Assessing Earthworm Contribution to Soil Fertility in the Coastal Savanna Region of Ghana

E. A. Ampofo
Department of Soil Science, University of Cape Coast, Cape Coast, Ghana
Email: edwardakwasi@yahoo.com

Abstract

The study investigated the contribution of earthworm to soil fertility improvement by comparing some soil properties of earthworm casts and the original soil on garden eggs field, elephant grass field and tree plantation field at the University of Cape Coast. Generally, the exchangeable cations (K^+, Na^+, Ca^{2+}, Mg^{2+}) analysed were higher in the earthworm cast than the corresponding original soil on all the fields. On the tree plantation field, the exchangeable K^+, Na^+, Ca^{2+} and Mg^{2+} in the earthworm cast (TE) were 0.8, 0.7, 13.5 and 1.59 cmolkg^{-1}, respectively, and were 102%, 25%, 71% and 52%, respectively, higher than obtained in the corresponding original soil (TS). Similar percentage increase was obtained on the garden eggs cultivation and the elephant grass fields. The earthworm cast on the tree plantation (TE) recorded 5.1% organic matter which was about 80% higher than obtained from the original soil (TS). The percentage increase of organic matter content of earthworm cast, with respect to the original soil on the elephant grass and garden eggs fields were 55% and 12%, respectively. The number of earthworm burrows on the fields ranged from 0.57×10^6 to 1.5×10^6/ha. Garden eggs field had the highest number followed by the elephant grass field, and the tree plantation field the least. The quantity of earthworm casts followed the same trend and ranged from 4.0 to 1.7 t/ha. It was noted that earthworm activity was enhanced by both organic material covering the soil surface and the condition of the soil itself. The study showed that huge quantity of soil, which is more fertile as a result of earthworm activity, than the original soil is brought to the soil surface by the same earthworms and that, if allowed to wash away, could accelerate the deterioration of a field.

Introduction

Earthworms are long time adored creatures in many cultures, probably because of the role they are believed to play in the fertility improvement of the soil. The Chinese characterised earthworms as the 'angel of the earth'. Aristotle aptly referred to them as the 'intestines of the soil', though he might be referring to the appearance rather than their functions, and Cleopatra decreed them 'sacred' (Blakemore, 2003; Ramsay & Hill 1978). Parkin & Berry (1994) and Hidalgo *et al.* (2002) observed that earthworm is the most useful and active agent in introducing suitable physical, chemical and micro-biological changes in the soil, thereby, directly increasing the fertility and crop producing power of the soil. Logsdon (1994) noted that in Bangalore, India, earthworms successfully decomposed sugar factory residuals and turned them into soil nutrients that made farmers using the material reduce chemical fertilizers by 50%. Bohlen *et al.* (1997) examined the influence of earthworms on surface litter decomposition in maize agroecosytems and noted an increased rate of decomposition of the surface litter.

Earthworm casts contain 5 times more nitrogen, 1.5 times more calcium, 3 times more magnesium, 11 times more potash and 1.4 times more humus than the original top soil (Edwards & Lofty, 1997). Elliot *et al.*

(1990) noted that earthworm casts generally have a higher ammonium concentration and water holding capacity than the corresponding original top soil. Earthworm casts have high denitrification potentials and assimilable products that mineralised rapidly and, therefore, represent a potentially significant source of readily available nutrients for plant growth (Curry & Byrne, 1992; Elliot *et al.*, 1990; Mackay & Kladivko, 1985). Higaldo *et al.* (2002) observed that there is early seedling and rapid plant growth when earthworm casts are mixed with soil.

Earthworm burrows provide network of passages through the soil which improves soil aeration. Blakemore (2003) stated that earthworm burrows can make up 5% of the total soil volume, and observed that high earthworm population enhances soil aeration, drainage and infiltration. Morgan (1995) noted that earthworms bring to the soil surface casts of about 2–5.8 t/ha on agricultural land, 15 t/ha in temperate woodland and about 50 t/ha in tropical forest. Earthworm populations and distribution vary widely in different soils and different land use systems because of their sensitivity to soil *p*H, moisture, texture, temperature and chemical composition (Ruz-Jerez *et al.*, 1988; Brady & Weil, 1996).

In spite of the many benefits to the soil accrued from the activities of earthworms, little is known in Ghana about their contribution to soil fertility in terms of assessment and documentation. The objective of the study is, therefore, to assess the contribution of earthworm in soil fertility development under different land use systems in the tropical coastal savanna.

Materials and methods

The study was carried out at the School of Agriculture Teaching and Research Farm, and Technology Village, in the University of Cape Coast. The sites lie within the coastal savanna zone of Ghana. Both the Research Farm and the Technology Village fall within the same latitude of 5.1^{o} N and longitude 1.4^{o} W, and about 300 m above mean sea level. The area has bimodal rainfall regime with the major rainy season between March and July, and the minor season between September and November. The mean annual rainfall is about 950 mm (Asamoah, 1973; Asare, 2004). The temperatures are high throughout the year with the mean of 23.5 ^{o}C. The relative humidity is generally high and is about 90 –100% during the night and about 70% during the day (Asamoah, 1973; Asare 2004). The soils at both sites belong to Benya series (Asamoah, 1973), and could be classified as Acrisol (FAO) or Ultisol (USDA).

Three sites were selected, namely garden eggs field at the University Research Farm, tree (acacia interspersed with mango) plantation field and an elephant grass, *Pennisetum purpureum*, field, both of which were at the University Technology Village. The Research Farm was generally grassland with patches of shrubs due to continuous cultivation while the undergrowth of the tree plantation field was scattered grasses. The sites were selected because the crops/plants found on each field represented different crop/plant family. The garden eggs represented vegetable (tap rooted) family, the trees represented deep-rooted trees/plants family and the elephant grass represented the grass family, and each family had unique features in terms of the rooting system, canopy cover, height and quantity of organic materials (leaf-fall) produced.

Earthworm casts and soil samples (original soils) were collected from each field for the study. A square wooden structure (quadrant) measuring 0.5 × 0.5 m was randomly put on each field and the earthworm casts covered by each 'put' was collected manually. The earthworm casts collected from every 4–6 'puts' (depending on the quantity of earthworm casts covered) were then bulked into composite sample. The composite sample was then equally divided into three. Soil samples (original soils) were also randomly collected within the top 15 cm depth from each respective field with each sample replicated three times. The experimental design was complete randomised design. The earthworm casts and the original soils from the garden eggs field were designated GE and GS, respectively, that from the elephant grass field were EE and ES, respectively, and that from the tree plantation field were TE and TS, respectively.

The number of earthworm burrows covered by the quadrant 'puts' on each field were counted. The depths of some randomly selected burrows were measured by carefully digging at the side from the top to the end of the burrow, and measurement taken using a string and a meter rule. The earthworm casts collected from the 'puts' on each field were weighed after air drying till almost free from moisture and the average weight determined. The weight of sediment brought to the soil surface by the earthworm and the number of burrows per hectare on each field was calculated by simple proportion. The earthworm specie(s) was not identified but was believed to be *Hippopera nigeriae* because this type of specie dominates in the tropics of at least 800 mm annual rainfall (Brady & Weil, 1996; FitzPatrick, 1983)

The original soils and the earthworm casts were air-dried till almost free from moisture. The samples were then sieved through 2-mm mesh and the fine earth used for the various analysis. The soil properties analysed for both the soil samples and the earthworm casts included particle size distribution, exchangeable cations (Ca^{2+}, Mg^{2+}, K^{+} and Na^{+}) and organic matter content. The particle size distribution was determined using the hydrometer method described by Gee & Bauder (1986). This method involved initial destruction of organic matter in the fine earth with H_2O_2, dispersion with Na_2SO_3 and Calgon, and then shaken thoroughly before the hydrometer reading was taken. The exchangeable cations were determined by extraction with neutral ammonium acetate (1 N NH_4OAc). The Ca^{2+} and Mg^{2+} were separated with alcohol and determined by EDTA titration. The K^{+} and Na^{+} were determined on the original extracts using flame photometry. The Walkley-Black method described by Edward & Brown (1982) was used to determine the organic carbon. The fine earth was treated with normal $K_2Cr_2O_7$ and H_2SO_4, followed by determination of excess chromic acid by titration with normal ammonium ferrous sulphate to green end point.

Results and discussion

Table 1 shows the particle size distribution and exchangeable cations of the earthworm casts and the corresponding original soil from each field. The sand content in the earthworm casts and the corresponding original soil was almost the same (Table 1). However, the earthworm casts had higher silt content than the corresponding original soils on both the garden eggs and the elephant grass fields but the reverse was true for the tree plantation field. The clay content in the earthworm cast was lower than the corresponding original soils on the garden eggs and the elephant grass fields. The higher percentage of clay content of the original soils than their corresponding earthworm casts on both garden eggs and elephant grass fields seemed contrary to the observation made by Logsdon (1994) that earthworms modified soil texture by breaking larger soil units into finer granules as the soil with organic material pass through the gut of earthworms. This could be that the earthworm casts deposited on the soil surface had some of the clay content washed back into the soil by rain or irrigated water or even blown away by wind because of its lighter weight and smaller sizes as these fields had scanty fallen leaves groundcover.

The earthworm cast on tree plantation field (TE), however, had higher clay content

TABLE 1

Particle size distribution and exchangeable cations of earthworm casts and the original soils on garden eggs, elephant grass and tree plantation fields

Sample	*Parameter**	*Sand(%)*	*Silt(%)*	*Clay(%)*	*Exchangeable cations*			
					K^+(cmolkg^{-1})	*Na^+(cmolkg^{-1})*	*Ca^{2+}(cmolkg^{-1})*	*Mg^{++}(cmolkg^{-1})*
GE	Mean	66.3	23.3	10.4	0.42	0.63	8.60	0.79
	Std. error	0.09	0.36	0.13	0.03	0.02	0.19	0.02
	CV	0.3	3.4	3.0	17.37	5.94	5.60	3.62
GS	Mean	66.2	14.7	19.1	0.26	0.49	7.25	0.48
	Std. error	0.2	0.4	0.6	0.02	5.32	0.06	0.02
	CV	0.8	6.5	7.3	16.32	13.29	1.80	10.79
EE	Mean	60.7	27.2	12.1	0.44	0.56	8.94	0.72
	Std. error	0.3	0.2	0.2	0.02	0.02	0.12	0.02
	CV	1.0	1.8	3.3	9.64	8.89	2.91	6.86
ES	Mean	62.6	19.3	18.1	0.24	0.49	7.65	0.48
	Std. error	0.3	0.2	0.3	0.02	0.02	0.06	0.02
	CV	1.1	2.8	3.3	18.44	7.64	1.77	10.62
TE	Mean	62.5	16.4	21.1	0.81	0.70	13.51	1.59
	Std. error	0.4	0.2	0.2	0.03	0.03	0.17	0.02
	CV	1.4	3.0	1.9	8.59	9.48	2.88	2.52
TS	Mean	60.7	23.2	16.1	0.40	0.56	7.92	1.04
	Std. error	0.3	0.3	0.2	0.02	0.02	0.13	0.04
	CV	1.2	3.1	3.0	13.04	9.31	3.71	9.58

*Std. error: standard error; CV: coefficient of variation

(21.1%) than the corresponding original soil TS (16.1%), but the reverse was true for the silt content. This shows that some silt content had broken down into clay particles as the soil pass through the gut of the earthworms (Logsdon, 1994). The expected observation (Logsdon, 1994) which was realised could be that the tree canopy reduced the direct raindrop impact on the earthworm casts adding to the fallen leaves that might have covered and prevented the casts from being washed away by rainfall or blown away by wind.

The exchangeable cations generally increased significantly ($p \leq 0.05$) in the earthworm casts as compared with their corresponding original soils on all the fields. On the tree plantation field, the earthworm cast had 0.81, 0.70, 13.51 and 1.59 cmolkg^{-1} for K^+, Na^+, Ca^{2+} and Mg^{2+}, respectively (Table 1), an increase of about 102%, 25%, 71% and 53%, respectively, over that obtained in the corresponding original soil. The exchangeable cations of earthworm casts as compared with the original soils on the garden eggs field increased by about 62%, 29%, 19% and 51% for K^+, Na^+, Ca^{2+} and Mg^{2+}, respectively, and those of the elephant grass field were about 80%, 14%, 17% and 50%, respectively. This trend may be due to fast decomposition of organic materials (litter) by the earthworm to release the nutrients faster to the soil through the casts. This indicated that earthworm could make more nutrients available to plants through their casts (Hidalgo, 2002). Generally, the percentage increase of Na^+ was less than the other cations and, therefore, the rate of salinity formation was not enhanced.

The organic matter content was generally higher in the earthworm casts than in the corresponding original soil in all the fields (Fig. 1). The earthworm cast on the tree plantation (TE) recorded 5.1% organic matter content whilst the original soil (TS) recorded 2.8%. This indicated that the organic matter in the earthworm cast increased by about 80%. The percentage increase of organic matter content in the earthworm cast, with respect to the original soil on the elephant grass and garden eggs field, were 55% and 12%, respectively. The higher increase in the earthworm cast on the tree plantation field and the elephant grass field could be attributed to availability of litter. There was a large quantity of litter (organic material) on the tree plantation field, followed by the elephant grass and the garden eggs field having a small quantity of cleared weeds and leaves fall. The large quantity of the litter could provide a major source of food for the earthworms and, therefore, increased their activities hence higher percentage increase in organic matter in the casts on the tree plantation followed by casts on the elephant grass, with the casts on the garden eggs field having the least increase.

Fig. 2 shows the number of earthworm burrows on the different fields. The number of earthworm burrows was highest on the garden eggs field, 1.52×10^6/ha, followed by 1.37×10^6/ha on the elephant grass field and relatively the least of 0.57×10^6/ha on the tree plantation field. The highest number on the garden eggs field could be the loose and moist nature of the field since the field was ploughed and irrigated and, therefore, the soil conditions facilitated the activities of the earthworms. The elephant grass field, although not ploughed, was moist and, therefore, could enhance the activities of the

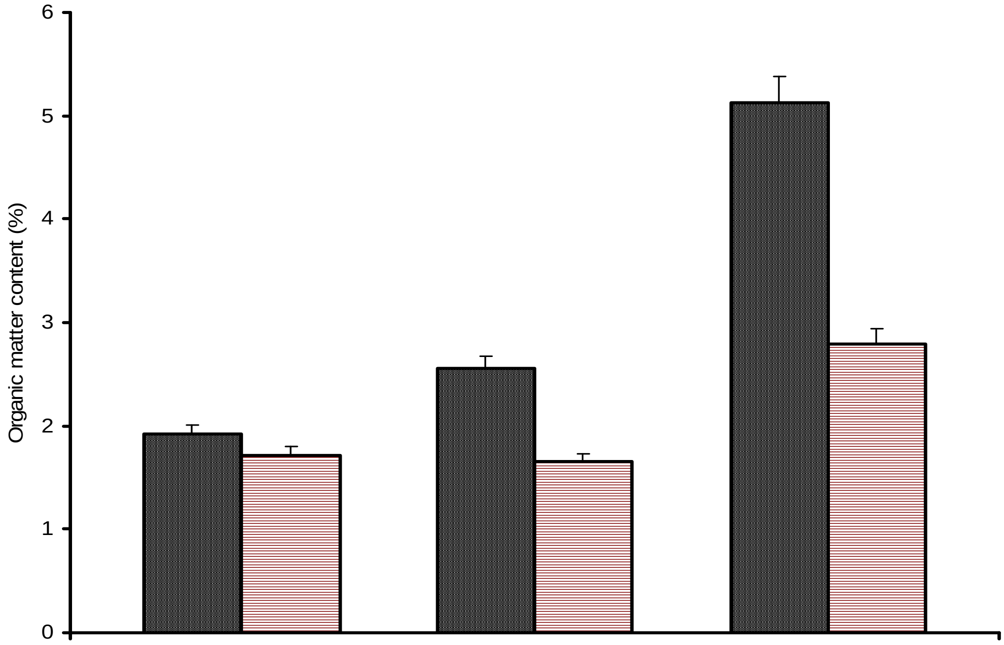

Fig. 1. Comparison of organic matter content of earthworm cast and original soils on different land use fields

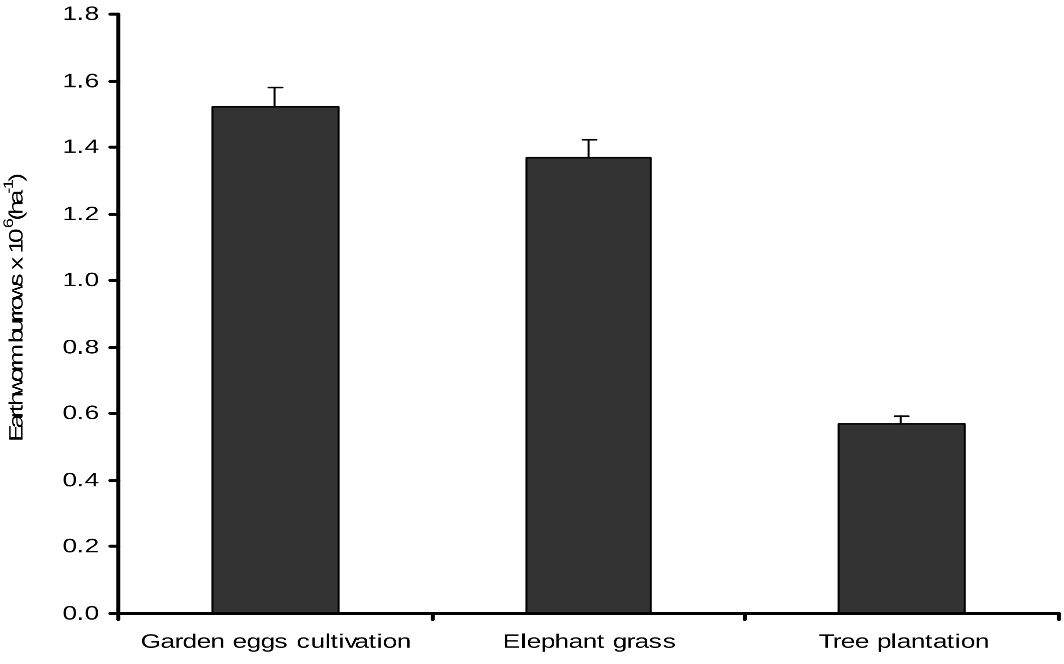

Fig. 2. Number of earthworm burrows on different land use fields

earthworm. The tree plantation field was relatively dry and seemed to be compact and that could be the cause of less number of burrows since earthworms require moist soil for their activities (Parkin & Berry, 1994). The quantity of sediment (cast) brought to the surface on each field followed the same pattern as the number of earthworm burrows (Fig. 3). During the study period the garden eggs field had 8.00 t/ha sediment, whilst the elephant grass field had 4.04 t/ha and the tree field had 1.73 t/ha (Fig. 3). The activities of the earthworms were enhanced by the moist soil condition on the garden eggs and elephant grass fields and, therefore, had higher quantity of sediments.

The earthworm activities on the tree plantation field was affected by the dry and compact nature of the soil which could have made the earthworms go aestivation. It was noted that whilst the number of burrows on the elephant grass field was about 90% of the number of burrows on the garden eggs field, the quantity of sediment on the elephant grass field was about 51% of the quantity on the garden eggs field. This indicates that the structure of the soil could play a major role on the quantity of sediment earthworms could bring to the soil surface. The burrows were generally shallow and almost connected to each other on all the fields, and this could be attributed to the nature of the earthworm specie in the region. The average depth of burrows on the garden eggs field was about 10.8 cm with maximum of about 12.0 cm and minimum of about 8.0

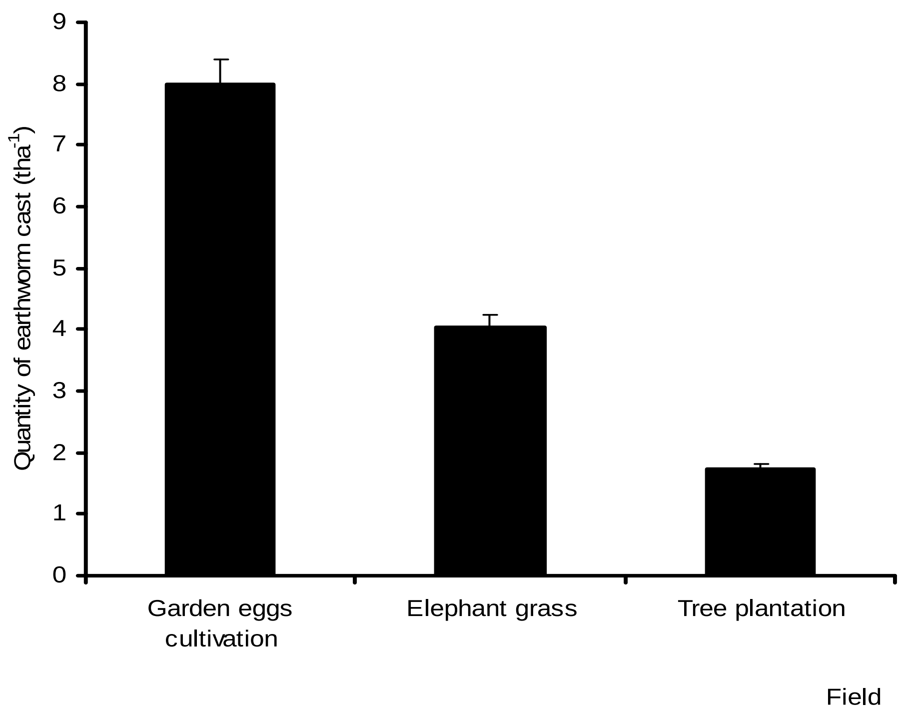

Fig. 3. Quantity of soil brought to soil surface by earthworm on different land use fields

cm, whilst the average was about 7.4 cm, maximum 8.2 cm and minimum 5.0 cm on the elephant grass, and an average of 5.8 cm, maximum of 6.2 cm and minimum of 5.0 cm, was found on the tree plantation field. The differences in the burrow depth could be as a result of differences in soil structure on the fields. This is because the garden eggs field, which was ploughed and had loose soil, had relatively deeper burrows than the burrows on the other fields which were not ploughed and seemed compact.

Conclusion

The soil particle size could be reduced into smaller units by the activities of the earthworm in the form of their casts, and this could improve the physical condition especially within the top soil. It was also found that, generally, the exchangeable cations increased tremendously in comparison with the original soil. Similarly, the organic matter content in the earthworm cast could be 80% higher than the original soil depending on the quantity of organic material on the soil surface. It was noted that the increase of the chemical properties of the soil by the earthworm depended on the quantity of available litter on the soil surface. The number of burrows and the quantity of cast also increased on tilled and moist field than untilled and dry soil.

The study showed that the organic material available on the field to a large extent determined the quality of the earthworm casts whilst the condition of the soil determined the quantity of the earthworm casts and the number of burrows. It was observed that though the tree plantation had higher increase in soil chemical properties because of the larger quantity of leaf fall, it had the least quantity of earthworm casts and number of burrows because of the condition of the soil compared with the garden eggs and the elephant grass fields. This meant that earthworms' activity could increase and, therefore, significantly improve soil fertility when there were enough organic material over the soil surface, and the soil was loose and moist. The full benefits of earthworm activity in increasing soil fertility could be realised if the crops grown on the field could produce sufficient leaf fall or mulch, and tillage practice to loosen the soil and irrigation to moisten the soil be adopted.

It must be added that, considering the large quantity and quality of soil that earthworm can bring to the soil surface in the form of earthworm cast, a field will soon deteriorate if earthworms casts are allowed to wash down. It could be concluded that a large presence of earthworms on a field could improve the soil tremendously in terms of aeration, texture and structure, and chemical properties especially when the soil was loose, moist and covered with organic material, and proper conservation practices adopted to prevent the erosion of the earthworm casts.

References

Asamoah G. K. (1973). Soils of the proposed farm site of the University of Cape Coast. *Soil Research Institute Report No. 88.*

Asare M. (2005). *Effect of climatic change on food production in some districts in the Central Region.* (BSc. Dissertation.) Department of Soil Science, University of Cape Coast, Cape Coast, Ghana. 40 pp.

Blakemore R. (2003). *Fact sheets on earthworms casting*. Queen Victoria Museum, Launceston.

Bolhen P. J., Parmelee R. W., McCartney D. A. and **Edwards C. A.** (1997). Earthworm effects on carbon and nitrogen dynamics of surface litter in corn agroecosystems. *Ecol. Applic.* **7**(4): 1341–1349.

Brady N. C. and **Weils R. W**. (1996). *The nature and properties of soils*, 10th edn. pp. 103–289. Macmillan Publishing Company.

Curry J. P. and **Byrne D**. (1992). The role of earthworms in straw decomposition and nitrogen turnover in arable land in Ireland. *Soil Biol. Biochem*. **27**(3): 341–348.

Edwards C. A. and **Lofty J. R**. (1997). The invertebrate fauna of the Park Grass plots: I. Soil fauna. *Rothamsted Report*, Part **2**: 133–154.

Elliot P. W., Knight D. and **Anderson J. M.** (1990). Denitrification in earthworm casts and soil from pastures under different fertilizer and drainage regimes. *Soil Biol. Biochem.* **22**(5): 601–605.

FitzPatrick E. A. (1983). *Soils: Their formation, classification and distribution*. New edn. Longman. London. 240 pp.

Gee G. W. and **Bauder J. W.** (1986). Particle size analysis. In *Methods of Soil Analysis.* Part 1, 2nd edn. (A. Klute, ed.), pp. 383–411. Agron. Monogr. 9, ASA and SSSA, Madison, WI.

Hilgado P., Sindoni M., Matta F. and **Nagel D. H**. (2002). *Earthworm castings increase germination rate and seedling development of cucumber*. CARES, MAFES, Mississippi State University.

Logsdon G. (1994). Worldwide progress in vermicomposting. *Biocycle* **35**(10): 63–65.

Mackay A. D. and **Kladivko E. J**. (1985). Earthworms and rate of breakdown of soybean and maize residues in soil. *Soil Biol. Biochem*. **17**(6): 851–857.

Morgan R. P. C. (1995). *Soil erosion and conservation,* 2nd edn. Longman.

Parkin T. and **Berry E**. (1994). Nitrogen transformations associated with earthworm casts. *Soil Biol. Biochem.* **26**(9): 1233–1238.

Ramsay J. A. and **Hill S. B.** (1978). Earthworms, the agriculturist's friends. *Macdonald J.* **39**(10): 6–8.

Ruz-Jerez B., Ball P. R. and **Tillman R. W.** (1988). The role of earthworms in nitrogen release from herbage residues. In *Nitrogen Efficiency in Agricultural Soils* (D. S. Jenkinson and K. A Smith, ed.), pp. 355–370.