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RESEARCH ARTICLE

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Earthworm species occurrence in agroecosystems in the Midlands, KwaZulu-Natal, South Africa

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Abstract

Little is known about the species composition of earthworms in agroecosystems in South Africa even though earthworms provide soil ecosystem services and are useful biological indicators of changes in the habitats. Given the land use and management impact biodiversity, the aim of this study was to document earthworm species that occur under cultivated land in the KwaZulu-Natal Midlands. A survey of nine farms that practise conservation agriculture was carried out between 2018 and 2020. Twelve earthworm species belonging to four introduced families: Acanthodrilidae (*Dichogaster bolaui*), Rhinodrilidae (*Pontoscolex corenthrurus*), Lumbricidae (*Aporrectodea caliginosa*, *Aporrectodea rosea*, *Aporrectodea trapezoides*, *Lumbricus rubellus*, *Octolasion cyaneum*, *Octolasion lacteum*), Megascolecidae (*Amynthas aeruginosus*, *Amynthas corticis*, *Amynthas gracilis*, *Amynthas rodericensis*) and juveniles from an indigenous family Tritogeniidae were recorded from cultivated fields. The type of crop (habitat) affected both species richness and abundance of earthworms significantly. However, post hoc results showed differences in species richness between the soya and the maize only, with greater species richness in the maize. Our results demonstrate that habitat type has a major influence on communities of earthworms in agroecosystems.

Keywords

agroecosystems, diversity, earthworms, indigenous

Introduction

Terrestrial ecosystems benefit immensely from soil organisms (Nielsen et al. 2015). Knowledge on soil fauna has increased and more attention has been given to these taxa in recent years (Brown et al. 2018) and earthworms' contribution to soil ecosystem and soil fertility has been documented. Earthworms contribute to ecosystem services by converting organic matter into rich humus in the form of casts. Earthworms improve soil fertility and quality, influence soil formation, improve soil nutrient availability, stabilise the soil, increase soil porosity, improve water infiltration and increase the overall health of the soil (Lavelle et al. 2006; Jouquet et al. 2006; Brown et al. 2018).

Food production relies on healthy soils and there is an urgent need to understand biodiversity and biophysical regulations of soil fertility better (Plisko and Nxele 2015). Therefore, access to accurate taxonomic information of soil organisms is essential. Unfortunately, taxonomists trained to identify soil fauna are in decline (Brown et al. 2018). The adoption of environmentally friendly and sustainable agriculture is therefore long overdue because of rapid increase in human population, climate change and deteriorating soils (Kassam et al. 2009; Delgado and Gantzer 2015).

Earthworm populations tend to do better in no-till systems (Bartz et al. 2013; Santos et al. 2018), hence earthworms are widely used as soil health indicators (Nadolny et al. 2020). A recent review in Brazilian no-tillage agriculture highlighted that the no-till system promotes earthworm populations (Demetrio et al. 2019). However, according to Santos et al (2018), although work has been done in South America on no-till systems, knowledge of earthworm diversity in agroecosystems is still limited.

In South Africa, few studies have documented earthworm species in agroecosystems. The studies that looked at the occurrence of earthworms in agricultural ecosystems reported that peregrine species were dominant (Visser and Reinecke 1977; Reinecke and Visser 1980; Dlamini et al. 2001; Haynes et al. 2003; Simonsen et al. 2010). Tillage is known to affect endogenic and anecic earthworm diversity and abundance negatively (Reinecke and Visser 1980) unlike no-tillage agriculture (Peigne et al. 2009; Hutcheon et al. 2001). According to Dlamini et al. (2001) and Haynes et al. (2003), earthworms in agroecosystems have not been studied adequately in South Africa. After Nxele (2015) recorded indigenous earthworms in sugar-cane fields that had been under no-till for more than twenty years, we hypothesised that more indigenous species occur under no-till agriculture. As such, a study to document earthworm diversity under cultivated fields was initiated in 2018 in minimum tillage or no-till agroecosystems.

Material and methods

Study sites

Nine farms in KwaZulu-Natal Midlands (Fig. 1) were sampled for earthworms. Each farm had either sugar-cane, maize, soya, ryegrass pasture, mixed species pasture or a

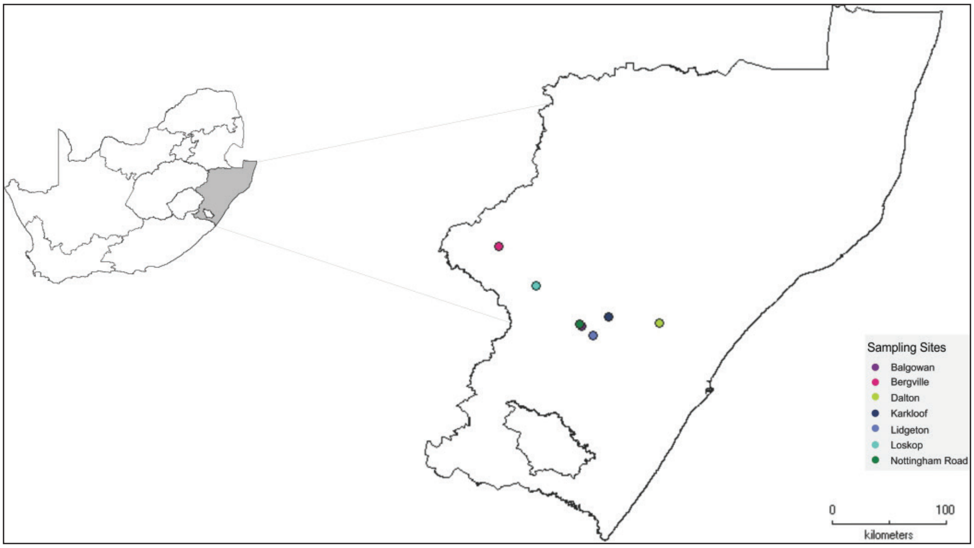

Figure 1. Sampling sites in KZN Midlands.

Table 1. Location, crop type and age of no-till agriculture and numbers of species of earthworms that were recorded in the KZN Midlands.

Area	Location	Crop sampled	Age (years)	Number of species
Loskop	28°54'33.2"S, 29°33'35.5"E	Maize, soya	> 20	5
Bergville	28°38'28.8"S, 29°16'37.8"E	Maize, soya	> 20	3
Karkloof	29°22'50.1"S, 30°17'34.5"E	Maize, ryegrass pasture	> 20	6
Karkloof	29°20'29.3"S, 30°13'03.6"E	Maize	> 20	2
Balgowan	29°25'27.0"S, 30°01'29.5"E	Maize, ryegrass pasture	< 10	3
Lidgeton	29°26'06.2"S, 30°05'10.0"E	Maize, mixed species pasture	< 20	4
Dalton	29°13'47.2"S, 30°40'54.7"E	Sugarcane	< 20	4
Nottingham Road	29°25'08.9"S, 30°00'27.7"E	Mixed species pasture	< 10	3
Nottingham Road	29°26'21.5"S, 29°59'03.0"E	ryegrass pasture	< 10	2

mixture of crops (Table 1). All the farms practise conservation agriculture; however, the farms have been under no-tillage for a different number of years.

Earthworm sampling

Earthworms were collected quantitatively and qualitatively. The quantitative method follows that of Nxele et al. (2015) and Bartz et al. (2014) with slight modification on plot sizes. Sampling was carried out in one hectare with nine sampling points; adjacent sampling points were 30 m apart. Earthworms were collected by digging out 50 cm x 50 cm × 20 cm soil monoliths. The soil was hand-sorted for earthworms in large plastic trays (50 cm × 40 cm × 5 cm). The holes were filled back with the soil after removing the specimens from the soil. Active searching under stones and logs was part of qualitative sampling. Specimens that were collected were washed and narcotised using 20% ethanol solution. Some specimens were preserved in absolute ethanol for DNA analysis. The remaining specimens were fixed in 4% formalin for at least 24 hours before being preserved in 75% ethanol. Studies of the internal anatomy were conducted after dorsal dissections. The KZN museum database and the following literature: Plisko 2001, 2010; Ljungstom 1972; Michaelsen 1899, 1908, 1913; Reynold and Reinecke 1976; Zicsi and Reinecke 1992; Visser and Reinecke 1977 and Pickford 1937 were used to obtain information on distribution. All new material is deposited in the Oligochaeta collection in the KwaZulu-Natal Museum (**NMSA**).

Data analyses

Data analysis was per crop type regardless of which farm it came from. Species richness and abundance datasets were analysed in R using the generalised linear mixed models (GLMMs) because data were not normally distributed. The lme4 package (Bates et al. 2015) was used when calculating GLMMs. The Poisson distribution was the best fit for the species richness dataset, while the negative binomial distribution was the best fit for the species abundance dataset (Bolker et al. 2009). In the models, the type of crop (maize, pasture, soya and sugar-cane) was the fixed factor, while the random factor was the farm. The multcomp package (Hothorn et al. 2008) was used to determine the similarities and/or differences between pairs of crops.

Abbreviations

KZN KwaZulu-Natal;
EC Eastern Cape;
WC Western Cape;
NC Northern Cape;
LP Limpopo,
NW North West;
GP Gauteng;
MP Mpumalanga;
FS Free State.

Checklist

Family Acanthodrilidae Claus, 1880 sensu Csuzdi (2010)

Subfamily Benhamiinae Michaelsen, 1897 sensu Csuzdi (1996)
Genus *Dichogaster* Beddard, 1888
Subgenus *Dichogaster* (*Diplothecodrilus*) Csuzdi, 1996

***Dichogaster bolaui* (Michaelsen, 1891)**

Type locality. Bergedorf, Germany

RSA distribution (Old material). LP: Entabeni State Forest and Soutpansberg; **MP**: Witbank; **KZN**: Mapelane Nature Reserve, Karkloof Nature Reserve, Skyline Nature Reserve, Bluff Nature Reserve, Ngome Forest, Mvutshini River Valley, Merrivale area, Pietermaritzburg and surroundings, Oribi Gorge Nature Reserve, Cedara Agriculture College, Baynesfield and Eshowe in agricultural fields; **GP**: Coal mines. New material: **KZN**: Dalton, Loskop and Bergville.

Remarks. In the current study, this species was found in sugar-cane, maize and soya fields. It was the common species in the sugar-cane fields although not in high numbers. In soya, it was found with megascolecids and lumbricids.

Family Rhinodrilidae Benham, 1890 sensu James in James and Davidson (2012)
Genus *Pontoscolex* Schmarda, 1861

***Pontoscolex corenthrurus* (Müller, 1857)**

Type locality. Brazil

RSA distribution (Old material). KZN: Port Shepstone area, Oribi Gorge Nature Reserve, Skyline Nature Reserve, Bluff Nature Reserve, Dlinza Forest Nature Reserve, Greater St Lucia Wetland Park. Kosi Bay, Krantzkloof Nature Reserve, Langepa Natural Heritage Site, Mbumbazi Nature Reserve, Ngoye Forest Reserve, Umfolozi Game Reserve, Mapelane Nature Reserve, Melmoth, Empangeni, Richards Bay, Empangeni, Stanger, Entumeni Nature Reserve, Eshowe, Fairfield Farm, Brooklee Farm, KwaMahleka Farm, Benhurst Farm, Harebottle, Mistyridge Farm, Rockyridge Farm, Cathedral Peak, Monks Cowl Nature Reserve, Umlalazi Nature Reserve, Gingindlovu, Ottor's Bluff The Craig's Farm, Pietermaritzburg area, Durban area, Tongaat, Inanda, Mt Edgecombe, Ichanga, Westville, Stamford Hill, North Park Nature Reserve, Kenneth Stainbank Nature Reserve, Ixopo area, Vernon Crookes Nature Reserve, Amanzimtoti Mission Reserve, Adams Mission, Umzinto area, Hibberdene, Mpenjati Nature Reserve, Kasseepursad, Tugela area and Umgababa.

MP: Kruger National Park, Thalalanati, Nelspruit, White River and Graskop. **LP**: New Agatha, Soutpansberg Ratombo, Entabeni State Forest, Letsitele and Tzaneen area. **GP**: Pretoria. New material: **KZN**: Dalton.

Remarks. This species occurs in numerous sites, both natural and agricultural. In natural sites, Plisko (2001) reported this species in grasslands, forests, natural bushes and near rivers. In cultivated fields, *Pontoscolex corenthrurus* has been collected under most crops including maize, sugar-cane, banana, avocado, citrus; some specimens were collected in pine and gum plantations, some even from vegetable gardens (Plisko 2001). This species has been used in experiments at different institutions. *Pontoscolex corenthrurus* has also been collected in polluted sites in KZN (Plisko 2001). The current collection was in sugarcane on one farm only, although we had expected to collect the species in other areas in the KZN Midlands because of its wide occurrence.

Family Lumbricidae Rafinesque-Schmaltz, 1815
Genus *Aporrectodea* Örley, 1885

***Aporrectodea caliginosa* (Savigny, 1826)**

Type locality. Unknown

RSA distribution (Old material). EC: Port Elizabeth, Cradock, Tarkastadt, Tsitsikama. **WC**: Kirstenbosch Botanic Garden, Ceres, Newlands Forest, Wellington, Stellenbosch, "Kapland", Cape Flats, Bergvliet Farm and Jonkershoek Nature Reserve. **NC**: Komaggas, Namaqualand. **NW**: Potchefstroom, Stytfontain. **GP**: Zoological Gardens, Pretoria, Krugersdorp and Witportje Falls. FS: Drakensberg. New material: **KZN**: Nottingham Road.

Remarks. In the current collection, *Aporrectodea caliginosa* was collected in mixed species pasture. This species is closely related to *A. trapezoides* and they are found together mostly; however, *caliginosa* is less common (Plisko 2010). This is the first report of this species in this region.

Aporrectodea trapezoides (Dugès, 1828)

Type locality. Montpellier, France

RSA distribution (Old material). KZN: Howick, Mooi River and Underberg. **EC**: Cradock, Storm River area, Winterberg Farm, Tsitsikamma, Fish River, Port Elizabeth, Humansdorp, Groot Brak River Staasie, Uitenhage Kerkstraat, Molteno and Burgersdorp. **WC**: Cape Town, Stellenbosch, Piketberg, Knysna, Wellington, Ceres, Tulbagh, Moorreesburg, Kirstenbosch, Swellendam, Jonkershoek, Worcester, Caledon and Montagu. **NC**: Upington, Jan Kempdorp, Nieuwoudtville, Prieska, Studer's Pass, Liliefontein. **LP**: Pietersburg. **MP**: Ermelo, Lydenburg, Middelburg and Volksrust. **NW**: Potchefstroom, Klerksdorp and Tranvala Farm. **GP**: Heidelberg, Roodepoort, Pretoria and Irene. **FS**: Heunings Rug and Springfield, Rouxville. New material: **KZN**: Nottingham Road.

Remarks. *Aporrectodea trapezoides* has common occurrence compared to *A. caliginosa*. In the current study, this species was collected together with *A. caliginosa* on cultivated land with mixed species pasture. The mixed species field is under minimal tilling with little disturbance of the top soil from time to time. Previously, *Aporrectodea trapezoides* was collected from natural habitats that include forests, natural bush, cultivated fields and along rivers (Plisko 2010).

Aporrectodea rosea (Savigny, 1826)

Type locality. Paris, France

RSA distribution (Old material). KZN: Giants Castle, Cathedral Peak, Rosetta, Cedara, Greytown, Nottingham Road, Sevenoaks, Underberg, Pietermaritzburg, Karkloof area and Baynesfield, Estcourt. **EC**: George, Uitenhage, Port Elizabeth, East London, King William's Town, Debe Nek, Cradock, Storm River area, Steynsburg, Tsitsikamma, Tsolo, Barkly Pass, Grahamstown, Hogsback, Burgersdorp, Stutterheim, Tarkastad, Maclear and Tradouw Pass. **WC**: Kirstenbosch area, Vanrhynsdorp, Eendekuil and Moorreesburg. **NC**: Upington and Nieuwoudtville. **MP**: Volksrust, Witbank, Chrissiemeer and Dullstroom. **NC**: Jan Kempdorp. **NW**: Potchefstroom, Klerksdorp, Mooi River, Wolmaranstad, Hartbeespoort and Middelburg. **LP**: Tzaneen and Haenertsburg. **FS**: Brandfontein, Rietfontein, Heunings Rug and Skandinavia Drift. **GP**: Pretoria and Irene. New material: **KZN**: Balgowan, Karkloof, Lidgeton, Nottingham Road and Bergville.

Remarks. A common species in RSA, which has been recorded in both natural and cultivated areas. In the present study, the species was collected under maize, ryegrass pasture, as well as mixed species pasture.

Genus *Lumbricus* Linneaus, 1758

Lumbricus rubellus Hoffmeister, 1843

Type locality. Unknown

RSA distribution (Old material). KZN: Karkloof, Ndema/Grotto, Nottingham Road area and Sevenoaks. **EC**: Cape Flats. **WC**: Newlands Forest, Cape Peninsula, Jonkershook, Kirstenbosch, Swellendam and Barrydale. New material: **KZN**: Balgowan and Nottingham Road.

Remarks. *Lumbricus rubellus* has been recorded in natural habitats, as well as from cultivated fields in small populations.

Genus *Octolasion* Örley, 1885

Octolasion cyaneum (Savigny, 1826)

Type locality. Paris, France

RSA distribution (Old material). Stutterheim area and Kirstenbosch. New material: **KZN**: Lidgeton

Remarks. This species has been collected in two areas in the EC and WC only. The EC record is from a private garden soil (Plisko 2010), whilst the WC record is from a forest in Kirstenbosch. The new material is from a mixed species pasture and the species occurred in high numbers. There is a high possibility that the distribution of this species in agroecosystems is wider than what is known because not much sampling in cultivated fields has been done.

Octolasion lacteum (Örley, 1881)

Type locality. Hungary

RSA distribution (Old material). KZN: Giants Castle, Karkloof Nature Reserve, Rosetta, Ngele Forest, Mooi River, Eshowe area, Merrivalle, Royal Natal National Park, Vryheid Nature Reserve, Cedara, Good Hope Farm, Baynesfield, Doreen Clark Nature Reserve, Impendle Nature Reserve, Underberg area, Greytown, Boston, Nottingham Road, Royal Natal National Park, Injasuthi, Vryheid Hill Nature Reserve, Dargle, Vernon Crookes, Royal Natal National Park, Pietermaritzburg area, Monks Cowl, Kamberg, Highmoor, Richmond, Hilton, Mt Michael and Estcourt. **EC**: Tsitsikamma, Knysna, Prentjies, Storm River area, Grahamstown, Hogsback, Stutterheim and Maclear. **WC**: Cape Town. **NC**: Magoebaskloof. **NW**: Potchefstroom and Grootbosch. **MP**: Sabie, Lydenburg and Amsterdam. **LP**: Tzaneen area, Entabeni State Forest, Haenertsburg and Limpopo Forests. **GP**: Pretoria. **FS**: Edendale Farm and Ficksburg. New material: **KZN**: Balgowan, Lidgeton, Nottingham Road, Karkloof and Loskop.

Remarks. This species generally occurs in high numbers. From the KZN Museum database, *Octolasion lacteum* occurs in a wide range of habitats: forests, cultivated fields, banks of rivers, fallow grounds, gardens and compost heaps. Current records are from maize, ryegrass pastures and mixed species pastures.

Family Megascolecidae Rosa, 1891
Genus *Amynthas* Kinberg, 1867

Amynthas aeruginosus Kinberg, 1867

Type locality. Guam

RSA distribution (Old material). KZN: Eshowe, Pietermaritzburg area, Richmond, Cedara, Baynesfield, Camperdown, Karkloof, Ngome Forest, Doreen Clark Nature Reserve, Greytown, Nottingham Road and Vryheid, Hilton. **GP**: Pretoria and Hartbeespoort. New material: **KZN**: Karkloof, Lidgeton, Nottingham Road, Dalton and Loskop.

Remarks. The species has been found in grasslands, agricultural fields and nature reserves in KZN and GP only. It is unclear why there are no records from other South African provinces although sampling has been done in these provinces. In the present study, *Amynthas aeruginosus* was collected under maize, soya, sugar-cane and mixed species pastures.

Amynthas corticis Kinberg, 1867

Type locality. Oahu, Hawaii.

RSA distribution (Old material). KZN: Cathedral Peak, Winterton, Bergville, Mkhomazi State Forest, Howick area, Doreen Clark Nature Reserve, Impendle Nature Reserve, Mbumbazi Nature Reserve, Nkandla area, Cedara, Karkloof area, Pietermaritzburg area, Mtunzini, Rainbow Gorge Forest, Umfolozi, Hluhluwe area, Ngome Forest, Port Shepston, Ixopo, Kokstad, Hlabeni Forest, Baynesfield, Eshowe, Hilton, Greytown, Nottingham Road, Sevenoaks, Underberg, Royal Natal National Park, Boston area, Vryheid area, Monks Cowl, Kamberg and Vernon Crookes. **EC**: Tsitsikamma, Port Elizabeth, Umtata, Maclear, King Williams Town, Port St Johns, Lusikisiki, Mbotyi, Langeni area and Storms River. **WC**: Swellendam, Kirstenbosch. **LP**: Ohrigstad, Soutpansberg, Magoebaskloof and New Agatha. **MP**: Nelspruit, Middelburg, Mariskop Forest, Loskop Dam. **GP**: Pretoria area and Krugersdorp. **NW**: Roodeport and Rustenberg. **FS**: Parys, Ficksburg and Bloemfontein.

New material. KZN: Karkloof and Loskop.

Remarks. The species has been reported from almost all over South Africa; it is apparent that this species occupies a wide range of biotopes. It is common in the upper layers of soil, mostly in rotting litter in plantations (Plisko 2010) and decomposed sugar-cane reeds (Ljungström 1972). In the present study, *Amynthas corticis* was collected from maize fields only.

Amynthas gracilis Kinberg, 1867

Type locality. Rio de Janeiro, Brazil.

RSA distribution (Old material). KZN: Pietermaritzburg area, Merrivalle, Eshowe, Otto's Bluff, Doreen Clark Nature Reserve, Hilton, Greytown, Hillcrest and Royal Natal National Park. **EC**: Tsitsikamma and Blueliliesbush. **WC**: Kirstenbosch and Claremont. **MP**: Nelspruit, Sabie, Kruger National Park, Pilgrim Rest, Loskop Dam and Middelburg. **NW**: Potchefstroom and Britz. **GP**: Pretoria and Krugersdorp.

New material. KZN: Karkloof and Loskop.

Remarks. It is common in natural, as well as agricultural habitats. We collected *Amynthas gracilis* under maize.

Amynthas rodericensis (Grube, 1879)

Type locality. Rodrigues, Mauritius.

RSA distribution (Old material). KZN: Pietermaritzburg area, Eshowe area, Durban, Merrivalle, Umtamvuna Nature Reserve, Oribi Gorge, Albert Falls, Inanda, Cato Ridge, Otto's Bluff, Kenneth Stainbank Nature Reserve, North Park Nature Reserve, Mbumbazi Nature Reserve Mtunzini, Skyline Nature Reserve, Port Shepstone, Margate, Howick, Mt Edgecombe, Port Edward, La Mercy, Hluhluwe and Cedara. **WC**: Kirstenbosch. **LP**: New Agatha. **MP**: Nelspruit, Ermelo and Loskop Dam. **GP**: Pretoria.

New material. KZN: Karkloof, Dalton and Loskop.

Remarks. *Amynthas rodericensis* is common in natural and agricultural fields.

Discussion

This checklist adds to the knowledge of the species composition of earthworms on farms in South Africa. These data will contribute to future studies on the importance of earthworms in agriculture. Commercial farmers, who were the first to adopt the no-till system in KZN own some of the farms that we sampled. The earthworms that we collected from cultivated fields were introduced, except specimens of *Tritogenia*. *Tritogenia* specimens were collected from a ryegrass pasture field in Karkloof, which is near a veld (natural grassland), so it is possible that the indigenous species are recolonising the pasture in this particular instance. However, *Tritogenia* have been collected from ryegrass pasture in the past from KZN Midlands (Haynes et al. 2003) making this a second record of *Tritogenia* in ryegrass pasture in the KZN Midlands. Visser and Reinecke (1977) collected small numbers of *Tritogenia* in cultivated fields at Mooi River.

Two species, *Aporrectodea caliginosa* and *Octolasion cyaneum*, were recorded for the first time in KwaZulu-Natal. *Aporrectodea caliginosa* is morphologically similar to *Aporrectodea trapezoides* with the external difference being tubercula pubertatis on two separate tubercles 31 and 33 for *caliginosa*, but continuous bands on 31–33 for *trapezoides*. The colour of the two species is also different with *trapezoides* mostly dark brownish-grey, whilst *caliginosa* is mostly pale (Plisko and Nxele 2015). *Octolasion cyaneum* has been collected from the Cape in two sites, one being the garden where imported flowers were planted and at a resort (Plisko 2010). It is likely that this species may have a wider range than previously reported; however, more sampling is needed to confirm this for agroecosystems.

According to Visser and Reinecke (1977), introduced earthworm species are more abundant in most parts of South Africa. The presence of introduced species in agricultural fields is consistent with Walsh et al. (2013) who recorded alien earthworms, dominated by a lumbricid, *Aporrectodea trapezoides*, from across wheat growing fields. Earthworm communities were dominated by introduced species in a study by Manono and Moller (2015) in New Zealand pastures. Similarly, lumbricids were dominant in the present study; they were collected in almost all crops, except in sugar-cane and soya. Amuza et al. (2021) assessed the presence of earthworms in agricultural crops in Romania and found that the lumbricid, *Aporrectodea caliginosa nocturna*, was the dominant species. Reinecke and Visser (1980) conducted a study in the Mooi River irrigation field to look at the effect of land use and fertilisers on earthworms. The lumbricids, *A. trapezoides* and *E. rosea*, had high population densities, which suggested that, in South Africa, the common earthworms in cultivated fields were lumbricids (Reinecke and Visser 1980). Advantages of introduced earthworms is that they adapt easily to different environments and they may reproduce parthenogenetically (Visser and Reinecke 1977; Ljungström 1972; Reynolds and Reinecke 1976) resulting in rapid increase in numbers.

Southern African indigenous earthworms tend to vanish almost immediately after the land is used for agricultural purposes (Reinecke and Visser 1980). However, the current collection of *Tritogenia* in ryegrass pasture, the results of Haynes et al. (2003), Visser and Reinecke (1977) and Nxele (2015), suggest that, with sustainable land use, it is possible that the indigenous earthworms will re-colonise cultivated fields.

The type of crop affected both species richness ($p = 0.02$) and abundance ($p < 0.001$) of earthworms significantly (Table 2). Species richness ($p = 0.04$) and abundance ($p < 0.001$) of earthworms were significantly higher in the pasture than in the soya; this observation contradicted Manono and Moller (2015) who reported lower species richness in pasture. Geographical differences in our study and that of Manono and Moller (2015) could be the reasons for differences in our results. According to Manono and Moller (2015), food supply determines earthworm abundance and agricultural practices may affect the availability of organic material in the soil. The farms, on which we sampled, also plant cover crops, which increase the availability of organic

Table 2. Species richness and abundance of earthworms in different types of crops.

	Species richness			Species abundance		
	df	**χ^2**	**p**	**df**	**χ^2**	**p**
Type of crop	3	9.51	0.02	3	21.4	< 0.001
Paired crops	**z**	**p**		**z**	**p**	
Pasture – maize	-0.13	0.99		1.62	0.35	
Soya – maize	-2.80	**0.02**		-3.60	**0.002**	
Sugar-cane – maize	-0.78	0.86		-1.51	0.42	
Soya – pasture	-2.56	0.05		-3.81	**< 0.001**	
Sugar-cane – pasture	0.72	0.89		-2.64	**0.04**	
Sugar-cane – soya	1.59	0.37		0.44	0.97	

matter in the soil. However, the change in plant communities may affect the quality and quantity of organic matter that maybe available to earthworms (Hubbard et al. 1999; Bohlen et al. 1997); this may explain why the perennial pasture, which has no plant rotation, had more earthworms.

Our results also demonstrated significantly greater species richness ($p = 0.02$) and abundance ($p < 0.001$) of earthworms in the maize than in the soya. These results are similar to those of Amuza et al. (2021) who reported greater abundance of earthworms in maize than in soybean. All the maize fields had old maize residues on the ground, as well as short stubs, which would have provided a continuous food supply for earthworms.

As introduced earthworms have been collected in all biotopes in South Africa (Plisko 2010) and from agricultural fields (Dlamini et al. 2001; Haynes et al. 2003; Reinecke and Visser 1980), it is not surprising that introduced earthworms were collected from all the farms on which we sampled. There are gaps in our knowledge of the species composition of earthworms in different agroecosystems. As such, more extensive sampling during different seasons is necessary in order to gain more insight into the taxonomic diversity and distribution of earthworms in agroecosystems in South Africa.

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