Carabidae preference to specific niches of farming systems at different altitudes can to some extent be explained by the belowground microclimate. For instance, *Harpalus* spp. were more abundant at low altitude. Low altitude had relatively low soil moisture levels (mean 0.392 m^3/m^3; vs. 0.455 for high altitude) but high soil EC (mean 0.224 dS/m vs. 0.214 for high altitude), and in fact, the regression analysis showed that *Harpalus* spp. had a significant negative relationship with soil moisture but a more significant positive relationship with soil EC, which could explain the preference of the coffee monocrop which had the highest EC at that altitude. The coffee monocropped fields are mostly maintained under slashed predominantly grassy undergrowth conditions with no tillage, which could have retained stable soil moisture and EC levels that favored *Harpalus* spp. The work of Twardowski et al. (2017) reported Carabidae preference for less disturbed grassy areas (mowed once a year); and the study by Desender and Bosmans (1998) reported grasslands as important niches for Carabidae populations. Also, Sadej et al. (2012) indicated a better chance for survival of Carabidae under grassy land conditions. This could explain why in this study, total Carabiade were higher in coffee monocrop and coffee+banana+shade trees systems.

In this study, *Chlaenius* spp. occurrence was highest at mid-altitude in the coffee+banana+shade trees system, a system that recorded a relatively lower pH (6.827 c.f. mean of 6.886). *Chlaenius* spp. was the only Carabidae genera

Table 4 Regression parameter estimates, standard error, and *T* statistic for the relationship of Carabidae counts with below and above ground microclimate parameters

Carabidae genera	Parameter	Estimate	s.e.	*T* statistic
Belowground microclimate parameters				
Anisodactylus spp.	Constant	0.242	0.949	0.26
	soil moisture (m^3/m^3)	3.86	1.500	2.58**
	pH	0.047	0.139	0.34
	soil EC (dS/m)	− 1.041	0.989	− 1.05
Harpalus spp.	Constant	3.80	1.22	3.12**
	soil moisture (m^3/m^3)	− 5.80	1.92	− 3.01
	pH	− 0.285	0.178	− 1.60
	soil EC (dS/m)	6.73	1.27	5.30***
Chlaenius spp.	Constant	2.418	0.912	2.65*
	soil moisture (m^3/m^3)	0.840	1.44	0.58
	pH	− 0.292	0.133	− 2.19*
	soil EC (dS/m)	− 1.753	0.95	− 1.84
Above ground microclimate parameters				
Anisodactylus spp.	Constant	0.730	1.69	0.43
	% relative humidity	0.0142	0.025	0.57
	Light intensity (foot candles)	0.0006	0.001	0.43
Harpalus spp.	Constant	0.920	4.63	0.20
	% relative humidity	0.0305	0.038	0.81
	Temperature (°C)	− 0.088	0.113	− 0.78

Carabidae genera	**Parameter**	**Estimate**	**s.e.**	***T* statistic**
Belowground microclimate parameters				
Anisodactylus spp.	Constant	0.242	0.949	0.26
	soil moisture (m^3/m^3)	3.86	1.500	2.58**
	pH	0.047	0.139	0.34
	soil EC (dS/m)	− 1.041	0.989	− 1.05
Harpalus spp.	Constant	3.80	1.22	3.12**
	soil moisture (m^3/m^3)	− 5.80	1.92	− 3.01
	pH	− 0.285	0.178	− 1.60
	soil EC (dS/m)	6.73	1.27	5.30***
Chlaenius spp.	Constant	2.418	0.912	2.65*
	soil moisture (m^3/m^3)	0.840	1.44	0.58
	pH	− 0.292	0.133	− 2.19*
	soil EC (dS/m)	− 1.753	0.95	− 1.84
Above ground microclimate parameters				
Anisodactylus spp.	Constant	0.730	1.69	0.43
	% relative humidity	0.0142	0.025	0.57
	Light intensity (foot candles)	0.0006	0.001	0.43
Harpalus spp.	Constant	0.920	4.63	0.20
	% relative humidity	0.0305	0.038	0.81
	Temperature (°C)	− 0.088	0.113	− 0.78

Chlaenius spp. *(parameters were minor to the model and dropped off)*

*** Sig. at < 0.001, ** sig. at < 0.01, * sig. at < 0.05

responsive to soil pH with a marked negative association. In this study, the soil pH decreased with increasing altitude as earlier reported by De Bauw et al. (2016) working in the same region, and the lowest pH was recorded in the coffee+banana+shade tree's system at high altitude (6.472). The coffee+banana+shade trees system had the most litter. Decomposing

Table 5 Regression parameter estimates, standard error, and *T* statistic for the relationship of Carabidae counts and semi-natural vegetation diversity

Carabidae genera	Parameter	Estimate	s.e.	*T* statistic
Anisodactylus spp.	Constant	5.400	1.560	3.47
	Semi-natural vegetation	− 0.287	0.456	− 0.63
Harpalus spp.	Constant	− 0.66	1.400	− 0.47
	Semi-natural vegetation	0.684	0.410	1.67
Chlaenius spp.	Constant	− 0.772	0.599	− 1.29
	Semi-natural vegetation	0.416	0.176	2.37*

Values with * sig. at $P < 0.05$

vegetative materials under acidic conditions have been reported to provide shelter, breeding, and dispersal environments for the Carabidae (Hance 2002). Baranová et al. (2018) also reported humus accumulation was promoting the presence of Carabids under acidic conditions.

Anisodactylus spp. showed a marked preference for high altitudes in coffee+ annual farming systems. The coffee+ annual crop systems undergo frequent tillage operations during seasonal additions of the annual crops; which create loosened soil conditions that may favor this genera. The preference for high altitude could be due to the high soil moisture levels high up on the slopes of the mountain as it showed a significant positive relation with soil moisture. Members of this genera have been reported to exhibit specific preference for habits/niche with moderately moist conditions (Eo et al. 2016; Qodri et al. 2016).

Though distinct in effect for the three Carabidae genera, this study provides further evidence of soil moisture and soil pH as important drivers of Carabidae occurrence. The study adds to the findings of Baguette (1993) who reported that distributions of Carabids were mostly related to the acidity, organic content, and water holding capacity of the soils to Holopainen et al. (1995) who ranked soil water content and soil pH as some of the soil factors of importance to Carabidae; to Luff (1996) who stated that, soil moisture is the most important environmental factor affecting Carabid assemblages and, more recently, to Vician et al. (2015) who reported higher species diversity of Carabid beetles in the plots with a higher pH and humus content.

The soil moisture, soil pH, and soil EC found in the studied parcels are a result of prevailing physical and management aspects, in this case the interaction between altitude and farming systems, a fact that is echoed by other studies (Adis 1998; De Bauw et al. 2016; Baranová et al. 2018; Hiramatsu and Usio 2018; Allema et al. 2019).

Semi-natural vegetation diversity and Carabidae occurrence

Though some studies have shown Carabidae to prefer more diverse crop habitats (Noordijk et al. 2011), in this study *Chlaenius* was the only genera that were positively influenced by increased semi-natural vegetation diversity. Luff and Rushton (1989) also reported that ground beetle communities are influenced more by soil parameters than vegetation structure. Tscharntke et al. (2005), Liu et al. (2012) showed Carabidae to uniquely prefer intensively cultivated arable land compared to undisturbed or semi-natural habitats.

Even in the cultivated habitats, our study has shown that it is not a “one size fits all” scenario for the Carabidae. What is clear is that Carabidae occurrence is to some extent shaped by farming practices linked to the respective decisions made on the farms, for example, management directly impacting the diversity of the plant communities, and soil and water conservation techniques.

Carabidae were the most abundant group in the trap catches. *Anisodactylus, Chlaenius and Harpalus* were the predominant Carabidae. There were specific genera niche preferences as a result of soil properties, and semi-natural vegetation diversity, which stemmed from the farming system and altitudinal placement. The findings highlighted a complex system that is not amenable to collective recommendations but looks to a more pragmatic strategy in nurturing diversity on a holistic scale.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s13744-021-00872-4.

Acknowledgements We are very thankful to the farmers, extension staff, technical advisors, field assistants, and technicians that participated in this study. The team from The Kenya National Museum, and the CABI Plantwise diagnostic and advisory services in the UK for their taxonomic support.

Author contribution IAR, KS, and KJ conceived the research. IAR, CS, and SC conducted experiments. KS and KJ contributed material. IAR analyzed data and conducted statistical analyses. IAR and KJ wrote the manuscript. KJ secured funding. All authors read and approved the manuscript and that there are no other persons who satisfied the criteria for authorship but are not listed. We further confirm that the order of authors listed in the manuscript has been approved by all of us.

Funding This study was funded by the Volkswagen Foundation through the African Initiative Project (#89 365).

Declarations

Conflict of interest The authors declare no competing interests.

References

Adhikari S, Menalled F (2018) Impacts of dryland farm management systems on weeds and ground beetles (Carabidae) in the Northern Great Plains. Sustainability 10:2146

Adis J (1998) On occurrence, habitat specificity and natural history of adult tiger beetles (Coleoptera: Carabidae: Cicindelinae) near Manaus, Central Amazonia, and key to the larvae of tiger beetle genera. Acta Amazonica. https://doi.org/10.1590/1809-43921998283272

Allema B, Hemerik L, RossingWA GJC, van Lenteren JC, van der Werf W (2019) Dispersal of a Carabid beetle in farmland is driven by habitat-specific motility and preference at habitat interfaces. Entomol Exp et App 167:741–754. https://doi.org/10.1111/eea.12804

Aviron S, Burel F, Baudry J, Schermann N (2005) Carabid assemblages in agricultural landscapes: impacts of habitat features, landscape context at different spatial scales and farming intensity. Agric Ecosyst Environ 108:205–217

Baguette M (1993) Habitat selection of carabid beetle in deciduous woodlands of southern Belgium. Pedobiologia 37:365–378

Baranová B, Fazekašová D, Peter Manko P, Jászay T (2018) Variations in Carabidae assemblages across the farmland habitats in relation to selected environmental variables including soil properties. J Cent Eur Agric. https://doi.org/10.5513/JCEA01/19.1.2022

Chiverton PA (1987) Predation of Rhopalosiphum padi (Homoptera: Aphididae) by polyphagous predatory arthropods during the aphids' pre-peak period in spring barley. Ann Appl Biol 109:49–60

Dauber J, Purtauf T, Allspach A, Frisch J, Voigtländer K, Wolters V (2005) Local vs. Landscape controls on diversity: a test using surface-dwelling soil macroinvertebrates of differing mobility. Global Ecol Biogeogr 14:213–221

De Bauw P, Van Asten P, Jassogne L, Merckx R (2016) Soil fertility gradients and production constraints for coffee and banana on volcanic mountain slopes in the East African Rift: a case study of Mt. Elgon, Agriculture. Ecosyst Environ 231:166–175

Desender K, Bosmans R (1998) Ground beetles (Coleoptera, Carabidae) on set-aside fields in the Campine region and their importance for nature conservation in Flanders (Belgium). Biodivers Conserv **7**: 1485–1493

Diekotter T, Wamser S, Wolters V, Birkhofer K (2010) Landscape and management effects on structure and function of soil arthropod communities in winter wheat. Agric Ecosyst Environ 137:108–112

Dunning MJ (2009) Weather Products Manager. Spectrum Technologies, Inc.

Edwards CA, Sunderland KD, George KS (1979) Studies on polyphagous predators of Cereal aphids. J Appl Ecol 16:811–823

Eo J, Kim M, Bang H, Choi S, Na Y, Cho K, Oh Y, Yang D, Park S (2016) Effects of climate and landscape heterogeneity on the distribution of ground beetles (Coleoptera: Carabidae) in agricultural fields. J Asia Pac Entomol 19(2016):1009–1014

Evans EW (2016) Biodiversity, ecosystem functioning, and classical biological control. Appl Entomol Zool 51:173–184. https://doi.org/10.1007/s13355-016-0401-z

French BW, Chandler LD, Ellsbury MM, Fuller BW, West M (2004) Ground beetle (Coleoptera: Carabidae) assemblages in a transgenic corn–soybean cropping system. Environ Entomol 33:554Ð563

Gallagher J, Stern R, Palmer A, Latham S (2011) Analyzing climatic data using GenStat for Windows

Goulet H (2003) Biodiversity of ground beetles (Coleoptera: Carabidae) in Canadian agriculturalsoils. Can J Soil Sci 83:259–264

Hance T (2002) Impact of cultivation and crop husbandry practices. In: Holland JM (ed) The agroecology of carabid beetles. Intercept Ltd, Andover, pp 231–249

Hiramatsu S, Usio N (2018) Assemblage characteristics and habitat specificity of Carabid beetles in a Japanese Alpine-Subalpine Zone. Psyche. https://doi.org/10.1155/2018/9754376

Holland JM, Luff ML (2000) The effects of agricultural practices on Carabidae in temperate agro ecosystems. Integr Pest Manag Rev 5:109–129

Holopainen JK, Bergman T, Hautala E-L, Oksanen J (1995) The ground beetle fauna (Coleoptera: Carabidae) in relation to soil properties and foliar fluoride content in spring cereals. Pedobiologia 39:193–206

Ijala AR, Kyamanywa S, Cherukut S, Sebatta C, Karungi J (2019) Parasitism of *Hypothenemus hampei* (Coleoptera: Scolytidae) in different farming systems and altitudes of Mount Elgon, Uganda. J Appl Entomol. https://doi.org/10.1111/jen.12689

International Union of Soil Science (2007) World reference base for soil resources. First FAO, Rome http://www.fao.org/ag/agl/agll/wrb/doc/wrb_corr.pdf

Jonsson M, Ijala AR, Ekbom B, Kyamanywa S, Karungi J (2014) Contrasting effects of shade level and altitude on two important coffee pests. J Pest Sci. https://doi.org/10.1007/s10340-014-0615-1

Kapchorwa District Local Government (2011) Approved five year district development plan 2011/2012–2015/2015. Republic of Uganda, Kampala

Karungi J, Cherukut S, Ijala AR, Tumuhairwe JB, Bonabana-Wabbi J, Nuppenau EA, Otte A (2018) Elevation and cropping system as drivers of microclimate and abundance of soil macrofauna in coffee farmlands in mountainous ecologies. Appl Soil Ecol. https://doi.org/10.1016/j.apsoil.2018.08.003

Koivula MJ (2011) Useful model organisms, indicators, or both? Ground beetles (Coleoptera, Carabidae) reflecting environmental conditions. ZooKeys. https://doi.org/10.3897/zookeys.100.1533

Kromp B (1999) Carabid beetles in sustainable agriculture: a review on pest control efficacy, cultivation impacts and enhancement.Agriculture. Ecosyst Environ 74:187–228

LaRochelle A (1990) The Food of Carabid Beetles *(Coleoptera:* Carabidae*,* including Cicindelinae*)*. Fabreries Supplement 5

Leslie TW, Biddinger DJ, Mullin CA, Fleischer SJ (2009) Carabid population dynamics and temporal partitioning: Response to coupled neonicotinoid-transgenic tecnhologies in maize. Environ Entomol 38(3):935–943

Li WB, Liu NY, Wu YH, Zhang YC, Xu Q, Chu J, Fang J (2017) Community composition and diversity of ground beetles (Coleoptera: Carabidae) in Yaoluoping National Nature Reserve. J Insect Sci. https://doi.org/10.1093/jisesa/iex081

Lindroth CH (1974) Coleoptera, Carabidae. Handbooks for the Identification of British insects, Volume 4, part 2. Royal Entomological Society, London

Liu Y, Axmacher JC, Wang C, Li L, Yu Z (2012) Ground beetle (Coleoptera: Carabidae) assemblages of restored semi-natural habitats and intensively cultivated fields in Northern China. Restor Ecol 20(2):234–239

Liu Y, Duan M, Zhang X, Yu Z, Axmacher JC (2015) Effects of plant diversity. Habitat and agricultural landscape structure on the functional diversity of carabid assemblages in the north china plain insect conservation and diversity 8:163–176. https://doi.org/10.1111/icad.12096

Loughridge AH, Luff ML (1983) Aphid predation by Harpus rufipes (Coleoptera carabidae) in the laboratory and field. J Appl Ecol 20: 451–462

Lovei GL, Sunderland KD (1996) Ecology and behavior of ground beetles (Coleoptera: Carabidae). Annu Rev Entomol 41:231–256

Luff ML (1996) Use of carabids as environmental indicators in grasslands and cereals. Ann Zool Fenn 35:185–195

Luff ML, Rushton SP (1989) The ground beetle and spider fauna of managed and unimproved upland pasture. Agric Ecosyst Environ 25:195–205

Menalled FD, Smith RG, Dauer JT, FoxTB (2007) Impact of agricultural management on carabid communities and weed seed predation. Agric Ecosyst Environ 118:49–54

Merivee E, Renou M, Mända M, Luik A, Heidemaa M, Ploomi A (2004) Electrophysiological responses to salts from antennal chaetoid taste sensilla of the ground beetle *Pterostichus aethiops*. J Insect Physiol. https://doi.org/10.1016/j.jinsphys.2004.09.001

Merivee E, Must A, Milius M, Luik A (2006) External stimuli in searching for favourable habitat,overwintering sites and refugia of ground beetles: a short review. Agron Res 4:299–302

Milius M, Merivee E, Williams I, LuikaA MM, Must A (2006) A new method for electrophysiological identification of antennal pH receptor cells in ground beetles: the example of *Pterostichus aethiops* (Panzer, 1796) (Coleoptera, Carabidae). J Insect Physiol. https://doi.org/10.1016/j.jinsphys.2006.06.003

Mwambala AN, Nyundo BA, Kalumanga E (2019) Interface of biodiversity and ecosystem services: Does soil organic carbon correlate with the diversity of carabid beetles (Coleoptera: Carabidae) in the Uzungwa Scarp Nature Reserve, Tanzania? Int J Biodivers Conserv 11(4):114–124

National environmental Management Authority (2010) State of Environment Report for Uganda. National Environment Management Authority, Kampala, Uganda

Nietupski M, Kosewska A, Markuszewski B, Sądej W (2015) Soil management system in hazelnut groves (Corylus sp.) versus the presence of ground beetles. Carabidae, Coleoptera. https://doi.org/10.1515/jppr-2015-0004

Noordijk J, Schaffers AP, Heijerman T, Boer P, Gleichman M, Sykora KV (2011) Effects of vegetation management by mowing on ground-dwelling arthropods. Ecol Eng 36:740–750

O'Neill M (2010) Regression and generalized linear (Mixed) Models. Statistical Advisory and Training Service Pty Ltd. www.stats.net.au

Ogunrinde S, Afolabi A (2007) Permanent Crops Production, ACP303. ISBN:

Okalebo JR, Gathua KW, Woomer PL (2002) Laboratory methods of soil plant analysis. A Working Manual.2nd Edition.TSBF and SACRED Africa, Nairobi, Kenya.

Park YH, Won DS, Jang TW, Chae HM, Kim JH, Kubota K, Kim JK (2015) Community structure and distribution of ground beetles (Coleoptera: Carabidae) in Baekdudaegan Mountain, Gangwon-do, Korea. Forest Science and Technology. https://doi.org/10.1080/21580103.2014.975159

Qodri A, Raffiudin R, Noerdjito WA (2016) Diversity and Abundance of Carabidae and Staphylinidae (Insecta: Coleoptera) in Four Montane Habitat Types on Mt. Bawakaraeng, South Sulawesi. HAYATI Journal of Biosciences. https://doi.org/10.1016/j.hjb.2016.04.002

Sadej W, Kosewska A, Nietupski M (2012) Effects of fertilizer and land-use type on soil properties and ground beetle communities. Bulletin of Insectology, 65, 239-246. Available at: http://www.bulletinofinsectology.org/pdfarticles/vol65-2012-239-246sadej.pdf

Shannon CE, Weaver W (1949) The Mathematical Theory of Communication. University of Illinois Press, Urbana

Siemann E (1998) Experimental tests of effects of plant productivity and diversity on grassland arthropod diversity. Ecology 79:2057–2070

Skalski T, Kędzior R, Maciejowski W, Kacprzak (2011) Soil and habitat preferences of ground beetles (*Coleoptera, Carabidae*) in natural mountain landscape. Balt J Coleopterol l11(2):105–115

Snyder WE, Ives AR (2001) Generalist predators disrupt biological control by a Specialist parasitoid. Ecology 82:705–716

Sunderland KD (2002) Invertebrate pest control by Carabids. In: Holland JM (ed) The Agroecology of Carabid Beetles. Intercept, Andover, UK, pp 165–214

Szyszko J, HJW V, Klimaszewski K, Abs M, Schwerk A (2000) Mean individual biomass (MIB) of ground beetles (Carabidae) as an indicator of the state of the environment. In: Brandmayr P, Lövei G, Zetto Brandmayr T, Casale A, Taglianti AV (eds) Natural history and applied ecology of Carabid beetles. Proceedings of the IX European Carabidologists' Meeting (26–31 July 1998, Camigliatello, Cosenza, Italy). Pensoft, Sofia-Moscow, pp 289–294

Thiele HU (1977) Carabid beetles in their environment: a study on habitat selection by adaptations in physiology and behaviour. Springer, Berlin

Tooley J, Brust GE (2002) Weed seed predation by Carabid beetles. In: Holland JM (ed) In The agroecology of Carabid Beetles. Intercept Ltd, Andover, pp 215–230

Traugott M, Bell JR, Raso L, Sint D, Symondson WOC (2012) Generalist predators disrupt parasitoid aphid control by direct and coincidental intraguild predation. Bull Entomol Res. https://doi.org/10.1017/S0007485311000551

Tscharntke T, Klein AM, Kruess A, Steffan-Dewenter I, Thies C (2005) Landscape perspectives on agricultural intensification and biodiversity-ecosystem service management. Ecol Lett 8:857–874

Twardowski JP, Pastuszko K, Hurej M, Gruss I (2017) Effect of different management practices on ground beetle (Coleoptera: Carabidae). Assemblages of uphill grasslands. Pol J Ecol 65(3). https://doi.org/10.3161/15052249PJE2017.65.3.007

Vician V, Svitok M, Kočík K, Stašiov S (2015) The influence of agricultural management on the structure of ground beetle (Coleoptera: Carabidae) assemblages. Biologia. https://doi.org/10.1515/biolog-2015-0028

Wadsworth M (2015) Decagon Devices, Inc., (2015). Procheck operation manual. 2365 NE Hopkins Court Pullman WA 99163

Welsh RC (1990) Dispersal of invertebrates in the agricultural environment. In: Bunce RGH, Howard DC (eds) Species Dispersal in Agricultural Habitats. Belhaven Press, London, UK, pp 203–218

Wilson MV (2007) Measuring the components of competition along productivity gradients. J Ecol 95:301–308. https://doi.org/10.1111/j.1365-2745.2007.01215

Yüksek F, Altun L, Karaöz O, Şengönül K, Yuksek T, Küçük M (2013) The Effect of altitude on soil properties and leaf traits in Wild Vaccinium arctostaphylos L. populations in the forest understory in Fırtına River basin