



Clive Edwards and earthworms: in memoriam

Dedicated to Professor Clive Edwards (1925–2021), The Ohio State University, USA

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Professor Clive Arthur Tudor Edwards, who was an internationally recognized soil ecologist, passed away peacefully on 20 July, 2021 in Dublin, Ohio, aged 96. Clive was born on 16 June, 1925 in Worcester, England. After obtaining a BSc (Honours) in Zoology, Physics and Biochemistry at Bristol University, UK, in 1951, Clive completed postgraduate dissertations in 1955 (MSc in Zoology at the University of Bristol) and 1956 (MSc in Toxicology at the University of Wisconsin). He carried out graduate research for a PhD in Entomology at the University of Wisconsin in 1958. In 1986 he was honoured with the degree of Doctor of Science (DSc) by his *alma mater*, University of Bristol, UK, in recognition of his contributions to science. Clive was employed as a Government Entomologist by the British Ministry of Agriculture, Fisheries, and Food from 1951 to 1955 and from 1957 to 1960. He was then appointed to the post of Principal Scientific Officer at the Rothamsted Experimental Station in Harpenden, Herts, UK, a post that he held until 1966. This was followed by an appointment as Visiting Professor at Purdue University, Indiana (Senior NSF Fellowship) where Clive served between 1966 and 1968. He then returned to the Rothamsted Experimental Station, acting as Principal Scientific Officer between 1968 and 1982 and as Senior Principal Scientific Officer between 1982 and 1985.

Before 1985, Clive also acted as a consultant for the UK Overseas Development Administration (ODA), Food and Agriculture Organization of the United Nations (FAO), UN Development Program (UNDP), International Atomic Energy Agency (IAEA), UN Educational Scientific and Cultural Organization (UNESCO), World Health Organization (WHO), European Economic Community (EEC) and other international agencies. Clive visited many international agricultural centres and worked for various of these for different lengths of time, including the IIRI (Manila), ICRISAT (India), IITA (Nigeria) and CIAT (Columbia) and other centres in East Asia (Sri Lanka, Indonesia, and the Philippines) Africa, (Egypt, Nigeria, Ghana, Tanzania, Uganda, Kenya, South Africa), the South Pacific, (Australia, New Zealand, the Solomon Islands, Fiji, Cook Islands, Tonga, West Samoa, Nauru, Tarawa, and Hawaii), the Caribbean and South America.

Between 1984 and 1988 Clive led a Food and Agricultural Organization (FAO)/International Atomic Energy Agency (IAEA) project funded by the Swedish International Development Cooperation Agency (SIDA) and aimed at comparing pesticide degradation in temperate and tropical countries under different regional and climatic conditions. This involved providing guidance and visiting collaborative projects in Pakistan, Kenya, India, Malaysia, Sudan, Brazil, Egypt, Thailand, Ecuador and Mexico. In 1990, he was appointed as Research Fellow in The Ohio State University's Center for African Studies and as a founder member of the World Sustainable Agriculture Association. In 1991, the FAO/IAEA project was expanded to evaluate the environmental effects of pesticides under tropical conditions in Africa. Within the project, Clive Edwards designed and led a five-year collaborative experiment on the environmental effects of pesticides in Africa (again under the auspices of FAO/IAEA and funded by SIDA). This involved collaborative projects in Egypt, Algeria, Kenya, Uganda, Tanzania, Nigeria, Ghana and Zimbabwe, and Clive worked with scientists from all of these countries on the design and implementation of different projects and visited most of the countries involved. When the project ended in 1996 Clive organized a final meeting of all participants in Uganda.

In 1985, Clive moved to The Ohio State University, where he remained as Full Professor of Entomology until the end of his career and as a distinguished Emeritus Professor until his death in 2021. During his long tenure at OSU he served

as Chair of the department of Entomology and as Director of the Sustainable Agriculture Program of The Ohio State University.

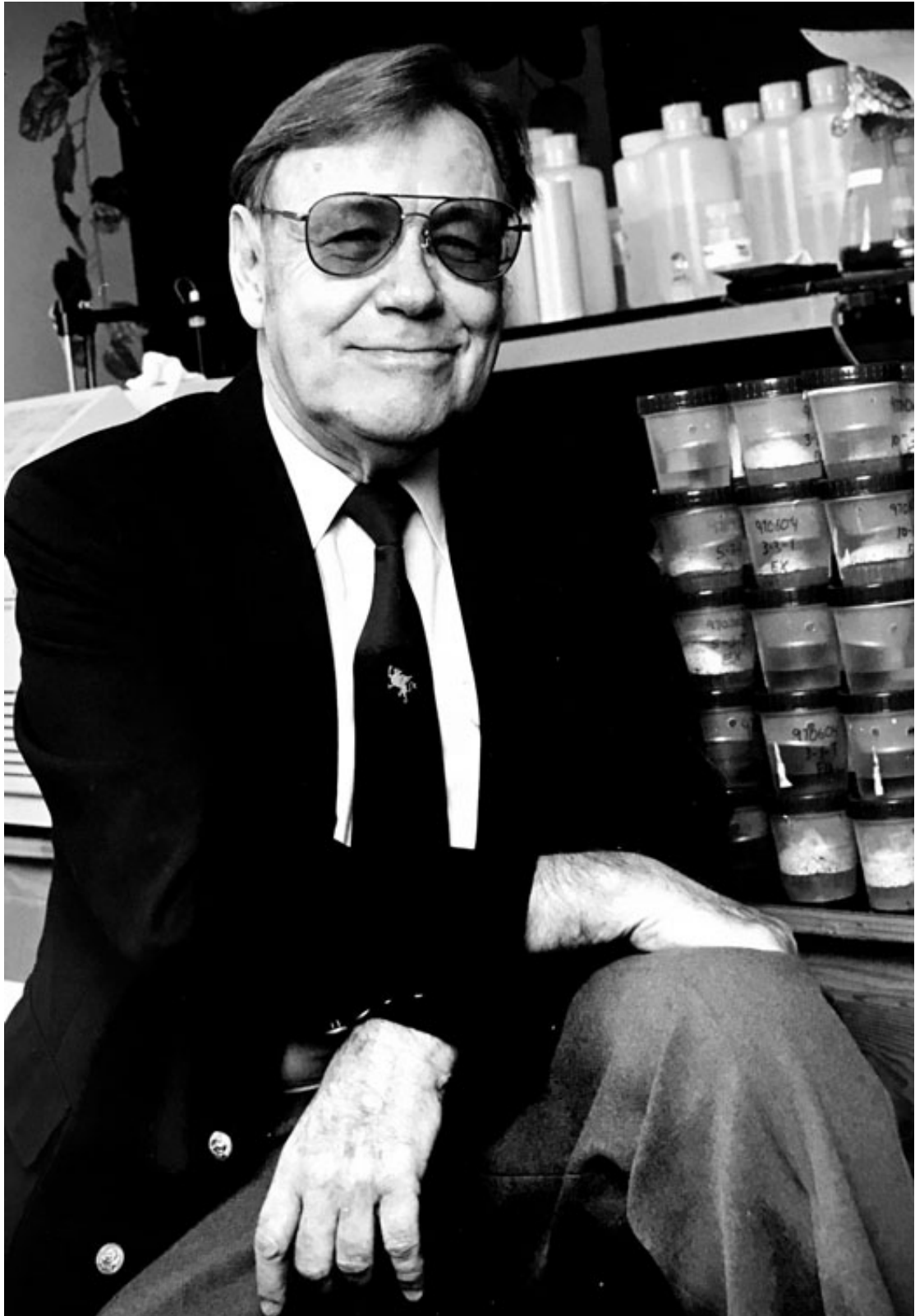


FIGURE 1. Clive Edwards (Family archive).

THE EARTHWORM BOOKS BY CLIVE EDWARDS

Clive published a large number of scientific publications and wrote, edited or co-edited 35 books on soil ecology, environmental toxicology and sustainable agriculture. He was recognized as a world authority on earthworms. His book, *Biology and Ecology of Earthworms*, was the first comprehensive book on earthworms since Charles Darwin's *The Formation of Vegetable Mould Through the Action of Worms* was published in 1881. In 1996, *Biology of Earthworms* won a Presidential citation from the US Soil & Water Conservation Society.

Before the seminal book on earthworm natural history was written by Charles Darwin, many soil scientists and laymen considered earthworms to be pests and generally overlooked their contribution to soil formation, health, and fertility. More than 140 years have passed since Darwin wrote *The Formation of Vegetable Mould Through the Action of Worms* (1881), which was the result of 40 years of careful personal observations on the activities and natural history of the earthworms. Darwin established the importance of these animals in maintaining soil fertility, demonstrated how much soil they turn over and aroused an interest of many scientists in the habits and role of earthworms in soil. Despite the surprising commercial success of Darwin's book (he sold many more copies of this book than of *On the Origin of Species*), the studies and knowledge of these ubiquitous soil invertebrates progressed very slowly over the following 60 years. It was not until after the Second World War, when Soil Zoology first came into its own -as indicated by organization of the first International Conference on the subject held in 1955 (at the University of Nottingham, UK)- that research on earthworm biology and ecology began to grow and the discipline of soil biology emerged. Thereafter, the regular International Soil Zoology conferences encouraged a strong interest in soil-inhabiting invertebrates, especially earthworms, and consequently the publication of studies on earthworms began to increase greatly.

Biology of Earthworms. First edition 1972.

In 1972 Clive A. Edwards and John R. Lofty published *Biology of Earthworms*, a seminal book for earthworm researchers and students worldwide. This book appeared 42 years after the last monograph on Oligochaeta, *The Oligochaeta*, was written by Stephenson (1930) and which included much information on almost all aspects of the morphology, physiology, taxonomy, ecology and geographical distribution. Edwards and Lofty realized that sufficient new information had been produced in the meantime and, accordingly, that an update was necessary. Moreover because, as John Satchell highlighted (Satchell 1992), there was an exponential increase in publications in the period 1930-1970.

John Stephenson was a brilliant taxonomist who dedicated a great deal of his career to describing Oriental and Indian earthworms; he followed a similar path to his contemporary and associate Wilhelm Michaelsen, as implied by the dedication in his monograph, which reads "to W. Michaelsen, my Friend and Master". Stephenson was not an ecologist, and his book only briefly covered this area (5%), relying to some extent on Darwin's findings (Darwin 1881). Stephenson's book mainly focused on the morphology and taxonomy of all oligochaetes (aquatic and terrestrial). The subjects of embryology, physiology, phylogeny (and geographical distribution) were also covered, but to a lesser extent.

The first edition of *Biology of Earthworms* was influenced by Stephenson's book. This edition, for example, dedicated several pages to the morphology (12.7% of total content), biology (7.8%) and physiology of earthworms (7.1%). Moreover, it also included a section on taxonomy and distribution (12.7%). However, the ecological and agronomical background of both authors was clearly indicated by the amount of information dedicated to ecology (15.2%); soil fertility (3.9%), organic matter cycles (4.9%) and effect of agricultural practices (14.5%). Two original and very useful sections of *Biology of Earthworms* include i) simple laboratory and field experiments with earthworms and ii) a simplified key to some common genera of terrestrial earthworms (Europe and USA), including a list of some lumbricid species. These sections established the necessary bridge to attract and interest young pre-graduate students and scientists studying earthworms, but who lacked the necessary taxonomical training for identification of the species. This edition includes 567 references.

Biology of Earthworms. Second edition. 1977.

This edition, also authored by Edwards and Lofty (333 pp.), includes the same sections as the former, with some noteworthy differences: i) a glossary of terms and ii) more information in the chapters on taxonomy-global distribution (8.4%) and biology (8.4%). In the five years that elapsed between the two editions, almost 100 new references were added. Again, the chapter on ecology (populations and communities) was the largest (50 pp, 15%).

In both editions the chapter on taxonomy was particularly useful for non-specialist researchers and for those undertaking taxonomic studies. For each family, a short diagnosis and a list of genera with their geographic distribution were provided.

The family Megascolecidae was treated in greater detail, mainly because its classification changed according to different authors; Edwards and Lofty made a superb summary of the differences between these classifications. This chapter greatly influenced the decision of one of the co-authors of this paper (CF) to study the ecology and taxonomy of Mexican earthworms.

Biology and Ecology of Earthworms. Third Edition. 1996.

The third edition of *Biology of Earthworms* (426 pp) was published in 1996 (19 years after last edition) and included some further changes relative to former editions. The title of the book, now authored by C.A. Edwards and P.J. Bohlen, was changed to *Biology and Ecology of Earthworms*, highlighting the importance of ecological aspects. Accordingly, the ecology section, was split into populations and communities, and further details were added to the agronomy and soil-related sections (41%). Two new chapters on environmental and waste management were also added. Consequently, aspects of morphology, taxonomy, biology and physiology were given less attention (20.7%) than in former editions (covering 34-35%). Nonetheless, the chapter on earthworm diversity and geographical distribution included the first cladistic tree of earthworm families published by Jamieson some years before (Jamieson, 1988), predicting the future of earthworm taxonomy. Sadly, the simplified key to terrestrial genera was eliminated and the simple and laboratory experiments were limited to toxicological experiments. A noteworthy aspect was the large number of references (1444), twice the number included in the previous edition.

Undoubtedly all three editions of the book have been a continuous source of knowledge, encouragement and inspiration for students and researchers of earthworm biology all around the world.

Fortunately, Clive Edwards has bequeathed future generations of biology students a fourth edition of his book, which will be available by the middle of 2022. We are sure that the new edition will surprise us in the same way that former editions did.

Earthworm Ecology. First edition. 1998. Edited by Clive A. Edwards

The tradition of publishing books after the celebration of international earthworm meetings began in 1980, when the first Applied Workshop on the Role of Earthworms in the Stabilization of Organic Residues, was held in Kalamazoo, Michigan, and the Proceedings were published in 1981 (see below). This set the scene for the use of earthworms in applied problems for the first time and stimulated a great deal of interest in applied earthworm ecology.

Also in 1981, the centenary of the publication of Darwin's book, the First International Conference on Earthworms, attended by 150 scientists, was held in Grange-over-Sands, UK. The Conference Proceedings were published under the title *Earthworm Ecology*, edited by J. E. Satchell. This was followed four years later in 1985 by the Second International Conference held in Bologna, Italy, with the Conference Proceedings published under the title *On Earthworms*, edited by A.M. Pagliai and P. Omodeo in 1987.

Following this tradition, the first edition of the book *Earthworm Ecology* owed its origin to the Fifth International Symposium on Earthworm Ecology, which was held in Columbus, Ohio, in July 1994. Many of the 165 research presentations made at this symposium, which was attended by more than 220 scientists from 38 countries, were published in a special volume of the journal *Soil Biology and Biochemistry*. In the eight sessions that were held at the Columbus symposium, each opened with an invited review paper of a key topic by a distinguished earthworm scientist and concluded with a final overview of the subject and conclusions by another well-known earthworm scientist. The 16 invited papers were edited to form the eight sections in the first edition of *Earthworm Ecology*, which covered all of the major aspects of earthworm ecology, including earthworm diversity, behaviour, physiology and general ecology, and the roles of earthworms in nutrient cycling, soil maintenance, plant growth, ecotoxicology and waste management, with two chapters summarizing current research at that time on each topic. The first edition of *Earthworm Ecology* was very well received by soil scientists, students and the public.

Earthworm Ecology. Second edition. 2004. Edited by Clive A. Edwards

Since the first edition of *Earthworm Ecology* was published in 1998, two further symposia on earthworm ecology were held, in Vigo (Spain) in 1998 and in Cardiff (Wales) in 2002. The numbers of publications on earthworms increased greatly, and in view of the rapidly expanding developments and discoveries in earthworm biology and ecology, Clive felt that it was appropriate to update, and revise extensively, the first edition of *Earthworm Ecology* by adding new chapters addressing the most rapidly developing areas of earthworm research. Thus, the second edition of *Earthworm Ecology* included extensive revisions of the original chapters published in the first edition of the book in 1998, as well as additional chapters on the history of earthworm research, the mechanisms by which earthworms increase soil

fertility and promote plant growth, and the importance of invasions of exotic species of earthworms in North America and other regions of the world. It also included discussions on how climate, soil properties, predation, disease-parasitism and competition affected earthworm ecology and on advances in vermiculture and vermicomposting. These updates made the book an even more valuable addition to the publications that summarized the increasing importance of earthworms in natural ecosystems and crop production. It also addressed key issues in earthworm biology and ecology and was another essential key reference treatise for soil scientists and agronomists as well as anyone with an interest in earthworms and soil biology and ecology.

Earthworms in waste and environmental management (1988) C.A. Edwards & E.F. Neuhauser (eds.).

The contributions to this book include most of the papers presented at the First International Conference on Earthworms in Waste and Environmental Management, held in Cambridge, UK, in 1984. The Conference was held in response to the great expansion of interest and research into the application of earthworms into waste management and land reclamation. This started with research by R. Hartenstein and his associates into the use of earthworms in stabilizing sewage sludge, at the State University of New York, Syracuse in 1976, and was followed up by Clive A. Edwards and his associates at Rothamsted Experimental Station in England and elsewhere, by research aimed at using earthworms to break down a wide range of types of organic waste. During the same period, there was increasing interest in the use of earthworms in land reclamation and soil improvement and in the use of earthworms as key bioindicators of soil contamination by chemicals. This volume edited by Clive Edwards and Edward F. Neuhauser gave a comprehensive overview of those studies and demonstrated the great potential for a multitude of practical uses for earthworms, some of which ultimately conformed the basis of extensive commercial and industrial development. At that time, these types of commercial applications had already begun in many different parts of the world. The book was organized in the following six sections: I) processing of animal and human waste by earthworms (8 chapters), II) engineering waste management by earthworms (6 chapters), III) earthworms as animal feed (4 chapters), IV) earthworms in production of plant growth media (4 chapters), V) earthworms in land reclamation, soil amelioration and land improvements (3 chapters) and VI) earthworms as indicators of environmental contamination (10 chapters).

This book served as a source of and basis for the rapid expansion of the use of earthworms in waste and environmental management.

Vermiculture Technology: Earthworms, Organic Wastes, and Environmental Management. 2011. Edited by Clive A. Edwards, Norman Q. Arancon and Rhonda Sherman.

This is probably the first international and comprehensive book on vermiculture and vermicomposting. At that time, many books covered the importance of composting for reducing the amount of organic waste in landfills. This treatise on vermicomposting focused on the innovative vermiculture technology that turns organic waste into value-added environmentally friendly products that can improve soil health and fertility promoting productivity under sustainability paradigms on a large scale.

This book was dedicated to Mary Appelhof, a pioneer in developing low-scale or home vermicomposting, who was responsible for several initiatives in the early development of vermiculture, making the topic accessible to a general audience. In 1979, Mary organized a milestone workshop in Kalamazoo, Michigan, which addressed the bioprocessing of organic wastes, especially sewage sludge, by earthworms. With funding support from the US National Science Foundation, she brought together more than 40 international scientists, entrepreneurs and commercial earthworm breeders who were interested in the potential use of earthworms to break down organic wastes, focusing on sewage biosolids. The proceedings of the workshop were published in 1981 under the title *Workshop on the Role of Earthworms in the Stabilization of Organic Residues* (Volume I, Proceedings; Volume II, Bibliography), by Beech Leaf Press, Kalamazoo, Michigan. These publications set the scene for the expansion of further research on the breakdown of sewage wastes by earthworms at the State University of New York (SUNY) in Syracuse, New York, and was the basis of a new research programme on the breakdown of agricultural organic wastes by earthworms, initiated at the Rothamsted Experimental Station, Harpenden, United Kingdom, under the leadership of Clive Edwards, and financially supported by the British Agricultural Research Council. This eventually led to the major commercialization of vermiculture in the UK in the 1980s and established the basis for developments in vermiculture in many other countries.

Mary had begun to develop a personal programme promoting domestic vermicomposting systems for widespread use

in homes and schools. She published a book entitled *Worms Eat My Garbage* in 1982, and by 1997 had sold more than 100,000 copies through her mail-order business Flowerfield Enterprises. She then revised the book for a second edition, which sold a further 30,000 copies and supplemented it with other paperback books aimed at interesting schoolchildren in recycling food wastes with earthworms.

In 2000, Mary and Clive collaborated in organizing an International Symposium and Training Workshop in vermiculture and vermicomposting, again in Kalamazoo, Michigan, under the

catchy title of Vermillenium. The proceedings could not be published as planned soon after the symposium, and then Mary died suddenly in 2005. However, the international presentations at Vermillenium were so useful that Clive Edwards, with the support of Professor Rhonda L. Sherman of North Carolina University and Assistant Professor Norman Q. Arancon of the University of Hawaii, completely revised and updated the edition of the manuscripts that had been written by the presenters at Vermillenium and also recruited authors to write some new chapters, with the aim of compiling the first comprehensive review of all aspects of the innovative vermiculture technology. The book again provided seeds that expanded vermiculture and vermicomposting into a major technology across the world, resulting in substantial environmental benefits.

Professor Clive A. Edwards had an outstanding scientific career which left an indelible mark on research on soil biology and ecology in many laboratories all over the world. He will be sorely missed by his many friends, colleagues and former students and he leaves a gap that will be difficult to fill. We miss a colleague from whom we learned much. His contribution to world soil science, earthworm biology and ecology and sustainable agriculture has been enormous, but perhaps more than anything, Clive will be remembered as a kind, funny English gentleman. Clive had a long-standing interest in international soil science and soil ecology and attended almost all of the International Soil Zoology Colloquia from 1962 onwards, and all of the International Symposiums in Earthworm Ecology, making many close friendships with soil scientists and establishing important international collaborations which notably marked his research. He loved to socialize with his colleagues and graduate students, and his students all emphasized how considerate, personable and supportive he was in guiding their research. Clive was so lucky to have married his incredible wife Elvira, who was very involved in Clive's career and was always attentive to Clive's students and all matters relating to their travel and the organization of meetings and events, both academic and social. Clive lived a long and happy life as an active scientist. Although he always said his longevity could be attributed to "pickling himself" with regular visits to the pub, it was more likely due to his zeal for his hobbies, his work, and the people in his life and by his continued willingness to forge friendships with younger people, being surrounded by a loving family and a far-reaching network of friends all over the world.

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