References

Anderson, J. M. 1975. The enigma of soil animal species diversity. In: Vanek, J. (Ed.) *Progress in Soil Zoology*. Czech Acad. of Sciences, Prague. pp. 51–58.

Anderson, J. M. 1995. Soil organisms as engineers: microsite modulation of macroscale processes. In: Jones, C. G. & Lawton, J. H. (eds.) *Linking Species and Ecosystems*. Chapman and Hall, London. pp. 94–106.

Anderson, J. M. & Ingram, J. (Eds). 1993. *Tropical Soil Biology and Fertility. A Handbook of Methods*. 2nd Edition. CAB, Oxford. 221p.

Barros, M. E., Blanchart, E., Neves, A., Desjardins, T., Chauvel, A. & Lavelle, P. 1996. Relaçao entre a macrofauna e agregagaçao do solo em tres sistemas na Amazonia central (in Portuguese). Solo/Suelo XII Congresso Latino America de Ciencia do Solo, Aguas Lindoia, Brazil.

Barros, E., Pashanasi, B., Constantino, R. & Lavelle, P. 2002. Effects of land-use systems on soil macrofauna in Western Amazon basin. *Biol. Fertil. Soils*, 35: 338–347.

Baskin, Y. 1994. Ecosystem function of biodiversity. *BioScience*, 44(10): 657–660.

Beare, M. H., Coleman, D. C., Crossley, Jr., D. A., Hendrix, P. F. & Odum, E. P. 1995. A hierarchical approach to evaluating the significance of soil biodiversity to biogeochemical cycling. *Plant Soil*, 170: 5 22.

Birkeland, P. W. 1984. *Soils and Geomorphology*. Oxford University Press, New York.

Black, H. I. J. & Okwakol, M. J. N. 1997. Agricultural intensification, soil biodiversity and agroecosystem function in the tropics: the role of termites. *Appl. Soil Ecol.*, 6: 37–53.

Blanchart, E., Lavelle, P., Braudeau, E., Bissonnais, Y.L. & Valentin, C. 1997. Regulation of soil structure by geophagous earthworm activities in humid savannas of Cote d'Ivoire. *Soil Biol. Biochem.*, 29(3/4), 431–439.

Bouché, M. B. 1977. Stratégies lombriciennes. *Ecol. Bull.*, 25: 122–132.

Boyer, J. 1998. Interactions Biologiques (Faune, Ravageur, Parasites, Microflore) Dans des Sols Sous Cultures en Milieu Tropical Humide (Ile De La Réunion). Thèse de l'Université Paris 6, Paris. 115 p.

Brewer, R. 1954. Soil parent material. *Aust. J. Sci.*, 16: 134–138.

Brewer, R. 1964. *The Fabric and Mineral Analysis of Soil*. CSIRO Division of Soils, Melbourne.

Brown, G. G. 1995. How do earthworms affect microfloral and faunal community diversity? *Plant Soil*, 170: 209–231.

Brown GG; Pashanasi B; Gilot-Villenave C; Patrón JC; Senapati BK; Giri S; Barois I; Lavelle P; Blanchart E; Blakemore RJ; Spain AV & Boyer J. 1999. Effects of earthworms on plant production. In: Lavelle, P., Brussaard, L. & Hendrix, P. F. (Eds). *Earthworm Management in Tropical Agroecosystems*. CAB International, Wallingford, UK. pp. 87–147.

Brussaard, L. & Hijdra, R. D. W. 1986. Some effects of scarab beetles in sandy soils of The Netherlands. *Geoderma*, 37(4): 325–330.

Burle, M. L., Mielniczuk, J., Focchi, S. 1997. Effect of cropping systems on soil chemical characteristics, with emphasis on soil acidification. *Plant Soil*, 190: 309–316.

Carlson, S. R. & Whitford, W. G. 1991. Ant mound influence on vegetation and soils in a semiarid mountain ecosystem. *Am. Midl Nat.*, 126(1): 125–139.

Castro Filho, C., Muzilli, O. & Podanoschi, A. L. 1998. Estabilidade dos aggregados e sua relação com teor de carbono orgânico num latossolo roxo distrófico, em função de sistemas de plantío, rotações de culturas e métodos de preparo das amostras. *R. Bras. Ci. Solo*, 22: 527–538.

Chauvel, A., Grimaldi, M., Barros, E., Blanchart, E., Desjardins, T., Sarrazin, M. & Lavelle, P. 1999. Pasture damage by an Amazonian earthworm. *Nature*, 398:32–33.

Chesworth, W. 1992. Weathering systems. In: Martini, I. P. & Chesworth, W. (Eds.) *Weathering, Soils and Paleosols*. Elsevier Science Publications, Amsterdam. pp. 19–40

Collins, N. M. 1989. Termites. In: Lieth, H. & Werger, M. J. A. (Eds). *Tropical Rain Forest Ecosystems: Biogeographical and Ecological Studies*. Elsevier, Amsterdam. pp. 455–471

Coûteaux, M.-M., Mousseau, M., Celerier, M.-L. & Bottner, P. 1991 Increased atmospheric CO_2 litter quality: decomposition of sweet chestnut leaf litter with animal food webs of different complexities. *Oikos*, 61: 54–64.

Cowan, J. A., Humphreys, G. S., Mitchell, P. B. & Murphy, C. L. 1985. An assessment of pedoturbation by two species of mound-building ants, *Camponotus intrepidus* (Kirby) and *Iridomyrmex purpureus* (F. Smith). *Aust. J. Soil Res.*, 22: 95–107.

Decaëns, T. 2000. Degradation dynamics of surface earthworm casts in grasslands of the Eastern Plains of Colombia. *Biol. Fertil. Soils*, 32: 149–156.

Decaëns, T., Galvis, J. H. & Amézquita, E. 2001. Propriétés des structures produites par les ingénieurs écologiques à la surface du sol d'une savane colombienne. *C. R. Acad. Sci. Séries III*, 324(5): 465–478.

Decaëns, T., Mariani, L & Lavelle, P. 1999. Soil surface macrofaunal communities associated with earthworm casts in grasslands of the Eastern plains of Colombia. *Appl. Soil Ecol.*, 13: 87–100.

Decaëns, T., Lavelle, P., Jiménez, J. J., Escobar, G. & Rippstein G. 1994. Impact of land management on soil macrofauna in the Oriental Llanos of Colombia. *Eur. J. Soil Biol.*, 30(4):157–168.

Deleporte, S. 1987. Rôle du Diptère Sciaridae Brasidia confinis (Winn., Frey) dans la dégradation d'une litière de feuillus. *Rev. Ecol. Biol. Sol*, 24: 341–358.

Duboisset, A. 1995. Caractérisation et quantification par analyse d'image des modifications structurales engendrées par *Pontoscolex corethrurus* (Glossoscolecidae, Oligochaeta) sur un sol ferrallitique cultivé (Pérou). DEA Pédologia, Université Nancy I, France.

Duchaufour, P. 1982. *Pedology: Pedogenesis and Classification*. George Allen and Unwin, London.

Dufour, R. 2000. Farmscaping to enhance biological control. ATTRA, Fayetteville, AK.

de Souza, O. F. F. & Brown, V. K. 1994. Effects of habitat fragmentation on Amazonian termite communities. *J. Trop. Ecol.*, 10(2): 197–205.

Edwards, C. A. & Bohlen, P. J. 1996. Biology and Ecology of Earthworms. 3rd edition. Chapman and Hall, London. 426 p.

Edwards, C. A. & Fletcher, K. E. 1988. Interactions between earthworms and microorganisms in organic matter breakdown. *Agr. Ecosyst. Environ.*, 24: 235–247.

Eggleton, P., Bignell, D.E., Sands, W.A., Mawdsley, N.A., Lawton, J.H., Wood, T.G. & Bignell, N.C. 1996. The diversity, abundance and biomass of termites under differing levels of disturbance in the Mbalmayo Forest Reserve, Southern Cameroon. *Phil. Trans. Royal Soc. London B*, 351: 51–68.

Ehlers, W. 1975. Observations on earthworm channels and infiltration on tilled and untilled loess soil. *Soil Sci.*, 119: 242–249.

Ester, A. & van Rozen, K. 2000. Earthworms (*Aporrectodea* spp.; Lumbricidae) responsible for soil structure problems in young polders of the Netherlands. In: J. Rusek (ed.), XIIIth International Colloquium on Soil Zoology, Abstracts. pp. 189.

FAO. 2000. Guidelines and Reference Material on Integrated Soil and Nutrient Management and Conservation for Farmer Field Schools. FAO report.

Folgarait, P. J. 1998. Ant biodiversity and its relationship to ecosystem functioning: a review. *Biodiv. Cons.*, 7: 1221–1244.

Fragoso,C. & Lavelle, P. 1992. Earthworm communities of tropical rain forests. *Soil Biol. Biochem.*, 24(12): 1397–1408.

Gay, F. J. & Calaby, J. H. 1970. Termites of the Australian region. In: Krishna, K. & Weesner, F. M. (Eds.), *Biology of Termites*, Vol. 2. Academic Press, New York. pp. 393–448.

Giller, P. S. 1996. The diversity of soil communities, the "poor man's tropical rainforest". *Biodiv. Cons.*: 5: 135–168.

Giller, K. E., Beare, M. H., Lavelle, P., Izac, A.-M. N. & Swift, M. J. 1997. Agricultural intensification, soil biodiversity and agroecosystem function. *Appl. Soil Ecol.*, 6: 3–16.

Gitay, H. & Noble, I. R. 1997. What are functional types and how should we seek them? In: Smith, T. M. , Shugart, H. H. & Woodward, F. I. (Eds). *Plant Functional Types: Their Relevance to Ecosystem Properties and Global Change*. Cambridge University Press, Cambridge. pp. 3–19.

Gold, C. S. & Messiaen, S. 2000. The banana weevil *Cosmopolites sordidus*. Musa Pest INIBAP Fact Sheet No 4.

Guggenberger, G., Thomas, R. J. & Zech, W. 1996. Soil organic matter within earthworm casts of an anecic-endogeic tropical pasture community, Colombia. *Appl. Soil Ecol.*, 3: 263–274.

Guía Salud de Suelos. 2002. Zamorano University and Cornell University

Gullan, P. J. & Cranston, P. S. 1994. *The Insects. An Outline of Entomology*. Chapman and Hall, London.

Haukka, J. 1991. Spatial distribution and formation of earthworm burrows. *Pedobiologia*, 35: 175–178.

Healey, I. N. & Russel-Smith, A. 1971. Abundance and feeding preferences of fly larvae in two woodland soils. In: Organismes du sol et production primaire, Proceedings of the 4th Colloquium Pedobiologiae, 14–19 September 1970, Dijon, France. Institut national de la recherche agronomique, Paris. pp. 177–191.

Hendrix, P.F., Crossley, D.A. Jr., Blair, J.M. & Coleman, D.C. 1990. Soil biota as components of sustainable agroecosystems. In: Edwards, C. A., Lal, R., Madden, P., Miller, R. H. & House, G. (Eds.) *Sustainable Agricultural Systems*. Soil and Water Conservation Society, IA. pp. 637–654.

Holt, J. A., Bristow, K. L. & McIvor, J. G. 1996. The effect of grazing pressure on soil animals and hydraulic properties in two soils of semi-arid tropical Queensland. *Aust. J. Soil Res.*, 34: 69–79.

Hurpin, B. 1962. Super-famille des Scarabaeoidea. In: Balachowsky, A. S. (Ed.), *Entomologie Appliquée à l'Agriculture*. I. Masson et Cie., Paris. pp. 24–204.

IBOY. 2000. Soil macrofauna: an endangered resource in a changing world. Report of an international workshop held at IRD, Bondy (France) 19–23 June 2000. Downloadable at URL: http://www.bondy.ird.fr/lest/iboy/workshop-report.pdf.

Ingham, R. E., Trofymov, J. A., Ingham, E. R. & Coleman, D. C. 1985. Interactions of bacteria, fungi and their nematode grazers: effects on nutrient cycling and plant growth. *Ecol. Monogr.*, 55: 119–140.

Jaffe, K., Ramos, C. & Issa, S. 1995. Trophic interactions between ants and termites that share common nests. *Ann. Am. Entom. Soc.*, 24(3): 328–333.

Jayaraj, S., Rangarajan, A. V., Murugesan, S., Santhramj, G., Jayaraghovan, S. V. & Thangaraj, D. 1986. Studies on the outbreak of whitefly, *Bremisia tabaci* (Gennadius) on cotton In Tamil Nadu. In: Jayaraj, S. (Ed.) *Resurgence of Sucking Pests*. Proc. Nat. Symp. Coimbatore, India Tamil Nadu University.

Jenkinson, D. S. & Ladd, J. N. 1981. Microbial biomass in soil: measurement and turnover. In: Paul, E. A. & Ladd, J. N. (Eds.) *Soil Biochemistry*. Vol. 5. Marcel Dekker, New York.

Jiménez, J. J. & Thomas, R. J. 2001. Nature's Plow: *Soil Macroinvertebrate Communities in the Neotropical Savannas of Colombia*. CIAT publication 324, Cali. 389 p.

Jones, C. G., Lawton, J. H. & Shachack, M. 1994. Organisms as ecosystem engineers. *Oikos*, 69: 373–386.

Jones, C. G., Lawton, J. H. & Shachack, M. 1997. Positive and negative effects of organisms as physical ecosystem engineers. *Ecology*, 78(7): 1946–1957.

Josens, G. 1983. The soil fauna of tropical savannas. III. The termites. In: Bourlière, F. (Ed.), *Tropical Savannas*. Elsevier Scientific Publishing Co., Amsterdam. pp. 505–524.

Kirk, V. M. 1981. Earthworm burrows as oviposition sites for western and northern corn rootworms (*Diabrotica* : Coleoptera). *J. Kans. Entomol. Soc.*, 54: 68–74.

Kooyman, C. & Onck, R. F. M. 1987. Distribution of termite (isoptera) species in Southwestern Kenya in relation to land use and the morphology of their galleries. *Biol. Fertil. Soils*, 3: 69–73.

Laakso, J. & Setälä, H. 1997. Nest mounds of red wood ants (Formica aquilonia): hot spots for litter-dwelling earthworms. *Oecologia*, 111: 565–569.

Lavelle P. 1981. Stratégies de reproduction chez les vers de terre. *Acta Oecol.*, 2: 117–133.

Lavelle, P. 1996. Diversity of soil fauna and ecosystem function. *Biol. Int.*, 33: 3–16.

Lavelle, P. 1997. Faunal activities and soil processes: adaptive strategies that determine ecosystem function. *Adv. Ecol. Res.*, 27: 93–132.

Lavelle, P. 2002. Functional domains in soils. *Ecol. Res.*, 17(4): 441–450.

Lavelle, P. & Pashanasi, B. 1989. Soil macrofauna and land management in Peruvian Amazonia (Yurimaguas, Loreto). *Pedobiologia*, 33:283–291

Lavelle, P. & Spain, A. 2001. *Soil Ecology*. Kluwer Academics, The Netherlands.

Lavelle, P., Brussaard, L. & Hendrix, P. F. 1999. *Earthworm Management in Tropical Agroecosystems*. CABI publishing, Wallingford. 300 p.

Lavelle, P., Blanchart, E., Martin, A., Martin, S., Spain, A., Toutain, F., Barois, I. & Schaefer, R. 1993. A hierarchical model for decomposition in terrestrial ecosystems: application to soils of the humid tropics. *Biotropica*, 25: 130–150.

Lavelle P., Lattaud, C., Trigo, D. & Barois, I. 1994a. Mutualism and biodiversity in soil. *Plant Soil*, 170: 23–33.

Lavelle, P., Dangerfield, M., Fragoso, C., Eschenbrenner, V., López-Hernández, D. & Pashanasi, B. 1994b. The relationship between soil macrofauna and tropical soil fertility. In: Woomer, P. L. & Swift, M. J. (Eds). *The Biological Management of Tropical Soil Fertility*. Wiley & Sons, Chichester, UK. pp. 137–169.

Lavelle, P., Pashanasi, B., Charpentier, F., Gilot, C., Rossi, J.-P., Derouard, L., André, J., Ponge, J. P. & Bernier, N. 1998. Large-scale effects of earthworms on soil organic matter and nutrient dynamics. In: Edwards, C. A. (Ed). Earthworm ecology. St. Lucies Press, Boca Raton, FL. pp. 103–122.

Lee, K. E. 1985. *Earthworms: Their Ecology and Relationships with Soils and Land Use*. Academic Press, New York. 411 p.

Lee, K. E. & Foster, R. C. 1991. Soil fauna and soil structure. *Aust. J. Soil Res.*, 29:745–775.

Lee, K. E. & Wood, T. G. 1971. Physical and chemical effects on soils of some Australian termites, and their pedological significance. *Pedobiologia*, 11: 376–409.

Lévieux, J. 1976. La structure du nid de quelques fourmis arboricoles d'Afrique tropicale: *Ann. Univ. Abidjan.*, 12: 5–22.

Lobry-de-Bruyn, L. A. & Conacher, A. J. 1990. The role of termites and ants in soil modification: a review. *Aust. J. Soil Res.*, 28: 55–93.

Lockaby, B. G. & Adams, J. C. 1985. Pedoturbation of a forest soil by fire ants. *Soil Sci. Soc. Am. Proc.*, 46: 785–8.

López-Hernández, D., Lavelle, P., Fardeau, J. C. & Niño, M. 1993. Phosphorous transformations in two P-sorption contrasting tropical soils during transit through *Pontoscolex corethrurus* (Glossoscolecidae: Oligochaeta). *Soil Biol. Biochem.*, 25(6): 789–792.

Loranger, G., Ponge, J. F., Blanchart, E. & Lavelle, P. 1998. Impact of earthworms on the diversity of microarthropods in a vertisol (Martinique). *Biol. Fertil. Soils*, 27: 21–26.

Lubchenco, J., Olson, A. M., Brubaker, L. B., Carpenter, S. R., Holland, M. M., Hubbell, S. P., Levin, S. A., MacMahon, J. A., Matson, P. A., Melillo, J. M., Mooney, H. A., Pulliam, H. R., Real, L. A., Regal, P. J. & Risser, P. G. 1991. The sustainable biosphere initiative: an ecological research agenda. *Ecology*, 72: 371–412

Macias, F. & Chesworth, W. 1992. Weathering in humid regions, with emphasis on igneous rocks and their metamorphic equivalents. In: Martini, L. & Chesworth, W. (Eds.). *Weathering, Soils and Paleosols*. Elsevier, Amsterdam. pp. 283–306.

Mando, A. 1997. The role of termites and mulch in the rehabilitation of crusted Sahelian soils. Tropical Resource Management Papers 16. Wageningen Agricultural University. The Netherlands. 101 pp.

Mboukou-Kimbatsa, I. 1997. *Les Macroinvertébrés du Sol dans Différents Systèmes D'agriculture au Congo: Cas Particulier de Deux Systèmes Traditionnels (Écobuage Et Brûlis) dans La Vallée Du Niari*. Thèse de doctorat, Université de Paris VI, Pierre et Marie-Curie, Paris. p. 163.

McGinley, M.A., Dhillion, S.S. and Neumann, J.C. 1994. Environmental heterogeneity and seedling establishment: ant-plant-microbe interactions. *Funct. Ecol.*, 8: 607–615.

Mele, P. M. & Carter, M. R. 1999. Impact of crop management factors in conservation tillage farming on earthworm density, age structure and species abundance in south-eastern Australia. *Soil Till. Res.*, 50(1): 1–10.

Myers, R. J. K., Palm, C. A., Cuevas, E., Gunatillekeland, U. N. & Brossard, M. 1994. The synchronization of nutrient mineralization and plant nutrient demand. In: Woomer, P.L. & Swift, M.J. (Eds.) *The Biological Management of Tropical Soil Fertility*. John Wiley & Sons, Chichester, UK. pp. 81–116.

Nardi, J. B. 2003. *The World Beneath Our Feet: A Guide to Life in The Soil*. New York: Oxford University Press.

Palmer M., Ambrose, R. & Poff, L. 1997. Ecological theory and community restoration ecology. *Rest. Ecol.*, 5(4): 291–300.

Pankhurst, C. E., Doube, B. M. & Gupta, V. V. S. R. 1997. Biological indicators of soil health: synthesis. In: Pankhurst, C. E., Doube, B. M. & Gupta, V. V. S. R. (Eds.) *Biological Indicators of Soil Health*. CAB International, Wallingford. pp 419–435.

Petal, J. 1978. The role of ants in ecosystems. In: Brian, M. V. (Ed.) *Production Ecology of Ants and Termites*. Cambridge University Pres, UK. pp. 293–325.

Rangel, A. F., Thomas, R. J., Jiménez, J. J. & Decaëns, T. 1999. Nitrogen dynamics associated with earthworm casts of *Martiodrilus carimaguensis* Jiménez and Moreno in a Colombian savanna Oxisol. *Pedobiologia*, 43: 557–560.

Roessner, J. 1986. Investigation on the reduction of nematodes in soil by earthworms. International Symposium on Crop Protection. *Rijksuniversiteit Faculteit Landbouwwetenschappen*, 38: 1311–1318.

Rose, C. J. & Wood, A. W. 1980. Some environmental factors affecting earthworms populations and sweet potato production in the Tari Basin, Papua New Guinea Highlands. *Papua New Guinea Agric. J.*, 31: 1–10.

Rossi, J.-P. 1998. *Rôle Fonctionnel de la Distribution Spatiale des Vers de Terre dans une Savane Humide de Côte d'Ivoire*. Thèse de Doctorat. Université Pierre et Marie Curie, Paris VI, France.

Roth, C.H. 1985: Infiltrabilität von Latossolo-Roxo-Böden in Nordparaná, Brasilien, in Feldversuchen zur Erosionskontrolle mit verschiedenen Bodenbearbeitungs-systemen und Rotationen. *Göttinger Bodenkundliche Berichte*, 83: 1–104.

Ruiz, N. 2004. *Development of a Soil Quality Bioindication System Based on Soil Macro-Invertebrates Communities*. Thèse de Doctorat, Université Paris VI.

Scheu, S. & Wolters, V. 1991. Influence of fragmentation and bioturbation on the decomposition of ^{14}C-labelled beech leaf litter. *Soil Biol. Biochem.*, 23: 1029–1034.

Seastedt, T. R. 1984. The role of microarthropods in the decomposition and mineralization of N. *Ann. Rev. Ecol. Syst.*, 29: 25–46.

Senapati, B. K., Lavelle, P., Giri, S., Pashanasi, B., Alegre, J., Decaëns, T., Jiménez, J. J., Albrecht, A., Blanchart, E., Mahieux, M., Rousseaux, L., Thomas, R. J., Panigrahi, P. K. & Venkatachalam, M. 1999. In-soil earthworm technologies for tropical agroecosystems. In: Lavelle, P., Brussaard, L. & Hendrix, P. F. (Eds). *Earthworm Management In Tropical Agroecosystems*. CAB International, Wallingford, UK. pp. 199–237.

Settle, W. 2000. Living Soils: Training Exercises for Integrated Soils Management. FAO programme for Community Integrated Pest Management. 2nd edition. 101 p.

Sleaford, F., Bignell, D.E. & Eggleton, P. 1996. A pilot analysis of gut contents in termites from the Mbalmayo Forest Reserve, Cameroon. *Ecol. Entom.*, 21: 279–288.

Solbrig, O. T. 1992. Biodiversity, global change and scientific integrity. *J. Biogeogr.*, 19: 1–2.

Spratt, D. M. 1997. Endoparasite control strategies: implications for biodiversity of native fauna. Inter. *J. Parasitol.*, 27 (2): 173–180.

Stork, N. E. & Eggleton, P. 1992. Invertebrates as determinants and indicators of soil quality. *Am. J. Alt. Agr.*, 7(1–2): 38–47.

Swift, M. J. (Ed.) 1987. Tropical soil biology and fertility: Interregional research planning workshop. Spec. Issue 13. IUBS, Biology Int., Paris.

Swift, M.J. 1997. Biological management of soil fertility as a component of sustainable agriculture: Perspectives and prospects with particular reference

to tropical regions. In: Brussaard, L. & Ferrera-Cerrato, R. (Eds.) *Soil Ecology in Sustainable Agricultural Systems*. Lewis Publishers, Boca Raton, USA. pp. 137–159.

Swift, M. J., Heal, O. W. & Anderson, J. M. 1979. *Decomposition in Terrestrial Ecosystems*. Blackwell Scientific, Oxford.

Szlavecz, K. 1985. The effect of microhabitats on the leaf litter decomposition and on the distribution of soil animals. *Holarct. Ecol.*, 8: 33–38.

Thomas, R. J., Fisher, M. J., Ayarza, M. A. & Sanz, J. I. 1995. The role of forage grasses and legumes in maintaining the productivity of acid soils in Latin America. In: Lal, R., Stewart, B.A. (Eds.), *Soil Management. Experimental Basis for Sustainability and Environmental Quality*. Lewis Publishers, Boca Raton, USA, pp. 61–83.

Tian, G., Kang, T. & Brussaard, L. 1992. Biological effects of plant residues with contrasting chemical compositions under humid tropical conditions – decomposition and nutrient release. *Soil Biol. Biochem.*, 24: 1051–1060

Tian, G., Brussaard, L., Kang, B. T. & Swift, M. J. 1997. Soil fauna-mediated decomposition of plant residues under constrained environmental and residue quality conditions. In: Cadisch, G. and Giller, K. E. (Eds). *Driven by Nature: Plant Litter Quality and Decomposition*. CAB-I Publishing, Wallingford, UK. pp. 125–134

Usher, M. B., Davis, P. R., Harris, J. R. W. & Longstaff, B. C. 1979. A profusion of species? Approaches towards understanding the dynamics of the populations of the micro-arthropods in decomposer communities. In: Anderson, R. M., Turner.

Villalobos, F. J. & Lavelle, P. 1990. The soil Coleoptera community of a tropical grassland from Laguna Verde, Veracruz (Mexico). *Rev. Ecol. Biol. Sol*, 27: 73–93.

Wagner, D. 1997. The influence of ant nests on Acacia seed production, herbivory and soil nutrients. *J. Ecol.*, 85: 83–93.

Wardle, D. A. 1995. Impacts of disturbance on detritus food webs in agro-ecosystems of contrasting tillage and weed management practices. *Adv. Ecol. Res.*, 26: 105–185.

Wardle, D. 2002. *Communities and Ecosystems. Linking the Aboveground and Belowground Components*. Princeton University Press, Princeton, NJ. 392 p.

Waterhouse, D. F. 1974. The biological control of dung. *Sci. Am.*, 230: 100–109.

Way, M. J. & Khoo, K. C. 1992. Role of ants in pest management. *Ann. Rev. Entomol.*, 37: 479–503.

Wood, T.G. 1996. The agricultural importance of termites in the tropics. *Agr. Zool. Rev.*, 7: 117–155.

Wood, T.G. & Sands, W. A. 1978. The role of termites in ecosystems. In: Brian, M. V. (Ed.). *Production Ecology of Ants and Termites*. Cambridge University Press, UK. pp. 245–292.

Yeates, G. W. 1981. Populations of nematode genera in soils under pasture. IV. Seasonal dynamics at five North Island sites. *New Zealand J. Agr. Res.*, 24: 107–121.

KEY ON SOIL MACROFAUNA

NO LEGS

1. NON-SEGMENTED, CLEAR HEAD WITH TENTACLES: *MOLLUSCA*
   a) With shell (Fig. 1)
   b) Without shell (Fig. 2)

Fig.1: *Mollusca with shell: Snails*

Fig.2: *Mollusca* without shell: Slugs

2. SEGMENTED
   a) Worm-like, more than >15 body segments, pigmented:
   - Earthworms (most > 20 mm long) (Fig. 3)
   - Suckers at both ends of flattened body – Hirudinea (leeches) (Fig. 4)

Fig.3: *Earthworm*

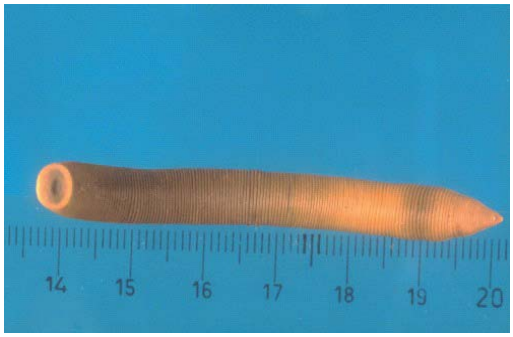


Fig.4: *Hirudinea* (leeches)

   b) Not worm like, less than < 15 segments
   - ***Beetle larvae***, generally with strongly developed head capsule (well-developed coronal structure). Often U-shaped and more or less swollen. (Fig. 5)

➢ ***Diptera larvae***, often without strongly developed head capsule. Long and thin, not U-shaped (Fig. 6)

Fig.5: *Beetle larvae*

Fig.6: *Diptera larvae* (larvae of certain flies)

LEGS

1. NO WINGS
   - ➢ **3 pairs of legs: insect**
     - Caterpillar-like - soft and fleshy body
       - Pseudo-legs (4 pairs or fewer): *Lepidoptera larvae* (butterfly larvae) (Fig. 7)
       - No pseudo-legs: Beetle larvae (often U-shaped "grubs") (Fig. 8)

Fig.7: *Lepidoptera larvae*

Fig.8: *Beetle larvae*

- Abdomen > 6 segments, > 4 segmented antennae
  - Conspicuous pronotum (the upper dorsal plate of the first segment of thorax):
    i. Pronotum saddle-shaped, not projecting forward: *Orthoptera* (grasshoppers) (Fig. 9)
    ii. Pronotum not saddle-shaped, projecting forward over head: *Blattaria* (cockroaches) (Fig. 10)

Fig.9: *Orthoptera*

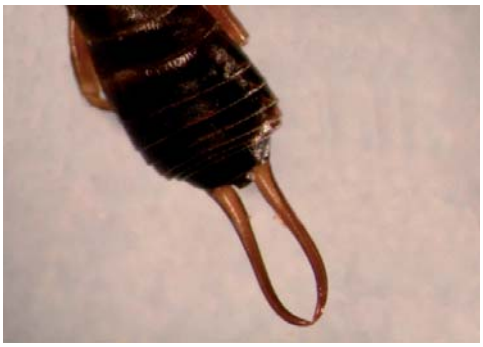
Fig.10: *Blattaria*

  - Pronotum not conspicuous:
    i. Mouthparts formed into sucking tube held under body, no palps: *Hemiptera* (such as lace bugs, aphids and woodlice) (Fig. 11)

Fig.11: *Hemiptera*

    ii. No tube, palps: Abdomen ends in a certain number of cerci (paired appendages on the rear-most segments of many arthropods) either:

      a) 2 cerci
        * Curved into pincers: *Dermaptera* (earwigs) (Fig.12)
        * Long and thin, at least 1/3 length of abdomen, projecting from tip, Antenna short - < 2 x head width: *Coleoptera larvae* (Fig. 13)



Dermaptera (earwigs) (Fig.12)

* Short – maybe located forward of tip of abdomen:
  » Antenna long, 8 segments: *Isoptera* (blind poorly pigmented, sometimes with large mandibles [soldiers], legs fully developed, tropics and subtropics) (Fig. 14)

Fig.13: *Coleoptera larvae*

Fig.14: *Isoptera*

  » Antennae short, < 6 segments: *Beetle larvae*, flat, short antennae (< 8 segments) (Fig. 15)

Fig.15: *Beetle larvae*

b) No cerci; with a certain number of antennal segments:
* <6 antennal segments, with 3 clear thoracic segments:
Beetle larvae (Fig. 16)

Fig.16: *Beetle Torax*

* >10 antennal segments, with wasp waist,
» with1-2 petioles: *Ants* (Fig. 17)

Fig.17: *Ants*

» no petiole: other *Hymenoptera* (bees and wasps)
* >10 antennal segments, with wasp waist,
» Long and thin: *Phasmida* (stick and leaf insects) Fig. 18)
» Long antennae, small: *Psocoptera* (bark lice) (Fig. 19)

Fig.18: *Phasmida*

Fig.19: *Psocoptera*

» Short antennae: *Beetle larvae* or *wingless adults* (Fig.20)

Fig.20: *Beetle larvae* or wingless adults

➢ **4 pairs of legs: Arachnida (sometimes pedipalps –the second pair of appendages of the head and thorax section– look like an extra pair)**

- Thorax and abdomen separated by a constricted waist, pedipalps without claws: *Spiders* (Fig. 21)
- Thorax and abdomen fused into one, without pedipalps
  - Body clearly segmented, with ocularium (eye-area tubercle): *Opilions* (very spider-like) (Fig. 22)

Fig.21: *Spiders*

Fig.22: *Opilions*

  - Body not segmented, without ocularium: *Acarina* (mites and ticks) (Fig. 23)

Fig.23: *Acarina* (mites)

- Pedipalps with claws
  - Large claws, telson (sting): *Scorpions* (Fig. 24)
  - Small claws, without telson: *Pseudoscorpions* (Fig. 25)

Fig.24: *Scorpions*

Fig.25: *Pseudoscorpions*

➢ 6/7pairs of legs: *Isopoda* (Fig. 26)

Fig.26: *Isopoda*

➢ more than >15 pairs of legs:

- One per segment: *Chilopoda* (centipedes, generally flattened) (Fig. 27)

Fig.27: *Chilopoda*

- Two per segment: *Diplopoda* (millipedes) generally more rounded, usually > 30 pairs of legs): (Fig. 28)

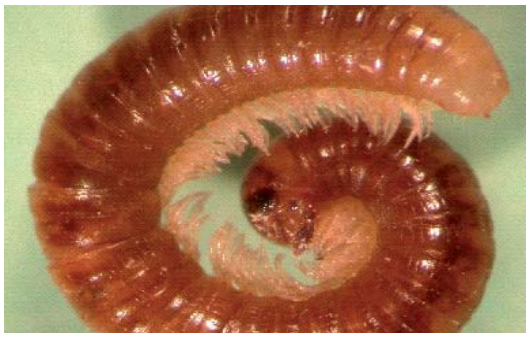



Fig.28: *Diplopoda*

2. WITH WINGS

a) 2 wings; no appendage: *Diptera* adults
(with halteres –small knobbed paired structures–) Fig. 29. *Diptera*

Fig.29: *Diptera*

b) 4 wings

- Mouthparts modified into sucking tube, no palps: *Hemiptera* (Fig.30)
- Biting mouthparts, palps

Fig.30: *Hemiptera*

- Forewings hardened to form a wing case
  - Hind legs long
    i. Hind legs modified for jumping, head not partially covered by pronotum: *Orthoptera* (Fig. 31)
    ii. Hind legs not modified for jumping, head partially covering pronotum: *Blattaria* (Fig. 32)

Fig.31 *Orthoptera*

Fig.32: *Blattaria*

  - Hind legs short
    i. Abdomen with terminal pincers: *Dermaptera* (Fig. 33)

Fig.33: *Dermaptera*

    ii. No pincers: *Coleoptera* (Fig. 34)

Fig.34: *Coleoptera*

- Forewings not hardened - hind legs modified for jumping, pronotum saddle shaped: Orthoptera (Fig. 31)

c) Other winged groups are rarely found in hand-sorted soil samples, but examples are shown: *Lepidoptera, Hymenoptera*,etc. (Fig. 35)

Fig.35: *Hymenoptera*

Glossary

Anecic
Anecic invertebrate species remove litter from the soil surface through their feeding activities. Considerable amounts of soil, mineral elements and organic matter may be redistributed through these activities, accompanied by physical effects on soil structure and hydraulic properties. Earthworms (large, dark antero-dorsal pigmentation and very muscular, with a wedge-shaped tail) and non soil-feeding termites are the main groups in this category, but also some arachnids.

Arthropods
Invertebrate animals (such as insects, arachnids, or crustaceans) having an exoskeleton, a segmented body and jointed limbs.

Autotroph (from the Greek *autos* = self and trophe = nutrition)
An organism that produces organic compounds from carbon dioxide as a carbon source, using either light or reactions of inorganic chemical compounds, as a source of energy. An autotroph is known as a producer in a food chain. Plants and other organisms that carry out photosynthesis are phototrophs (or photoautotrophs). Bacteria that use the oxidation of inorganic compounds such as hydrogen sulphide or ferrous iron as an energy source are chemoautotrophs.

Biogenic
A physical structure that is produced by living organisms or biological activity with important consequences in soil and ecosystem processes.

Bioremediation
The process by which living organisms act to degrade hazardous organic contaminants or transform hazardous inorganic contaminants to environmentally safe levels in soils, subsurface materials, water, sludges, and residues.

Bioturbation
The translocation of soil material within the soil profile mixing of above-ground litter with the mineral soil by animals or plants (roots).

Coprophagous
Feeding on dung or excrement (from the Greek *copros* = faeces and *phagein* = eat).

Decomposition
The biochemical breakdown of organic matter into organic compounds and nutrients, and ultimately into its original components.

Detritivore
Also known as saprophage, detrivore or detritus feeder (from the Latin, *detritus* = rubbed or worn away; *vorare* = to devour). It refers to an organism which feeds upon organic detritus of plant or animal origin, such as epigeic earthworms or dung beetles.

Diazotrophic
Organism that can use dinitrogen as its sole nitrogen source, i.e. capable of N_2 fixation.

Endogeic
Endogeic invertebrate species live in the soil and feed on organic matter and dead roots, also ingesting large quantities of mineral material. The two main groups are earthworms (light or no pigmentation and slow movers) and soil-feeding termites.

Entomopathogenic (from the Greek *entomon* = insect, and pathogenic = causing disease)
Insect-attacking organism.

Epigeic
Epigeic invertebrate species live and feed on the soil surface. These invertebrates affect litter breakdown and nutrient release. Mainly arthropods, for example: ants, beetles, cockroaches, centipedes, millipedes, woodlice, grasshoppers, together with gastropods (snails/slugs) and small or medium-sized entirely pigmented earthworms (dark red, green or brown colour, fast movers).

Exudates
Soluble sugars, amino acids and other compounds secreted by roots.

Heterotroph
An organism able to derive carbon and energy for growth and cell synthesis by utilizing synthesized organic compounds.

Humivorous
Organism feeding on the organic soil component.

Humus
It is the well-decomposed, relatively stable part of the organic matter, usually dark coloured. The term may refer to decaying plant material in advanced stages of decomposition; or the last stage of decomposition process, the humic compounds, i.e. where the more recalcitrant carbon components are found.

Invertebrate
Animal without a backbone (dorsal spine).

Litter
Upper layer of organic debris on the soil surface, essentially the freshly fallen or only slightly decomposed material (leaves, branches, bark fragments, twigs, etc).

Macro-invertebrates
Animals lacking a backbone and internal skeleton and that are visible to the naked eye, i.e. > 2 mm long, such as snails, earthworms, and insects.

Micro-arthropods
Micro-arthropods are small invertebrates (< 2 mm) with an exoskeleton. The most well known members of the micro-arthropod group are mites (Acari) and springtails (Collembola).

Micro-organism (microbe)
Living organism too small to be seen with the naked eye (< 0.1 mm); includes bacteria, fungi, protozoans, microscopic algae, and viruses.

Mineralization
The conversion of organic compounds into inorganic, plant-available compounds such as nitrates. This is accomplished by soil organisms as they consume organic matter and excrete wastes.

Mulch
The organic residues that are kept in the soil surface, not only to protect the soil from raindrops, but also to enhance infiltration, avoid weed development and provide nutrients to the soil.

Mycorrhiza (pl. mycorrhizae) – (from the Greek, *mycos* = fungus and *rhiza* = root)
The symbiotic association of certain fungi with roots. The fungi receive energy and nutrients from the plant. The plant receives improved access to water and some nutrients. Except for Brassicas (mustard, broccoli, canola) and Chenopods (beet, chard, spinach), most plants form mycorrhizal associations.

Necrophagous – (from the Greek, *nekros* = dead and *phagein* = to devour)
Pertaining to those organisms that feed on dead and/or decaying animals.

Organic matter
Any material that is part of, or originated from, living organisms. It includes plant residue, mulch, compost, and other materials.

Parasite
Organisms that live temporarily or permanently on or within other living organisms (plant or animal hosts) for the purpose of obtaining food.

Parasitism
A two species association in which one species, the parasite, lives on or in a second species, the host, for a significant period of its life and obtains nourishment from it. The parasite may or may not cause death to the host.

Pedogenic
Related to soil forming processes.

Pedology
The scientific study of soils, including their origins, characteristics, and uses form a physical point of view.

Phytoparasitic
Parasite on plants.

Phytophagous
Feeder on plants or materials of plant origin.

Phytosaprophagous
Feeding on decaying vegetable matter.

Predator
An animal that feeds on other animals.

Pronotum
The upper (dorsal), often shield-like, hardened body-wall plate of the prothorax, located just behind the head of an insect.

Rhizobacteria
Bacteria that colonize roots.

Rhizobia
Bacteria able to live symbiotically in roots of leguminous plants, from which they receive energy and often utilize molecular nitrogen. Collective common name for the genus *Rhizobium.*

Rhizophagous
Feeding on roots.

Rhizosphere
The area that is immediately (1-2 mm) around plant roots, including the roots itself. This is an area of intense microbial activity, where plants, microorganisms, other soil organisms, and chemistry, interact in complex ways.

Root nodule
A knoblike growth occurring on the roots, especially of leguminous plants, in which bacteria fix the atmospheric nitrogen and make it available in inorganic form for the plant.

Saprophagous (from the Greek, *sapros* = *rotten and phagein* = to eat)
Pertaining to organisms which feed on dead or decaying animal or vegetable matter.

Soil aggregation
The process whereby primary soil particles (sand, silt, clay) are bound together into large particles (soil aggregates), with secondary soil materials such as iron oxides, silica or organic matter, by physical and chemical forces and/or substances derived from root exudates and microbial activity. Soil aggregates are the building blocks of soil structure.

Soil macrofauna
Soil organisms visible to the naked eye (>2 mm diameter) that include those invertebrates that live in, feed in or upon the soil, the surface litter and their components (snails, earthworms and soil arthropods like ants, termites, millipedes, centipedes, pillbugs and other crustaceans, caterpillars, cicadas, ant-lions, beetle larvae and adults, fly and wasp larvae, earwigs, silverfishes, spiders, scorpions, crickets and cockroaches). A soil macrofauna group is an invertebrate group found within terrestrial soil samples which has more than 90 percent of its individuals visible to the naked eye.

Soil mesofauna
Soil organisms generally ranging in size from 0.1 to 2 mm in diameter. These include mainly micro-arthropods, such as pseudo-scorpions, protura, diplura, springtails, mites, small myriapods and the worm-like enchytraeids. Mesofauna have limited burrowing ability and generally live within soil pores, feeding on organic materials, microflora, microfauna and other invertebrates.

Soil microfauna
Soil-dwelling micro-organisms that cannot be seen with the naked eye (<0.1 mm diameter) extremely abundant, ubiquitous and diverse. The microfauna includes nematodes, protozoa, turbellarians, tardigrades and rotifers that generally live in the soil water films and feed on microflora, plant roots, other microfauna and sometimes larger organisms (e.g., entomopathogenic nematodes feed on insects and other larger invertebrates).

Soil microflora
The microflora includes algae, bacteria, archaea, cyanobacteria, fungi, yeasts, myxomycetes and actinomycetes that are able to decompose almost any existing natural material.

Soil organic matter (SOM)
The total organic matter in the soil. It can be divided into three general pools: living biomass of microorganisms, fresh and partially decomposed residues (the active fraction), and the well-decomposed and highly stable organic material (passive fraction). Surface litter is generally not included as part of soil organic matter.

Soil resilience
The capacity of a soil to recover its functional capacity after a disturbance.

Thorax
The insect body region behind the head which bears the legs and wings.

Vermicomposting *(Lombricompostage)*
Composting system based on intensive management of worms, usually in specialized containers. The soil-like by-product resulting from worms digesting organic matter can in turn be applied to plants.

Soil organisms are an integral part of agricultural ecosystems. The presence of a range of a diverse community of soil organisms is essential for the maintenance of fertile soils and productive lands for agriculture and forestry. However, one of the main gaps in agricultural management systems is the lack of awareness and understanding and hence inadequate management of soil biological processes to maintain and improve soil productivity. Soil organisms are responsible for a range of ecological functions and ecosystem services including: nutrient cycling and nitrogen fixation, control of pest and diseases, organic matter decomposition and carbon sequestration, maintenance of a good soil structure for plant growth and rainwater infiltration, detoxification of contaminants. An excessive reduction in soil biodiversity, especially the loss of species with key functions, may result in long-term degradation of soil and the loss of agricultural productive capacity. This manual provides information to help technical level staff, researchers and educators to assess soil health status, and provides some methods, tools and advice on how to sustain and improve soil quality under different farming systems. A major focus is placed on soil macrofauna, the visible part of the surprisingly rich soil life, and its activities in agricultural soils, as this is, firstly, reasonably representative of soil biodiversity as a whole (including micro- and meso-organisms and populations) and, secondly, is the part of soil life that can be readily observed and monitored in terms of effects of various management practices.