Chapter 6
Production of earthworms in Several Types of Vegetation

Introduction

The energetics of earthworms, besides population study, may be important for the comparative study on the ecological activities of earthworms in various environments. Because information on survivor rate and growth curve of small population is insufficient, the production and assimilation of the small size populations can not be calculated. Engelmann (1966) and Tanaka (1970) have proposed the calculation method for net production from maintenance metabolism (respiratory requirement). The net production and assimilation of population or of community can be obtained easily by using the R/A ratio (Tanaka 1970).

The objective of this paper is to estimate total assimilation of earthworms by using the average ratio of R/A of Pheretima species. The estimated budgets of earthworms are compared among various habitats and the contribution of earthworms to soil ecosystem are evaluated.

Method

The biomass of earthworms was total of the dry weight of individuals of all species. The biomass were converted to the energy equivalent by assuming 21.133 KJ g^{-1} dry wt of animal tissue of *Pheretima* sp. (H-1) (Oligochaeta: Megascolecidae) (Chapter 3). Number and weight frequency of earthworms in four areas has been shown in chapter 1. Total respiration in energy was estimated by using the CO_2 expiration rate of *Pheretima* sp. (H-1), assuming 0.79 of the respiratory quotient of earthworms and 4.775 × 4.184 KJ l^{-1} O_2 of oxycaloric coefficient (chapter 3).

The R/A ratios of litter dweller Pheretima were from 0.544 to 0.714 and those of soil dweller Pheretima were 0.874 and 0.869 (Chapter 3). The average ratio was 0.633 ± 0.067 in litter dweller and 0.872 ± 0.004 in soil dweller (Chapter 3). Then, the assimilations of small size population were 1.580 times for litter dwellers and 1.147 times for soil dwellers, of the respiration. The respiration rate and the amount of assimilation of a large population were shown in Chapter 3. The respiration and assimilation of earthworms are total of those of small size populations and of large populations. In chapter 3, the respiration and assimilation of large populations of soil dwellers were estimated with the corrected line of density, which were different to the observed density. The respiration and assimilation of *Ph. heterochaeta* in this chapter is estimated with the observed density.

The litter consumption and fecal pellet production of earthworms were estimated by using the rates of the cultivated individuals and the weight frequency of populations (chapter 1 and 4) assuming the law of Q_{10}. The litter consumption of earthworm except *Ph. vittata* were estimated by using the rate of *Pheretima* sp. (H-1) with the distinction between immature and mature (see chapter 4). The litter consumption of *Ph. vittata* was estimated by using the rate of this species in cultivation. As mentioned in another chapter, there were large difference in the rate of litter consumption between field and culture. Then, the estimated figures were regarded as the litter requirement of earthworms to distinguish it from the true rate of the earthworms in field.

Result

1. Seasonal change of biomass and respiration of entire earthworm

Fig. 6-1 - 6-4 show the biomass and respiration rate of earthworms in four areas.

Area H

The seasonal change of biomass and respiration rate of earthworms in area H depend mostly on those of two litter dwellers: *Pheretima* sp. (H-1) and *Pheretima vittata* (Goto et Hatai). The biomass in area H amounts to 0.165 g dry wt m^{-2} on March 20. After the biomass increased and it reached the maximum of 5.116 g dry wt m^{-2} on July 6. After, the biomass decreased and remained till Nov. (Fig. 6-1). The mean biomass of earthworms in March - Nov. was 1.83 g dry wt m^{-2}.

The respiration rate in area H was 0.092 KJ m^{-2} d^{-1} on March 20. Afterward, the respiration increased and it reached the maximum of 3.602 KJ m^{-2} d^{-1} on August 3. After, it decreased along with the decrease of the biomass. The increase of respiration rate in August, instead of the decrease of biomass, was due to high temperature in mid summer. Total respiration in area H was 315.139 KJ m^{-2}. The contribution of *Pheretima* sp. (H-1) and *Ph. vittata* to total respiration were 138.239 KJ m^{-2} and 126.566 KJ m^{-2}, respectively (Chapter 3). Among the respiration of rest population, 10.209 KJ m^{-2} due to litter dweller (*Ph. schmardae*) and 40.125 KJ m^{-2} due to soil dweller (*Ph. micronaria* and others).

Area K

The biomass and respiration in area K was similar to those in area H except the level of values. The maximum biomass and maximum respiration rate in area K 1968 were 0.926 g dry wt m^{-2} and 0.803 KJ $m^{-2}d^{-1}$ on July 3, respectively (Fig. 6-2). The average biomass was 0.446 g dry wt m^{-2} and total respiration was 98.077 KJ m^{-2}. The contribution of *Pheretima irregularis* (Goto et Hatai) Ohfuchi to total respiration was 43.639 KJ m^{-2} (Chapter 3). The respiration of rest population (54.438 KJ m^{-2}) due to the small size populations of soil dwellers: *Pheretima heterochaeta*, *Pheretima micronaria* and *Allolobophora japonica*.

Area D

The seasonal change in biomass and respiration rate of entire earthworms in area D depend largely on those of *Pheretima* sp. (H-1), and the residual change was due to those of *Pheretima heterochaeta* (Baird). The biomass and respiration rate in area D showed a minimum in winter and a maximum in early summer. In addition, these showed a small peak in autumn (Fig. 6-3). The maximum in early summer was due to the weight gain of *Pheretima* sp. (H-1) and the small peak in autumn was due to the weight gain of *Pheretima heterochaeta*. The maximum biomass and the maximum respiration rate in early summer of 1971 were 5.158 g dry wt m^{-2} and 3.933 KJ $m^{-2}d^{-1}$ on June 10, 1971 respectively. Those in summer of 1972 were 10.653 g dry wt m^{-2} on June 19, 1972 and 9.565 KJ $m^{-2}d^{-1}$ on July 15, 1972, respectively. The increase of respiration rate in spite of the decrease of biomass after June was due to the high temperature in mid summer. The annual mean of biomass of earthworms were 1.776 g dry wt in 1971, 4.793 g dry wt in 1972 and 2.953 g dry wt m^{-2} in 1973 (Jan. - Mar.). Total respiration of earthworms in area D were 438.835 KJ m^{-2} in 1971 (Mar. - Dec.), 1078.970 KJ m^{-2} in 1972 (Jan. - Dec.) and 104.022 KJ m^{-2} in 1973 (Jan. - Mar.). The contribution of *Pheretima* sp. (H-1) to total respiration was 193.669 KJ m^{-2} in 1971 and 589.275 KJ m^{-2} in 1972 (Chapter 3). Among the rest respiration, 28.514 KJ m^{-2} in 1971, 124.817 KJ m^{-2} in 1972 and 18.384 KJ m^{-2} in 1973 due to the small size populations of litter dwellers. The contributions of small size populations of soil dwellers were 216.652 KJ m^{-2} in 1971, 364.878 KJ m^{-2} in 1972 and 85.638 KJ m^{-2} in 1973.

Area G

The seasonal change in biomass and respiration rate of earthworms in area G depended mostly on those of *Ph. heterochaeta*, excluding a small role by *Pheretima* sp. (H-1) in May and June. The biomass in area G showed two peaks: in early summer and late autumn (Fig. 6-4). The peak in early summer was due to the weight growth of the matured generation and the peak in late autumn was due to the weight growth of the newly generation, of *Ph. heterochaeta* (Chapter 1). The biomass of each peaks were 1.983 g dry wt m^{-2} on November 7, 1971, 4.324 g dry wt m^{-2} on June 1, 1972 and 4.475 g dry wt m^{-2} on November 11, 1972. The mean biomass were 1.665 g dry wt m^{-2} in 1971 (Aug. - Dec.) and 2.42828 g dry wt m^{-2} in 1972 (Jan. - Dec.). The seasonal change of the respiration rate showed a peak per a year showing different change to the biomass (Fig. 6-4). The maximum rates of respiration were 2.343 KJ $m^{-2}d^{-1}$ on August 9, 1971 and 4.619 KJ $m^{-2}d^{-1}$ on August 28, 1972. The highest temperature caused the highest rate of respiration in August. Total respiration were 208.656 KJ m^{-2} in 1971 (Aug. - Dec.) and 834.231 KJ m^{-2} in 1972 (Jan. - Dec.). The contribution of *Pheretima* sp. (H-1) to total respiration in area G 1972 was 44.124 KJ m^{-2} (chapter 3). The rest respiration were 208.656 KJ m^{-2} in 1971 and 790.107 KJ m^{-2} in 1972. Most of rest respiration due to soil dwellers: *Ph. heterochaeta*, *Allolobophora caliginosa* and others.

2. Total assimilation of entire earthworms

Annual assimilation were calculated as 480.930 KJ m^{-2} in area H 1968, 123.652 KJ m^{-2} in area K 1968, 649.560 KJ m^{-2} in area D 1971, 1447.643 KJ m^{-2} in area D 1972, 127.274 KJ m^{-2} in area D 1973 (Jan. - Mar.) and 239.328 KJ m^{-2} in area G 1971. and 975.063 KJ m^{-2} in area G 1972. Table 6-1 summarized the biomass, respiration and assimilation of earthworms in four areas, together with the result in IBP Minamata (Sugi and Tanaka 1978 b).

3. Litter consumption and fecal pellet production of earthworms

The estimated litter requirement were 1946 g dry wt m^{-2} in area H 1968, 584 g dry wt m^{-2} in area K 1968, 2503 g dry wt m^{-2} in area D 1971, 6073 g dry wt m^{-2} in area D 1972, and 5095 g dry wt m^{-2} in area G 1972. The contribution of litter feeder species to the litter requirement in area H were 1687 g dry wt m^{-2}, 740 g dry wt for *Pheretima* sp. (H-1) and 947 g dry wt for *Ph. vittata*. The litter consumption by litter feeder in area D 1971 was 1193 g dry wt m^{-2}, 1083 g dry wt for *Pheretima* sp. (H-1) and 110 g dry wt m^{-2} for *Ph. vittata*. The litter consumption of litter feeder in area D 1972 was 3546 g dry wt m^{-2}: 2964 g dry wt for *Pheretima* sp. (H-1) and 583 g dry wt m^{-2} for *Ph. vittata*. Those in area G 1972 was 264 g dry wt m^{-2}, 252 g dry wt for *Pheretima* sp. (H-1) and 12 g dry wt for *Ph. vittata*. The estimated fecal pellet production of earthworms were 7198 g dry wt m^{-2} in area H 1968, 2068 g dry wt m^{-2} in area K 1968, 9297 g dry wt m^{-2} in area D 1971, 23104 g dry wt m^{-2} in area D 1972, and 17440 g dry wt m^{-2} in area G 1972. Table 6-1 summarized the litter requirement and fecal pellet production of earthworms in four areas, together with the result in IBP Minamata (Sugi and Tanaka 1978 b).

Discussion

1. The biomass of earthworms in the suburb of Fukuoka city Kyushu Japan

The average and maximum biomass of earthworms were abundant in old grass field (area D), moderately abundant in the forest having a rich ground flora (area H) and younger grass field (area G), and scarce in evergreen forests (IBP Minamata and area K) (Table 6-1). The biomass of earthworms is not proportional to the litter fall rate expected in each area (See table 1-1 in chapter 1). The litter fall in ever green forests (IBP Minamata and area K) were expected to be slightly larger than that in younger grass field (area G). The biomass of earthworms in earlier areas was less than half of that in later area. This inversion means that Litter fall rate is not only factor of having decided on biomass of earthworm community alone. The lower biomass of earthworms in ever green forest is presumably due to the litter type in those areas, only the decayed part of which may be preferable as food to foresty species such as *Ph. irregularis* and *Pheretima* sp. (M-3) (chapter 2). Besides, the acid soil condition in ever green forest may be another determinant for the level of biomass, which influenced the activity of soil microorganism and then impede the improvement of unpalatable resource (Cuendet 1984).

Inversely, the palatable resource of herbaceous plant and the moderately soil condition may explain the richness of earthworms in herbage areas (area G, area H, and D) (chapter 1). There are some differences in a pattern of activity of earthworms among three herbaceous areas. The average biomass and total assimilation in area G were the intermediate between area D and area H. However, the maximum biomass in earlier area was smallest among three earthworms' communities in herbaceous vegetations (Table 6-1). This difference depends on the difference of the length of the activity time of the dominant species in each area. The dominant species in dicotyledon vegetations (area D and area H) were litter dwellers having a generation per a year such as *Pheretima* sp. (H-1) and *Ph. vittata*. The active month of these species concentrate in early summer. Otherwise, the dominant species in monocotyledon vegetation (area G) was soil dweller having over lapping stage through a year, such as *Ph. heterochaeta*. Biomass and respiration of these species are maintained through year. As mentioned in chapter 1, the abundance of the dominant species closely related to the cover degree of above ground vegetation, thickness of A_0 horizon and the soil density. This mean that the habitat structure near soil surface closely correlate to the abundance and activity pattern of earthworms, besides the quantity and palatability of food resource and soil acidity.

2. Biomass and activity of earthworm activity in various region

Phillipson et al (1978) estimated the annual respiration metabolism of earthworm in the Brogden's Belt, of 214.727-268.409 KJ $m^{-2}a^{-1}$ and estimated a net production of 62.052 - 74.569 KJ $m^{-2}a^{-1}$. These values are the middle values of two forests in southwest Japan, area K, and IBP Minamata (Table 6 - 1).

Tsukamoto (1985) reported that the average biomass of earthworms in deciduous forest in Kyoto Japan, which were composed mainly by Pheretima group, were 5.0 - 10.3 g fresh wt m^{-2} in Ridge plot and 7.3 - 17.1 g fresh wt m^{-2} in Bottom plot. These values were very similar to the average value in similar vegetations in Kyushu Japan (0.446 g dry wt = 6.6 g fresh wt m^{-2} in area K and 0.948 g dry wt = 14.1 g fresh wt m^{-2} in IBP Minamata). The biomass of earthworm reported in another literature were 63-238 g fresh wt m^{-2} in orchard, 7-95 g fresh wt m^{-2} in arable (Edwards 1983), 1-300 g fresh wt m^{-2} in mixed forest, 0-153 g fresh wt m^{-2} in beech, oak and stepper forests, 1-45 g fresh wt m^{-2} in taiga, mountain spruce and pine forests, 1-15 g fresh wt m^{-2} in Mediterranean forest (Satchell 1983). The tendency that earthworm were more plentiful in grassland than in forest is well coincided with the result in present study.

The highest value of maximum biomass in present studies was 10.65 g dry wt m^{-2} (152.0 g fresh wt m^{-2}) in area D in June 1972. This value is smaller than the highest levels of the biomass in Europe. Earthworms in Europe are characterized with Lumbricidae species such as *Lumbricus terrestris*, *Allolobophora rosea* and *Allolobophora caliginosa* (Savigny). The populations of many Lumbricidae species consist of various developmental stages through a year (Satchell 1967). This means the larger average biomass of Lumbricidae than those of litter dweller Pheretima, if both have similar maximum biomass.

There were rarely comparable data on the metabolism of entire earthworms except the values in beech wood in Britain (Phillipson et al, 1978). The comparison of metabolism at maximum level between Lumbricidae and Pheretima was made with the population metabolism between *Pheretima* sp. (H-1) in area D 1972 and *L. terrestris* in Merlewood 1960 (Satchell 1967, Lakhani and Satchell 1970). Table 6-2 summarized the metabolic rate of both populations, together with that of the entire earthworms in area D 1972.

Table 6-2 show, there are no large difference in annual assimilation between those two populations though the biomass of *L. terrestris* is larger than that of *Pheretima* sp. (H-1). Because *L. terrestris* and *Pheretima* sp. (H-1), both are primary consumer (Chapter 2 and Satchell 1967), they may gain the most part of the resource from the litter of above ground vegetation. The annual litter fall rates in their habitats are 300 g (5380.7KJ) in Merlewood (Satchell 1967) and 1176.5g (21157.2 KJ) in area D (Chapter 1). The annual assimilation of each population is equivalent to 13 % in *L. terrestris* and to only 3.5 % in *Pheretima* sp. (H-1), of the energy supply from litter. The maximum rate of the litter requirement were estimated at 6.2 g dry wt $m^{-2}d^{-1}$ in *L. terrestris*, and 39.4 g dry wt $m^{-2}d^{-1}$ in *Pheretima* sp. (H-1). This mean that the litter supply of their habitats can maintain the litter requirement of *L. terrestris* for 48.7 days, and the litter requirement of *Pheretima* sp. (H-1) for 29.4 days. I think that the gluttony of *Pheretima* sp. (H-1) may be an important factor controlling the maximum biomass of this species at lower level than those of *L. terrestris*. However, litter consumption rate and digestive efficiency largely depended on the quantity and quality of resource and the population density of themselves (chapter 3 and 4). Then, the knowledge on the feeding activities of individual under field condition is necessary for more detail comparative consideration.

3. Role of earthworms as energy consumer, litter decomposer and ploughman

Annual respiration of earthworms ranged from 96.232 KJ in forest to 1062.736 KJ $m^{-2}y^{-1}$ in old grass field (table 6-1). Tanaka et al (1978) summarized oxygen consumption by major groups of soil animals in various ecosystems. The value in area D 1972 succeeds to the value of Nematoda (5547.984 KJ m^{-2}) and Enchytraeidae (2092 KJ $m^{-2}y^{-1}$) in IBP Minamata. These mean that earthworm is especially playing an important role as an energy consumer in old grass field.

Another role of earthworm in an ecosystem is their catalytic effect (Macfadyen 1963, Tanaka 1970). Annual litter fall rate in the suburb of Fukuoka city were about 600 g m^{-2} in area G, 1175 g m^{-2} in area D, 1000 g dry wt m^{-2} in area H and 750 g dry wt m^{-2} in area K. The estimated litter requirement of earthworms were 5095 g dry wt m^{-2} in area G 1972, 6073 g dry wt m^{-2} in area D 1972 1946 g dry wt m^{-2} in area H 1968 and 584 g dry wt m^{-2} in area K 1968. The values attained to 849 % in area G, 517 % in area D, 195 % in area H and 79 % in area K, of the annual litter fall rate of each habitats. The earthworms in IBP Minamata required 140 % of annual litter supply (1071 g dry wt $m^{-2}y^{-1}$) (Sugi and Tanaka 1978 b). These rough estimates show that some part of the food resource for earthworms is provide by other materials such as worm's pellet, humus or soil other than litter fallen in the current year (Sugi and Tanaka 1978 b). The gut content analysis confirmed the above estimate (chapter 4). Namely, the major component of gut materials of earthworms except *Pheretima* sp. (H-1) and *Ph. vittata* were amorphous humus, organic rich material and soil (Chapter 2).

The depth of litter layer were 0.0 cm in area G, 0.1-1.5 cm in area D, 2.0-4.0 cm in area H and 3.5-5.0 cm in area K (Chapter 1). The depth of litter layer show an inversely relation to the litter requirement of earthworms in each habitat. This result mean that earthworm plays a very important role as a litter decomposer, although all of earthworm species was not always a primary litter decomposer. The contribution of true primary litter feeder were 264 g dry wt m^{-2} in area G, 3546 g dry wt m^{-2} in area D 1972, and 1687 g dry wt m^{-2} in area H 1968. The value in area D 1972 is attained to two time of annual litter supply. This result will be studied in later paper, in detail.

The estimated annual fecal pellet production of earthworms ranged from 2068 g in area K to 23104 g dry wt m^{-2} in area D, which were equivalent to the cultivation of several cent meter of soil. Watanabe and Ruaysoongnern (1984) listed cast production data from various parts of the world. It is clarified, from their table, that the value in area D 1972 is highest one. As Darwin (1881) and many authors (Satchell 1967, Lee 1983) pointed out, that one important role of earthworm in an ecosystem may be a ploughman, they mix a litter with soil, modified the soil character and then improve the condition of their habitat.

Summary

1) Total assimilation of entire earthworms was estimated by using the average ratio of R/A of Pheretima species.

2) The maximum biomass and total assimilation of earthworms were 0.926-10.653 g dry wt m^{-2}, and 98.069-1573.184 KJ $m^{-2}y^{-1}$ respectively, in the suburb of Fukuoka City Kyushu Japan. Earthworms were more plentiful in grass field than in old forest. The maximum biomass of entire earthworms was largely depend on the structure of soil surface, and the quality of food resource.

3) There were some difference in the size order between the maximum biomass and the total assimilation. The earthworms in younger grass field show larger total assimilation than those in elder grass field, in spite of smaller maximum biomass in earlier than in later. This was due to the difference in the age composition of dominant species between two habitats.

4) It was discussed on the contribution of entire earthworms to ecosystem as energy consumer, litter decomposer and ploughman.

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