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ORIGINAL ARTICLE

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Soil composition affects the nesting behavior of blue-tailed bee-eaters (*Merops philippinus*) on Kinmen Island

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Abstract The blue-tailed bee-eater (*Merops philippinus*) is a summer migrant that breeds on Kinmen Island, located off the west coast of Taiwan, about 5 km from the southern coast of mainland China. The aim of this study was to investigate why blue-tailed bee-eaters build their nests in sandy loam and sandy clay loam, but not in clay loam. Soil chemical and physical properties, and mineralogical composition were measured for the different soil types. Clay loam had a significantly lower pH, Na, and base saturation than did sandy loam or sandy clay loam. Clay loam had a significantly higher N, cation-exchange capacity (CEC), K, and free iron (Fe_d) and aluminum oxide (Al_d) contents than the other soil types. Clay loam had significantly lower sand and higher clay content, and higher bulk density and penetration resistance than the other soil types. The correlation coefficients (r^2) between penetration resistance and Fe_d, Al_d, and clay contents were 0.997, 0.848, and 0.779, respectively. Soil strength and compaction are important criteria for bee-eaters' nesting-site selection. The lower pH of clay loam would enhance the exchangeable Al and acidity, further increasing the soil aggregation. Thus, it might prevent the bee-eaters from excavating nesting burrows.

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Introduction

Blue-tailed bee-eaters (*Merops philippinus*) belong to the order of Coraciiformes and the family of Meropidae. They are summer migrants that breed on Kinmen Island, which is off the west coast of Taiwan, about 5 km from the southern coast of mainland China. Blue-tailed bee-eaters have been recorded in India to southern China, southeast Asia, Sri Lanka, New Guinea, Indonesia, and the islands of the South Pacific Ocean (Fry and Fry 1992; Fry 2001; Clements 2000), but it is not known where the Kinmen Island population over-winters. Blue-tailed bee-eaters nest in burrows and often prefer habitats such as beach sand dunes, construction site sand piles, and sand piles created by excavation of farm ponds. They are generally colonial breeders, nesting in groups up to and even greater than 100 pairs; occasionally a single pair will nest alone. Nesting burrows are tunnels about 1–2 m long and 6–8 cm in diameter. At the end of the tunnel is a wider oval-shaped chamber in which the eggs are laid (Wang 2003).

Kinmen and its neighboring islands are all underlain by granite-gneiss and associated dyke rock of the Mesozoic age (Chen et al. 2004). Three main soil types on Kinmen Island are distributed as sandy loam (78%), clay loam (20%), and sandy clay loam (<2%) (Kuo and Chen 2002). During our 6 years of field study (2000–2005), we found bee-eater nesting in both sandy loam and sandy clay loam but never in clay loam. In 2002, 18 colonies with 822 breeding individuals were monitored, 16 colonies were found in sandy loam (74% of all individuals) and two were found in sandy clay loam (26% of all individuals). No colony was built in clay loam (Yuan et al. 2006). Thus, the aim of this study was to investigate why blue-tailed bee-eaters do not build their nests in clay loam by investigating soil chemical and physical properties, and mineralogical composition.

Methods

On Kinmen Island (118°8-21″E, 24°22-34″N, 13,425 ha), through interviews with residents and intensive surveys at the beginning of the breeding season, we located most of the bee-eater breeding colonies. We randomly collected soil samples from each site (with at least 20 m between sites by definition; 18 sites sandy loam, 13 sites sandy clay loam, and 13 sites clay loam) for soil chemical and physical analyses. We collected approximately 500 g of soil near nest cavities (sandy loam and sandy clay loam) and at random places (clay loam) at a depth of 30 cm. Samples were sealed in two layers of plastic bags and transported to the laboratory for analysis. For free iron (Fe_d) and aluminum oxides (Al_d), mineralogical analysis, bulk density, and penetration resistance measurements samples from each of five sites for each soil type were used. Soil chemical and soil texture (the percentage of sand, silt, and clay) were determined as described by Jackson (1979) and Brady and Weil (2002). Fe_d and Al_d were extracted with dithionite-citrate-bicarbonate (DCB) solution for free sesquioxides (Mehra and Jackson 1960), which is an empirical term for soil-aggregated materials. Fe_d and Al_d were determined by atomic absorption spectrometry (Hitachi, AAS 180-30). An X-ray diffractometer (XRD) (Rigaku Miniflex) was used for mineralogical analysis with CuKα radiation generated at 30 kV and 10 mA. The XRD patterns were recorded in the range of 2–40°2θ with a scan rate of 2°2θ min^{-1}. The paraffin clod method was used to measure soil bulk density (Blake and Hartge 1986). Penetration resistance was measured in the field with a recording constant rate cone penetrometer (Walczak et al. 1973; Lipiec and Håkånsson 2000).

We report means ± SD throughout this paper. Statistical analyses were performed using SAS software, version 8 (SAS Institute 2000). The Kruskal-Wallis test was used to analyze the differences in soil composition among the different soil types and the Mann-Whitney U-test was used for pair-wise comparisons.

Results and discussion

Clay loam, the soil without bee-eaters' nesting burrows, had significantly lower pH, Na, and base saturation than sandy loam or sandy clay loam, the soils with bee-eaters' nesting burrows. Clay loam had significantly higher N, CEC, K, and Fe_d and Al_d contents than the other two soil types (Table 1). However, all air-dried soils contained low water, C, and N contents (i.e., < 1%). The clay fractions of sandy loam and sandy clay loam were composed of kaolinite (90%) and illite (10%), but those of clay loam were composed of kaolinite (90%) and iron oxides (2–3%). Clay loam had significantly lower sand and higher clay content with higher bulk density and penetration resistance than the other two soil types (Table 2). The correlation coefficient (r^2) between penetration resistance and Fe_d, Al_d, and clay contents were 0.997, 0.848, and 0.779, respectively (all $P < 0.05$).

As far as we know, this is the first detailed study of both the chemical and physical properties of soils for burrow-nesting birds. We found that the choice of the blue-tailed bee-eaters' nesting site is related to the free sesquioxide content. Soil strength and compaction are also important criteria for bee-eaters' nesting-site selection. The lower pH of clay loam would enhance the exchangeable Al and acidity, further increasing the soil aggregation (McKeague et al. 1971), and possibly preventing the bee-eaters from excavating nesting burrows. Therefore, the soil chemical and physical properties influence the nesting-site selection of blue-tailed bee-eaters. However, there might also be other factors affecting bee-eaters' nesting-site selection, such as less vegetation cover, nearby water chemistries, and more

Table 1 Selected soil chemical properties of sandy loam, sandy clay loam, and clay loam (values are means ± SD)

	Sandy loam ($n = 18$)	Sandy clay loam ($n = 13$)	Clay loam ($n = 13$)	P value[d]
pH (soil:water = 1:5)	5.09 ± 0.16[a]	5.52 ± 0.24[b]	4.63 ± 0.07[c]	< 0.001
C (%)	0.029 ± 0.003[a]	0.002 ± 0.001[b]	0.013 ± 0.002[c]	< 0.001
N (%)	0.003 ± 0.001[a]	0.001 ± 0.001[b]	0.160 ± 0.003 [c]	< 0.001
Exchangeable cation (cmol kg^{-1} soil)				
CEC	1.07 ± 0.08[a]	1.79 ± 0.06[b]	5.73 ± 0.08[c]	< 0.001
Ca	0.05 ± 0.01[a]	0.11 ± 0.03[b]	0.05 ± 0.01[a]	< 0.001
Mg	0.04 ± 0.01[b]	0.25 ± 0.05[a]	0.18 ± 0.03[a]	< 0.001
K	0.001 ± 0.002[a]	0.014 ± 0.005[b]	0.048 ± 0.006[c]	< 0.001
Na	0.017 ± 0.026[a]	0.012 ± 0.004[a]	0.009 ± 0.018[b]	0.003
Base saturation (%)	10.32 ± 1.56[a]	21.55 ± 3.66[a]	5.08 ± 0.99[b]	< 0.001
Free iron and aluminum contents (g kg^{-1} soil)				
Fe_d	1.97 ± 0.05[a] ($n = 5$)	14.67 ± 0.11[b] ($n = 5$)	24.48 ± 0.16[c] ($n = 5$)	< 0.001
Al_d	0.68 ± 0.04[a] ($n = 5$)	0.98 ± 0.03[a] ($n = 5$)	2.69 ± 0.03[b] ($n = 5$)	0.003

[a,b,c]Significantly different from each other, $P < 0.05$, Mann-Whitney U-test
[d]Kruskal-Wallis test

Table 2 Soil texture, bulk density, and penetration resistance of sandy loam, sandy clay loam, and clay loam (values are means ± SD)

	Sandy loam (*n* = 18)	Sandy clay loam (*n* = 13)	Clay loam (*n* = 13)	*P* value[d]
Texture (%)				
Sand	78.95 ± 12.11[a]	59.78 ± 0.67[b]	46.42 ± 7.81[c]	< 0.001
Silt	12.30 ± 6.43[a]	22.27 ± 0.41[b]	25.37 ± 4.96[b]	< 0.001
Clay	8.92 ± 6.07[a]	17.93 ± 0.41[b]	28.29 ± 2.96[c]	< 0.001
Bulk density	1.30 ± 0.02[a] (*n* = 5)	1.35 ± 0.01[a] (*n* = 5)	1.50 ± 0.02[b] (*n* = 5)	0.024
Penetration resistance (MPa)	0.044 ± 0.003[a] (*n* = 5)	0.072 ± 0.008[b] (*n* = 5)	0.106 ± 0.014[c] (*n* = 5)	0.027

[a,b,c]Significantly different from each other, $P < 0.05$, Mann-Whitney *U*-test
[d]Kruskal-Wallis test

diverse and abundant dragonfly species (Yuan et al. 2006).

Blue-tailed bee-eaters prefer to nest in sandy soils as indicated in this study (see also Yuan et al. 2006). Furthermore, European bee-eaters (*M. apiaster*; White et al. 1978 and Kossenko and Fry 1998), blue-cheeked bee-eaters (*M. persicus*; Kossenko and Fry 1998) and rainbow bee-eaters (*M. ornatus*; Boland 2004) also prefer to nest in sandy soils. Sandy soils probably allow faster and easier excavation of nest cavities, and provide better drainage (Brooks and Davis 1987) and diffusion of gases to maintain a tolerable level of O_2 and CO_2 in the nest cavities (White et al. 1978). Heneberg (2001, 2003, 2004) and Heneberg and Simecek (2004) analyzed soil particle sizes for cliff-nesting sand martins (*Riparia riparia*), Euroasian kingfishers (*Alcedo atthis*) and European bee-eaters. They found that different soil particle sizes influence where species nest and at least partially explain why certain species do not co-nest. Heneberg (2003) also found that the length of the nest tunnel of sand martins increases with an increasing proportion of fine soil particles, which is therefore also associated with breeding success. More studies are needed to investigate the effects of soil chemical and physical properties, not only as they influence nesting-site selection but also breeding success of blue-tailed bee-eaters.

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