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The distribution of helminth infections along the coastal plain of Kwazulu-Natal province, South Africa

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The results of a previous study indicated that, in the province of KwaZulu-Natal, South Africa, *Necator americanus* and *Strongyloides stercoralis* were endemic to the coastal lowlands only. The prevalences of these helminths, as well as those of *Trichuris trichiura* and *Ascaris lumbricoides*, have now been investigated along a 1000-km-long transect through the coastal plain, at altitudes of <300 m, from the Mozambique border (26°57′S) to the border with Eastern Cape province (30°53′S). *Necator americanus* was by far the most dominant hookworm species. Although prevalences of *N. americanus* and *S. stercoralis* infection decreased with increasing southerly latitude, those of *T. trichiura* and *A. lumbricoides* did not. Determinants of these distribution patterns are examined in terms of a suite of temperature- and rainfall-related variables.

In a study of helminth infections along an altitudinal transect down the Drakensberg escarpment in KwaZulu-Natal province, South Africa, Appleton and Gouws (1996) found that *Necator americanus* and *Strongyloides stercoralis* infections occurred only on the coastal lowlands [from sea level to about 300 m above sea level (asl)] whereas those of *Trichuris trichiura*, and *Ascaris lumbricoides* occurred at higher altitudes, albeit at decreasing prevalences, to about 1500 and 1 700 m asl, respectively, in the foothills of the Drakensberg Mountains. The aim of the present study, an extension of that by Appleton and Gouws (1996), was to determine geohelminth prevalences down the length of the coastal plain in KwaZulu-Natal, by means of a north–south transect from the Mozambique border in the north to the border with Eastern Cape province in the south.

SUBJECTS AND METHODS

Selection of Study Schools

Ten primary schools were selected, at altitudes of <200 m asl, where possible, along the length of the KwaZulu-Natal coastal plain (Table 1; Fig. 1). The geographical information system (GIS) of the Institute for Natural Resources (University of Natal) was used to ensure that, as far as possible, all these schools served communities of similar socio–economic status, specifically in terms of levels of education and employment (Table 1). Thus, between 23.0% and 58.5% [mean (S.D.) percentage = 44.5 (12.4)] of adults in these

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communities had completed 'standard 4' (i.e. at least 6 years' schooling) and between 35.5% and 74.3% [mean (S.D.) percentage = 51.8 (12.6)] were employed. Population densities varied considerably, however, being lowest in the north (22.2–29.5/km^2) and highest in the south (363.7–417.1/km^2).

Sampling of Children

Overall, 156 children were randomly selected from each school: 13 boys and 13 girls from each of the six lowest standards (sub-standard A–standard 4). The age range was 5–21 years, with 91.7% between 5 and 13 years.

Processing of Samples

Harada–Mori coprocultures were prepared (Faust *et al.*, 1975) within an hour of collection at about 10.00 hours, after which subsamples (0.5–1.0 g) of stools were preserved in 10% buffered formalin for examination after formol–ether sedimentation (Allen and Ridley, 1970). Filariform hookworm larvae recovered from coprocultures were identified following Schad (1991). Children positive for *Strongyloides* were re-sampled and bone-charcoal cultures prepared (Speare, 1989) so that the free-living adults and rhabditiform larvae of the parasites could be identified.

Statistical Analysis

Eight components of the temperature regimes at each locality, five components of the rainfall regimes, and population density were used in the analysis. The climatic variables used (see Table 3) were those employed by Appleton and Gouws (1996) and were extracted from data provided by Schulze (1982). Wetness was calculated for days with ≤ 1 mm or ≤ 10 mm precipitation, according to Nwosu and Anya (1980), and defined as 0.1(number of rainy days $\times$ rainfall in mm). Heat units (degree days) were defined as the accumulation of mean temperatures above a threshold of 10°C (Schulze *et al.*, 1997).

RESULTS

Identification of Hookworms and *Strongyloides*

All hookworm filariform larvae, except those from two children from Mseleni, were identified as *Necator americanus*. The two exceptions were identified as *Ancylostoma duodenale*. All *Strongyloides* larvae were identified as *S. stercoralis*.

Helminth Distribution

The results of the transect are given in Table 2. These show a clear decrease in *N. americanus* prevalences from north to south, from about 89% close to the Mozambique border to 42% at Bashise, near the Eastern Cape border [mean (S.D.) percentage = 62.7 (24.5)]. Although less clear-cut, a trend towards decreasing prevalences in these same communities is also evident for *S. stercoralis* [mean (S.D.) percentage = 4.6 (5.1)]. No explanations can be offered for the low prevalence of *N. americanus* recorded at Amahlongwa or the relatively high prevalence of *S. stercoralis* at Monzilloa. *Trichuris trichiura* and *A. lumbricoides* prevalences remained within narrow ranges along the whole transect, with mean (S.D.) percentages of 89.5 (6.4) and 69.0 (6.8), respectively.

Statistical Methods

UNIVARIATE ANALYSIS

Spearman correlation coefficients were calculated between the prevalences of the four nematodes along the transect and the temperature- and rainfall-based variables listed in Table 3 at the same 10 localities. These coefficients are given below in order of decreasing significance for each species.

The prevalence of *T. trichiura* was significantly correlated only with MAP ($r = 0.67528$; $P = 0.0321$). The prevalence of *N. americanus* was correlated with MDmin for January ($r = 0.95988$; $P = 0.0001$), MDmax for January ($r = 0.93495$; $P = 0.0001$), wetness (≤ 10 mm/day in summer; $r = -0.92727$; $P = 0.0001$), MDmax for July ($r = 0.88230$; $P = 0.0007$), heat units ($r = 0.85280$;

TABLE 1

Location, altitude, education and employment data for the communities served by the 10 schools sampled

School	*Location*	*Altitude (m)*	*Population density (no./km^2)*	*Education (% of adults completing 6 years' schooling)*	*Employment (%)*
Star-of-the-Sea	26°56′47″S, 32°20′41″E	26	29.5	23.0	44.5
Mseleni	27°19′50″S, 32°32′46″E	30	22.2	27.5	54.0
Babazani	28°06′43″S, 32°20′41″E	120	56.7	38.8	36.8
Monzilloa	28°27′08″S, 32°17′28″E	61	28.1	50.0	74.3
Musi	28°51′32″S, 31°53′51″E	90	207.3	58.5	60.0
Sakhesetu	29°11′30″S, 31°29′50″E	60	207.3	58.5	60.0
Sizani	29°29′10″S, 31°13′40″E	59	126.1	51.1	61.5
Amahlongwa	30°14′10″S, 30°43′44″E	210	417.1	46.0	51.5
Gobhela	30°32′25″S, 30°35′08″E	30	363.7	53.8	35.5
Bashise	30°53′20″S, 30°18′53″E	209	303.0	37.5	40.0

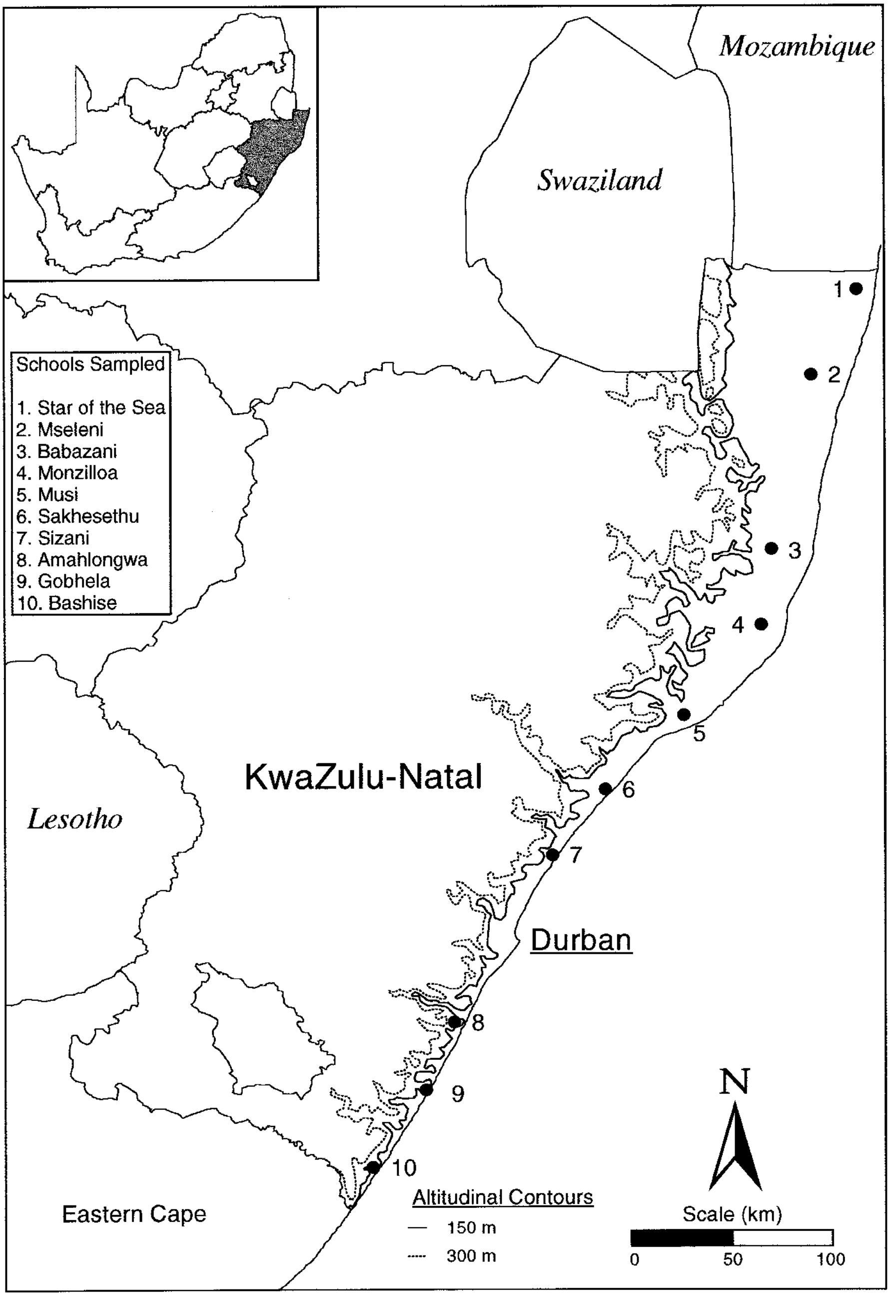

Fig. 1. Map of the province of KwaZulu-Natal showing the 10 schools sampled. The inset orientation map shows the position of KwaZulu-Natal within South Africa.

TABLE 2

Prevalences of infection with Necator americanus, Strongyloides stercoralis, Trichuris trichiura *and* Ascaris lumbricoides *at the 10 schools on the coastal plain of KwaZulu-Natal*

	Prevalence (%) and (no. positive/no. investigated)			
School	Necator	Strongyloides	Trichuris	Ascaris
Star-of-the-Sea	88.9 (136/153)	1.3 (2/153)	88.2 (135/153)	72.6 (111/153)
Mseleni	89.1 (90/101)	6.9 (7/101)	83.2 (84/101)	64.6 (74/101)
Babazani	82.7 (139/168)	5.4 (9/168)	83.9 (141/168)	72.0 (121/168)
Monzilloa	80.1 (129/161)	18.0 (29/161)	98.1 (158/161)	73.9 (119/161)
Musi	59.9 (94/157)	5.1 (8/157)	89.8 (141/157)	79.0 (124/157)
Sakhesetu	66.7 (112/168)	2.4 (4/168)	92.9 (156/168)	72.0 (121/168)
Sizani	58.3 (98/168)	3.0 (5/168)	88.1 (148/168)	67.3 (113/168)
Amahlongwa	11.6 (18/155)	1.9 (3/155)	78.1 (121/155)	56.1 (87/155)
Gobhela	48.2 (80/166)	1.8 (3/166)	95.2 (158/166)	62.1 (103/166)
Bashise	41.5 (70/164)	0.6 (1/164)	97.0 (159/164)	70.7 (116/164)

$P = 0.0017$), wetness (≤ 1 mm/day for a year; $r = -0.83030$; $P = 0.0029$), MT for July ($r = 0.81998$; $P = 0.0037$), MAT ($r = 0.78393$; $P = 0.0073$), MDmin for July ($r = -0.74940$; $P = 0.0126$) and MT for December ($r = 0.70960$; $P = 0.0215$). *Strongyloides stercoralis* was correlated with MT for December ($r = 0.82679$; $P = 0.0032$), MDmax for January ($r = 0.69186$; $P = 0.0266$) and MAT ($r = 0.66332$; $P = 0.0365$). *Ascaris lumbricoides* was significantly correlated only with MAT ($r = 0.74599$; $P = 0.0132$).

MULTIVARIATE ANALYSIS

Step-wise multiple regression was used to determine which of the variables listed in Table 3 contributed significantly to the observed changes in prevalence of the four nematode species. Each species was analysed separately and only variables meeting the $P = 0.10$ significance level were considered for the model.

The prevalence of *T. trichiura* was significantly correlated with MAP ($P = 0.1070$; $\beta = 0.021$; $R^2 = 0.2949$) and MMP for July ($P = 0.4891$; $\beta = -0.179$; $R^2 = 0.0501$) and the combination of MAP and MMP for July (total $R^2 = 0.3418$). *Necator americanus* was significantly correlated with MDmin for January ($P = 0.0015$; $\beta = 15.585$; $R^2 = 0.738$) and heat units ($P = 0.1785$; $\beta = 0.070$; $R^2 = 0.0635$) and with both of these (total $R^2 = 0.8012$). *Strongyloides stercoralis* was correlated with MAT ($P = 0.0001$; $\beta = 13.478$; $R^2 = 0.629$), heat units ($P = 0.0025$; $\beta = -0.057$; $R^2 = 0.269$) and MMP for December ($P = 0.1333$; $\beta = 1.506$; $R^2 = 0.0842$) and the combination of these three ($R^2 = 0.9318$). *Ascaris lumbricoides* was correlated with MMP for July ($P = 0.0178$; $\beta = 0.349$; $R^2 = 0.5249$), heat units ($P = 0.2618$; $\beta = 0.018$; $R^2 = 0.0833$), MAP ($P = 0.0644$; $\beta = 0.036$; $R^2 = 0.1802$) and the combination of these three ($R^2 = 0.7885$).

DISCUSSION

This study shows that *N. americanus* is by far the most common hookworm in KwaZulu-Natal. *Ancylostoma duodenale* larvae were only found in one community, Mseleni, 53 km south of the Mozambique border. It has been suggested (Goldsmid, 1991) that Mozambique may be the source of the sporadic reports of *A. duodenale* emanating from other countries in southern Africa.

The conclusion of Appleton and Gouws (1996) that *N. americanus* was common on the coastal plain of KwaZulu-Natal is confirmed but it is also shown that this parasite, and

TABLE 3

*Data for the eight temperature-derived variables (in °C) and five rainfall-derived variables (rainfall in mm) at the 10 schools sampled**

	Variable†												
		MT		MDmax		MDmin				MMP		Wetness	
School	MAT	July	December	July	January	July	January	Heat units	MAP	July	January	≤ 1 mm/day, whole year	≤ 10 mm/day, summer
Star-of-the-Sea	21	19	23	25	30	9	23	2250	1000	40	150	589	484
Mseleni	21	19	24	24	31	9	22	2250	800	30	130	443	371
Babazani	21	19	24	23	30	11	21	2250	1000	30	120	712	578
Monzilloa	22	18	24	23	30	12	21	2250	1200	50	130	698	523
Musi	21	18	24	23	29	12	20	2250	1400	70	130	925	642
Sakhesetu	21	17	24	23	29	11	20	2250	1200	50	120	731	562
Sizani	20	16	23	23	29	10	20	2000	1000	30	120	848	689
Amahlongwa	20	17	22	22	26	12	19	2000	1000	30	120	837	708
Gobhela	20	17	21	21	25	13	19	2000	1000	30	120	883	776
Bashise	20	17	21	21	25	13	19	2000	1200	30	140	977	870

* Data from Schulze (1982)

† MAT, Mean annual temperature; MT, mean temperature, in July (midwinter) or December (midsummer); MDmax, mean daily maximum temperature; MDmin, mean daily minimum temperature; MAP, mean annual precipitation; MMP, mean monthly precipitation.

probably *S. stercoralis* as well, becomes less common with increasing southerly latitude, from approximately 27° to 31°S. Reports from low-lying localities further south indicate that this trend continues, such that (unidentified) hookworm infections disappear south of latitude 31°S. Van Niekerk *et al.* (1979) recorded a hookworm prevalence of only 0.8% in children in the rural Tsolo district of the former Transkei, now part of the Eastern Cape (at 31°17′S), whereas Iputo *et al.* (1992) failed to find any hookworms in the neighbouring Libode district (31°33′S). Hookworm infections appear to be absent still further south, at Port Elizabeth (Freeman and Grunewald, 1980; C.C. Appleton and J. D. Kvalsvig, unpubl. obs.), Cape Town (Burger, 1968; Millar *et al.*, 1989; Bester *et al.*, 1993; Gunders *et al.*, 1993) and at Langebaan, to the north of Cape Town (Fincham *et al.*, 1996). No *Strongyloides* infections have been reported south of 31°S either. By way of contrast, prevalences of *T. trichiura* and *A. lumbricoides* did not decline with increasing southerly latitude and one or both of these species were found to be still common further south (in the studies and localities mentioned above).

Two constraints may affect the present attempt to assess the influence of climatic variables on helminth transmission. Firstly, the environmental gradients running north–south along the KwaZulu-Natal coastal plain are much shallower than those running west–east down the escarpment (Appleton and Gouws, 1996), and, secondly, the climatic data used were recorded in Stevenson screens and so may differ from those in the upper layer of the soil.

The univariate analysis showed significant correlations between changes in prevalence of infection and abiotic variables for each species:

(1) *Trichuris trichiura* was correlated only with MAP.
(2) *Necator americanus* was correlated with all eight temperature-related and two rainfall-related variables. The three most significant associations (i.e. at the $P = 0.0001$ level)—MDmin for January, MDmax for January, and wetness [≤ 10 mm/day in summer]—were all positive and indicate that interactions between temperature and heavy showers of rain during summer play an important role in facilitating transmission. The negative correlation with wetness (≤ 1 mm/day over the whole year) indicates that light rain showers may not facilitate transmission.
(3) *Strongyloides stercoralis* was correlated with three of the eight temperature-based variables. The most significant was MTDec—also a summer factor.
(4) *Ascaris lumbricoides* was correlated only with MAT.

Two additional points emerge from this analysis. Firstly, both *T. trichiura* and *A. lumbricoides* were correlated with variables based on annual data whereas *N. americanus* and *S. stercoralis* were correlated with variables relating only to summer. None was correlated only with winter data. Secondly, *T. trichiura* was correlated with rainfall whereas *A. lumbricoides* was correlated with temperature.

The multivariate analysis supported the univariate analysis inasmuch as changes in *T. trichiura* prevalences were correlated only with rainfall-derived variables. *Necator americanus* was also correlated with temperature-derived variables, with MDmin for January making the largest contribution. *Strongyloides stercoralis* was correlated with two temperature- and one rainfall-derived variables, with the former (MAT and HU) dominating. In the case of *A. lumbricoides*, two rainfall-derived variables (MMP for July and MAP) were important, with HU making a minor contribution. There were no significant correlations with population density.

Figure 2 illustrates the correlations between *N. americanus* and MDmin for January, *S. stercoralis* and MMT for December, *T. trichiura* and MAP, and *A. lumbricoides* and MAT.

In summary, these analyses indicate that transmission of the two helminths with thick-shelled eggs (*T. trichiura* and *A. lumbricoides*) is influenced by rainfall-derived variables. The frequency of transmission of the two helminth species with thin-shelled eggs and/or free-

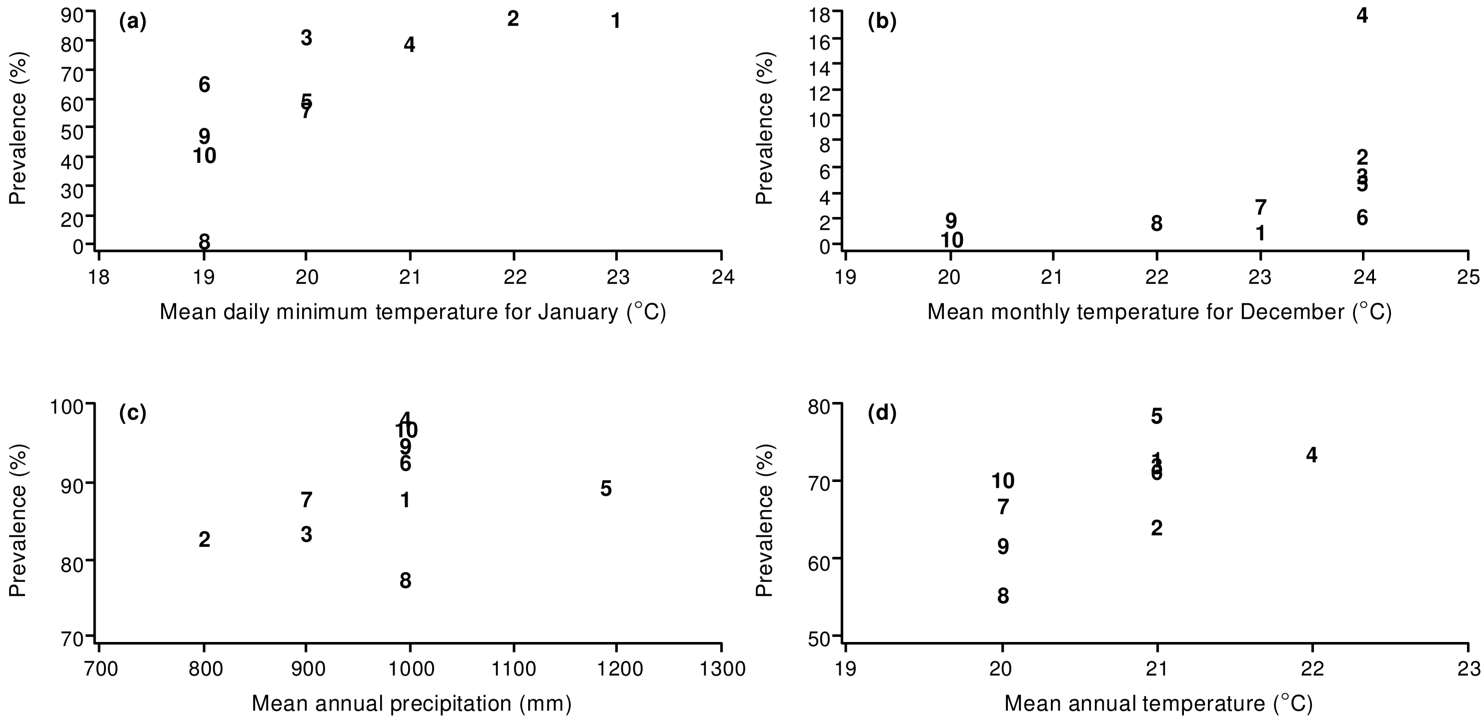

Fig. 2. Correlations between (a) *Necator americanus* and the mean daily minimum temperature for January, (b) *Strongyloides stercoralis* and the mean monthly temperature for December, (c) *Trichuris trichiura* and mean annual precipitation, and (d) *Ascaris lumbricoides* and mean annual temperature, for the 10 schools sampled. 1, Star-of-the-Sea; 2, Mseleni; 3, Babazani; 4, Monzilloa; 5, Musi; 6, Sakhasetu; 7, Sizani; 8, Amahlongwa; 9, Gobhela; 10, Bashise.

living larvae (*N. americanus* and *S. stercoralis*) appears to be multifactorial, with temperature-derived variables playing the greatest role. These results differ from those of Appleton and Gouws (1996), possibly because the coastal strip of KwaZulu-Natal is climatically a far more uniform area than the transect investigated in the earlier work, especially for winter rainfall and temperature.

The present results do support the general conclusion of Appleton and Gouws (1996), that there are important differences in the ecological requirements of *N. americanus* and *S. stercoralis* on the one hand and *T. trichiura* and *A. lumbricoides* on the other. They also reinforce the suggestion that the transmission of *T. trichiura* and *A. lumbricoides* depends on different environmental variables. More detailed explanations of these correlations are not possible because knowledge of the ecological requirements of the soil-dwelling stages of the four helminth species is inadequate (Smith, 1990).

Another environmental variable that changes with increasing southerly latitude in the study area is soil type, and this could also affect helminth transmission, particularly that of *N. americanus* and *S. stercoralis*. Soils in which interstitial spaces drain readily but retain a layer of moisture around the particles and are large enough for the free-living stages of *N. americanus* and *S. stercoralis* to move through will probably be suitable for the development of these parasites. Although a detailed study of the influence of soil type was not possible, Maurihungirire (1993) noted that the soil types north of Musi on the Zululand coastal plain (i.e. in areas where *N. americanus* prevalences generally exceed 60%) were predominantly red and grey coastal sands whereas those of the narrower coastal belt south of Musi (i.e. where *N. americanus* prevalences are mostly $<60\%$) included only a narrow strip of these sands. Most of this part of the plain comprises weakly developed soils, black and red clays and duplex soils (Schulze, 1982). The structure of the sandy soils seems particularly suitable for *N. americanus* and *S. stercoralis*, probably because the size (20–200 μm in diameter) and arrangement of the aggregated particles (Macvicar and de Villiers, 1991) create relatively large pores between them and soil nematodes require pores of only 30–100 μm in diameter to move between particles. When these interstitial spaces are drained, a thin layer of water remains in contact with the particles (Buckman and Brady, 1961), holding the larvae against the particles and allowing the larvae to be mobile. Such movement could be prevented in saturated soils such as clays, which have particles of <2 μm in diameter, allowing only small, often anaerobic spaces. The weakly developed soils of the southern part of the plain have a clay content of 15%–35%, whereas the sandy soils are only $\leq 0.6\%$ clay (Macvicar and de Villiers, 1991; J. C. Hughes, unpubl. obs.). The role of soil type in determining the distribution of *N. americanus* and *S. stercoralis* on the coastal plain needs to be properly examined.

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