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The effects of multiple applications of different organic wastes on the growth, fecundity and survival of *Eisenia fetida* (Savigny) (Lumbricidae)

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Summary

The growth, fecundity, and mortality of the epigeic earthworm *Eisenia fetida*, in a range of different wastes were studied for more than one year in the laboratory. Separated, pre-composted, and fresh cattle manure solids, fresh pig manure solids of different levels of maturity (nursery young, growing-finish, and sow pigs), and fruit and vegetable wastes from a supermarket were offered to the earthworms as substrates. The growth, fecundity and mortality of *E. fetida* were monitored for 23 weeks until the earthworms stopped producing cocoons. The surviving adult earthworms in each substrate were separated into two population groups. The first group was cultured without any further substrate additions (batch cultures), using the earthworm casts as bedding. The second group was cultured in their casts with new substrates added regularly (continuous cultures). The second and third new substrate changes were after intervals of 22 and 15 weeks respectively. *E. fetida* could not survive in fresh cattle solids, fresh young pig solids, fruit wastes, and vegetable wastes. The growth of *E. fetida* in growing-finish pig solids and sow pig solids was faster than in either separated cattle solids or pre-composted cattle solids. Most earthworms produced cocoons again when the second substrate was added. The rate of growth of *E. fetida* was slower and the cocoon and hatchling production was lower after adding the third substrate. Some *E. fetida* could survive without any new substrate addition up to 60 weeks.

Key words: *Eisenia fetida*, batch cultures, continuous cultures, cattle solids, pig solids, fruit wastes, vegetable wastes

Introduction

There are three main classes of organic wastes suitable for vermicomposting i.e. animal wastes, plant wastes, and urban wastes. The growth patterns of the epigeic earthworm *Eisenia fetida* (Savigny) in different types of organic wastes have been investigated by various authors in laboratory studies. Animal manures have been used as a main substrate for *E. fetida* e.g. cattle (Edwards et al. 1985; Reinecke & Viljoen 1990a, b; Gunadi et al. 2002), ducks (Edwards et al. 1985), horses (Hartenstein et al. 1979; Kaplan et al. 1980), pigs (Reeh 1992), poultry (Edwards et al. 1985), rabbits (Buchanan et al. 1988; Herrera & de Mischis 1994, 1995), and sheep (Edwards et al. 1985). *E. fetida* has been used in substrates such as plant wastes e.g. composted grasses, municipal prunings, and river weeds (Frederickson et al. 1997), maple pruning wastes

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(Vinceslas-Akpa & Loquet 1997), potato wastes (Edwards 1982), vegetable wastes (Shanthi et al. 1993), coffee grounds (Aranda et al. 1999) and tea leaf wastes (Gunadi et al. 1998). Urban wastes are very diverse, ranging from sewage bio-solids to food wastes from restaurants and supermarkets. There are few data available concerning the growth of *E. fetida* in urban wastes.

Most of the studies reported above concern the growth and fecundity but not the mortality of *E. fetida*. Moreover research on *E. fetida* has mainly included batch cultures not continuous cultures. Data on mortality in continuous cultures of *E. fetida* are of practical importance to the development of vermicomposting – which is an aerobic, bioxidation and stabilization non-thermophilic process of organic waste decomposition that depends upon earthworms to fragment, mix and promote microbial activity (Edwards 1998). During the vermicomposting processes the earthworms should be monitored for rates of growth, fecundity, population growth and mortality in continuous systems to identify their optimal needs. Continuous cultures of earthworms have a close relationship with multiple substrate additions of organic wastes commonly used as waste management systems.

There were three aims in this investigation. The first was to assess the growth, fecundity, and mortality of *E. fetida* in a range of different organic wastes. The second was to compare the rates of growth, fecundity, and mortality of *E. fetida* in batch cultures with those in continuous cultures. The third objective was to assess the moisture content, pH, electrical conductivity, C/N ratio, NH_4 and NO_3 contents of the different cattle solids, different pig solids, fruit wastes, and vegetable wastes.

Materials and Methods

Waste types

Eight different types of waste from three main groups i.e. cattle manure solids, pig manure solids, and urban wastes, in the form of supermarket food wastes, were used to culture *E. fetida*. There were three different types of cattle solids i.e. fresh cattle solids, separated cattle solids produced by squeezing using a large auger and screen mesh equipment to achieve approximately 75 % moisture content, and similarly-separated cattle solids that had been pre-composted for one week. There were three different types of pig solids of different maturity i.e. nursery young pig solids, growing-finish pig solids, and sow pig solids. The pigs received different amounts of protein in their food i.e. 21, 16 and 14 % respectively. There were two different types of supermarket wastes i.e. fruit wastes (e.g. apple, strawberry, pear, cucumber) and vegetable wastes (e.g. lettuce, parsley, celery, pea). The moisture contents of the different wastes were adjusted to approximately 80 % by air-drying or by spraying using distilled water. For the taxonomic determination of *Eisenia fetida* (Savigny, 1826) we used the taxonomic keys of Schwert (1990).

Culture of earthworms

First experiment. Batches of 100 g wet weight of each organic waste were used as an initial substrate with a moisture content of 80–85 %. They were placed in plastic boxes (12 × 12 × 6 cm) covered with pierced lids for aeration. Eight juvenile *E. fetida*, each in the range 10–15 mg fresh weight, were placed in each plastic box together with one of the different wastes. There were four replicate containers for each type of waste. The 32 plastic boxes with a total of 258 earthworms were incubated at a room temperature of 20 ± 1°C.

All the earthworms were counted and weighed weekly for 23 weeks until they stopped producing cocoons. The total numbers of cocoons produced in the different substrates were counted every week and the dates of individual cocoon production recorded. Cocoons were collected and put in cavities in microplates in a plastic container filled with distilled water for observation of the numbers of their hatchlings.

Second experiment. The surviving adult earthworms in each substrate were separated into two equal groups. The first group was cultured without addition of any new substrates, using the earthworm casts as bedding. The second group was cultured in the casts they produced with a new substrate of the same quantity and quality of wastes added i.e. 100 g wet weight of cattle and pig solids as in the initial experiment. Four kinds of new substrate were used i.e. separated cattle solids, separated cattle solids that had been pre-composted for one week, growing-finish pig solids, and sow pig solids. The second and third new substrates were added after intervals of 22 and 15 weeks.

The 8 plastic boxes each containing 10 adult earthworms were incubated at a room temperature of 20 ± 1°C. The earthworms were counted and weighed weekly for 37 weeks until they stopped producing cocoons or died. The total numbers of cocoons produced in the different substrates were counted weekly. The dates of individual cocoon production were recorded and the numbers of hatchlings produced were counted as in the first experiment.

The growth, fecundities, and mortalities of *E. fetida* in the different organic wastes in the batch cultures (without new substrates) and continuous cultures (with new substrates) were compared.

Chemical analyses

An approximately 2 g sub-sample of each waste was dried at 60° C to determine the moisture content and also in preparation for the measurements of C/N ratio, NH_4 and NO_3 contents. The pH and electrical conductivity were determinated using a water-diluted sample (1:10). pH was measured using a Cole Parmer pHtestr 3, and electrical conductivity was measured using Cole Parmer TDStestr 20. Carbon and nitrogen levels were determined using a Carlo Erba NA 1500 Series 2 Nitrogen/Carbon Analyzer. NH_4 and NO_3 levels were determined using a BIO-TEK Instruments Microplate EL311 Autoreader.

Statistical analyses

One-way analyses of variance and Duncan's new multiple-range tests were used to identify significant differences between growth rates, mean numbers of cocoons produced per earthworm, and mean numbers of hatchlings per cocoon of *E. fetida* in the first experiment. Student's *t*-test was used to compare the mean individual biomass, mean numbers of cocoons produced per earthworm, and mean numbers of hatchlings per cocoon of *E. fetida* in the second experiment between the batch cultures (without new substrates) and continuous cultures (with new substrates).

Results

Characteristics of the wastes

The moisture contents of the wastes varied between 71.2 % and 89.8 % (Table 1). The pH of the different wastes were also quite variable (4.1–8.9). Most of the electrical conductivities of the different wastes were about 3–4 dS m^{-1}. The highest electrical conductivities were 8.2 and 12.9 dS m^{-1} in the small pig solids and vegetable wastes, respectively. The lowest C/N ratio was 9.3 in the young pig solids, the highest was 36.4 in the separated cattle solids. The NH_4 contents ranged from 3.5 mg kg^{-1} in the fruit wastes to 1878.1 mg kg^{-1} in the vegetable wastes. The NO_3 contents ranged from undetected in the pre-composted cattle solids, sow pig solids, and fruit wastes to 9803.2 mg kg^{-1} in the small pig solids.

Individual growth, mortality, cocoon and hatchling production in the first experiment

During 23 weeks, *E. fetida* survived only in the separated cattle solids, pre-composted separated cattle solids, growing-finish pig solids, and sow pig solids. There were two distinct growth patterns of *E. fetida* in the cattle solids and pig solids (Fig. 1). The rates of growth of *E. fetida* in the pig solids (growing-finish and sow) were about twice as fast as in the cattle solids (separated and pre-composted). *E. fetida* survived only to the second week and third week in the fresh cattle solids and in the fruit wastes, but not in the young pig solids and vegetable wastes.

The fastest growth of individuals in the first three months, or during the period of active growth, was 8.5 mg day^{-1} in growing-finish pig solids; in this substrate there was an overall mortality of 75 % after 23 weeks. This growth rate was significantly different from those in the other substrates such as separated

Table 1. The physico-chemical characteristics of different organic wastes (n = 3 ± standard deviation)

Sources of wastes	**Moisture content** (% dry wt.)	**pH**	**Conductivity** (dS m^{-1})	**C/N ratio**	**NH_4** (mg kg^{-1})	**NO_3** (mg kg^{-1})
Separated cattle solids	83.3 ± 3.7	8.9 ± 0.1	3.2 ± 0.1	36.4 ± 0.1	5.3 ± 1.2	4.2 ± 1.8
Pre-composted cattle solids	81.1 ± 3.6	8.5 ± 0.1	3.4 ± 0.2	32.3 ± 0.2	21.2 ± 7.3	–
Fresh cattle solids	81.8 ± 3.7	7.2 ± 0.1	3.2 ± 0.2	16.1 ± 0.5	150.1 ± 9.5	11.4 ± 2.5
Young pig solids	71.2 ± 3.2	6.2 ± 0.3	8.2 ± 0.7	9.3 ± 0.4	44.0 ± 4.5	9803.2 ± 605.9
Growing-finish pig solids	74.4 ± 3.3	6.8 ± 0.1	4.5 ± 0.3	13.2 ± 0.3	227.3 ± 9.8	5582.2 ± 437.4
Sow pig solids	76.9 ± 3.3	8.8 ± 0.2	3.2 ± 0.2	16.9 ± 0.6	1424.4 ± 55.2	–
Fruit wastes	87.9 ± 2.9	4.1 ± 0.1	4.5 ± 0.3	15.9 ± 0.6	3.5 ± 0.5	–
Vegetable wastes	89.8 ± 2.4	5.7 ± 0.1	12.9 ± 1.7	13.1 ± 0.4	1878.1 ± 67.8	112.6 ± 11.7

– = undetected

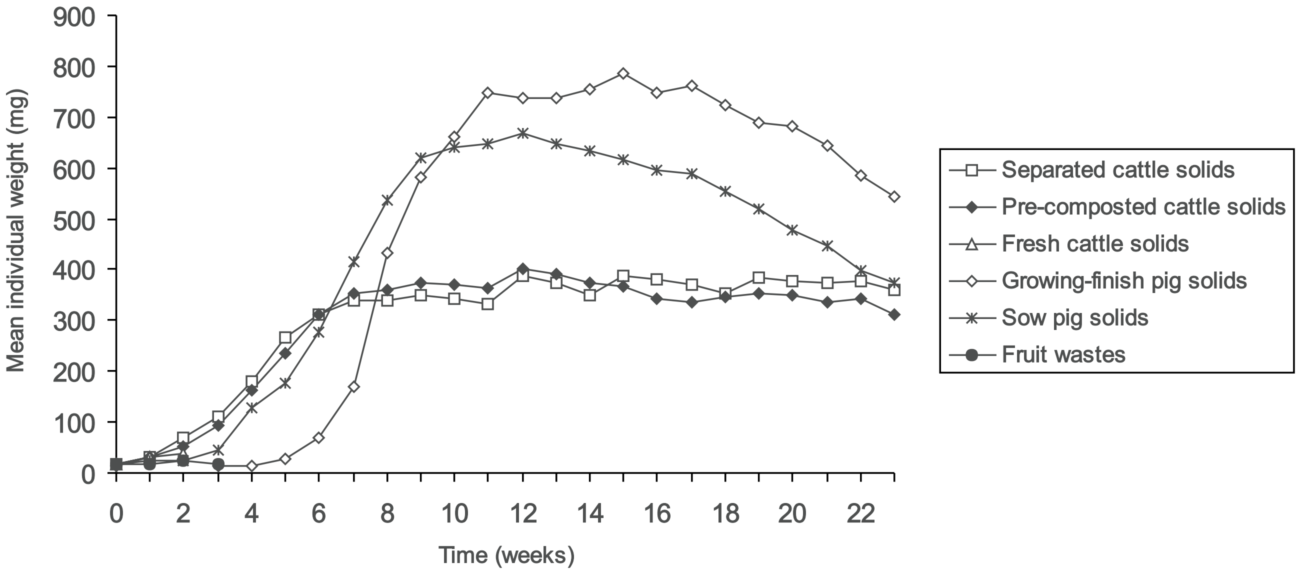

Fig. 1. The growth of *Eisenia fetida* in different organic wastes after addition of the substrate for the first time over 23 weeks

cattle solids and pre-composted cattle solids ($F = 7.8$, $P = 0.004$) but did not differ significantly from that in the sow pig solids (Table 2). After 23 weeks, the highest individual earthworm biomass reached was 784.7 mg in the adult pig solids and the lowest individual biomass was 388.5 mg in the separated cattle solids.

The highest mean numbers of cocoons and the greatest mean numbers of hatchlings per cocoon were in the separated cattle solids (9.5 cocoons earthworm^{-1} and 1.0 hatchlings cocoon^{-1}). These differed significantly from those in the other substrates such as pre-composted cattle solids, growing-finish pig solids, and sow pig solids ($F = 5074.5$, $P < 0.0001$ for cocoon production and $F = 74.4$, $P < 0.004$ for hatchling production) (Table 2).

Individual growth, mortality, cocoon and hatchling production in the second experiment

The mean individual biomass of earthworms was significantly lower when grown in cattle solids compared with pig solids ($P < 0.001$) (Table 3). Addition of a new substrate caused a larger mean individual earthworm biomass than no substrate addition (control). The largest mean individual earthworm biomass achieved was 926.4 mg in adult growing-finish pig solids. Over 22 weeks, most mortality (25 %) occurred in the growing-finish pig solids. There was no mortality in other substrates (Table 3).

After the second substrate addition the earthworms started to produce cocoons again after 1–3 weeks. The mean number of cocoons produced per earthworm

Table 2. Individual growth, mortality, cocoon and hatchling production of *Eisenia fetida* in different wastes (8 specimens, n = 4 ± standard deviation) in the first substrate during 23 weeks

Sources of wastes	Maximum individual biomass (mg)	Mean growth in the first three months (mg day^{-1})	Mortality after 23 weeks (%)	Start producing cocoons after	Mean number of cocoons earthworm^{-1}	Mean number of hatchlings cocoon^{-1}
Separated cattle solids	388.5 ± 36.4	4.6 ± 0.6 **A**	34	6 weeks	9.5 ± 0.1 **a**	1.0 ± 0.05 *a*
Pre-composted cattle solids	401.2 ± 62.2	4.7 ± 0.7 **A**	28	6 weeks	7.6 ± 0.1 **b**	0.3 ± 0.05 *c*
Fresh cattle solids	39.0 ± 8.8	1.5 (2nd week)	100	–	–	–
Growing-finish pig solids	784.7 ± 54.6	8.5 ± 0.8 **B**	75	8 weeks	4.4 ± 0.1 **c**	0.5 ± 0.08 *b*
Sow pig solids	669.3 ± 87.9	7.8 ± 0.5 **B**	22	8 weeks	1.8 ± 0.1 **d**	0.6 ± 0.08 *b*
Fruit wastes	24.3 ± 10.0	0.1 (3rd week)	100	–	–	–

Numbers followed by different letters are significantly different according to Duncan's multiple-range test ($P < 0.05$),
– = no observation

Table 3. Individual growth, mortality, and cocoon production of *Eisenia fetida* (10 specimens, n = 4 ± standard deviation) after addition of substrate for the second time during 22 weeks

Treatments	Mean individual biomass (mg)	Mortality after 22 weeks (%)	Start producing cocoons again after	Mean number of cocoons $earthworm^{-1}$	Mean number of hatchlings $cocoon^{-1}$
Separated cattle solids					
without substrate added	262.9 ± 15.1	0	1 week	0.7 ± 0.1	0.7 ± 0.1
with substrate added	380.2 ± 7.3 ***	0	2 weeks	6.9 ± 0.6 ***	1.2 ± 0.1 **
Pre-composted cattle solids					
without substrate added	195.1 ± 16.4	0	2 weeks	0.6 ± 0.2	0.5 ± 0.1
with substrate added	334.3 ± 14.3 ***	0	1 week	5.8 ± 0.5 ***	1.7 ± 0.3 **
Growing-finish pig solids					
without substrate added	357.8 ± 24.5	0	1 week	1.5 ± 0.6	0.2 ± 0.1
with substrate added	926.4 ± 39.9 ***	25	1 week	9.0 ± 0.7 ***	0.3 ± 0.1 NS
Sow pig solids					
without substrate added	268.0 ± 20.1	0	1 week	0.4 ± 0.1	–
with substrate added	638.3 ± 31.8 ***	0	3 weeks	5.6 ± 0.3 ***	1.2 ± 0.1 ***

Student *t*-test: NS = not significant, ** = P < 0.01, *** = P < 0.001

Table 4. Individual growth, mortality, and cocoon production of *Eisenia fetida* (10 specimens, n = 4 ± standard deviation) after addition of substrate for the third time during 15 weeks

Treatments	Mean individual biomass (mg)	Mortality after 22 weeks (%)	Start producing cocoons again after	Mean number of cocoons $earthworm^{-1}$	Mean number of hatchlings $cocoon^{-1}$
Separated cattle solids					
without substrate added	103.3 ± 6.6	40	–	–	–
with substrate added	413.9 ± 13.5 ***	0	3 weeks	6.8 ± 0.7 ***	0.8 ± 0.1 ***
Pre-composted cattle solids					
without substrate added	61.1 ± 3.3	100	–	–	–
with substrate added	273.3 ± 18.7 ***	0	3 weeks	0.1 ± 0.1 ***	1.0 ± 0.2 ***
Growing-finish pig solids					
without substrate added	145.3 ± 5.7	75	–	–	–
with substrate added	– ***	100	–	–	–
Sow pig solids					
without substrate added	97.2 ± 5.8	100	–	–	–
with substrate added	463.6 ± 26.6 ***	0	–	–	–

Student *t*-test: *** = P < 0.001

over 22 weeks was significantly different for earthworms in cattle and pig solid substrates (P < 0.001). Addition of a new substrate resulted in the production of more cocoons. The largest mean numbers of cocoons was in the growing-finish pig solids (9.0 cocoons $earthworm^{-1}$). The mean numbers of hatchlings per cocoon demonstrated the same trend as the mean numbers of cocoons per earthworm but there was no significant difference in the mean numbers of hatchlings produced per cocoon between the treatment with no substrate additions and that with addition of growing-finish pig solids. The greatest mean number of hatchlings produced per cocoon was 1.7 after addition of pre-composted cattle solids (Table 3).

After the third substrate addition, the mean individual biomass of earthworms was significantly lower for treatments with no new substrate additions (batch cultures) than those with substrate additions (continuous cultures) for all cattle solids and pig solids (P < 0.001) except for growing-finish pig solids where 100 % mortality occurred. The greatest mean individual earthworm biomass achieved was 463.6 mg after addition

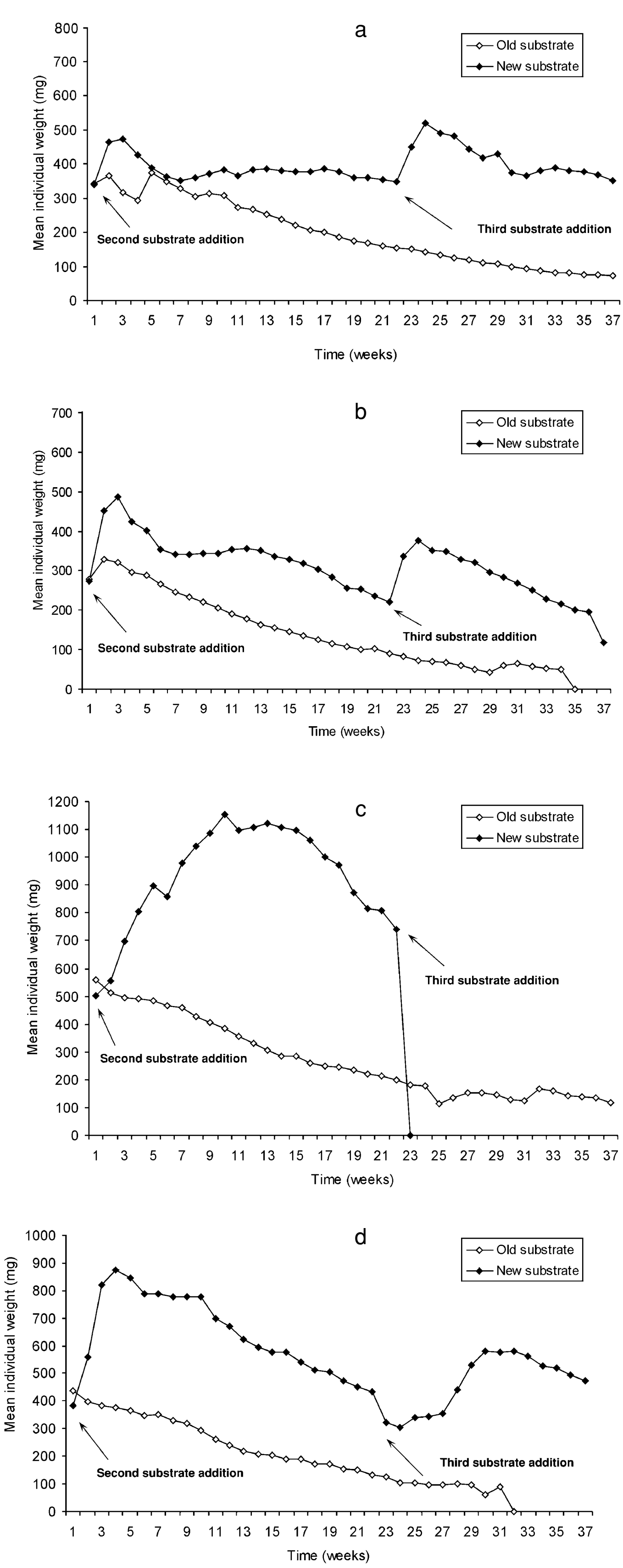

Fig. 2a–d. The effect of additions of substrates for a second and third time of separated cattle solids (**a**), pre-composted cattle solids (**b**), growing-finish pig solids (**c**), and sow pig solids (**d**) on the growth of *Eisenia fetida* over 37 weeks

of sow pig solids (Table 4). This was about half of the mean individual biomass produced in growing-finish pig solids after the second substrate addition. After 15 weeks of observations, 100 % mortality occurred in the controls with no substrate additions, in the bedding with pre-composted cattle solids and sow pig solids, and also after addition of growing-finish pig solids. No mortality occurred after addition of separated cattle solids, pre-composted cattle solids, and sow pig solids (Table 4).

After the third substrate addition, earthworms started to produce cocoons again after 3 weeks but only in the separated cattle solids and pre-composted cattle solids. The same trend occurred for hatchling production. The mean numbers of cocoons produced per earthworm and mean numbers of hatchlings produced per cocoon were significantly greater after substrate additions than with no additions (Table 4).

Growth pattern of earthworms following the second and third substrate addition

After the second and third new additions of separated cattle solids, the mean individual biomass of *E. fetida* increased from 350 mg to about 500 mg and subsequently stabilized at around 400 mg until the end of the experiment (Fig. 2a). For the control without addition of raw substrates, the mean individual earthworm biomass decreased from about 300 mg to 100 mg. All the earthworms from both treatments survived until the end of the experiment, 60 weeks from the beginning of the first substrate addition (Figs. 1 and 2a).

For the treatment with pre-composted cattle solids, the mean individual biomass of earthworms increased from 300 mg to 500 mg after the second substrate addition and from 200 mg to 400 mg after the third addition (Fig. 2b). The peak mean individual earthworm biomass occurred 2 weeks after the second and third substrate additions. There was a tendency for the biomass of the earthworms after substrate additions to decrease from about 300 mg to about 100 mg. The mean individual biomass of *E. fetida* without addition of pre-composted cattle solids (control) decreased from about 300 mg to 50 mg and the earthworms died 57 weeks after the first addition (Figs. 1 and 2b).

The peak mean individual biomass after second addition of growing-finish pig solids occurred at around 1200 mg after 9 weeks (second addition), but the earthworms did not survive after the third addition (Fig. 2c). In the control without new substrate addition, the earthworms survived until the end of the experiment with a mean individual biomass of 100 mg (Figs. 1 and 2c).

The effects of the second and third additions of sow pig solids on the growth of the earthworms differed. The earthworms survived until the end of the experiment with a mean individual biomass of about 500 mg (Fig. 2d). In the control without addition of raw substrates the earthworms survived only for 54 weeks after the first feeding (Figs. 1 and 2d).

Discussion

This experiment differed from experiments reported by most other authors (e.g. Tomlin & Miller 1980; Chan & Griffiths 1988; Haimi 1990; Cluzeau et al. 1992; Dominguez & Edwards 1997; Kaplan et al. 1980; Dominguez et al. 2000) in that single kinds of organic wastes not mixtures of wastes were used as the first substrate.

The other difference was the aim of this investigation to quantify the mortality of *E. fetida* in different organic waste substrates. As a consequence, some *E. fetida* did not survive in nursery pig solids and vegetable wastes or survived only until the second week or third week in fresh cattle solids and fruit wastes respectively. The earthworms may have been unable to survive in the vegetable wastes possibly because of their high electrical conductivity (12.8 ± 1.7 dS m^{-1}) and the high NH_4 content (1878.1 ± 67.8 mg kg^{-1}). Mitchell (1997) reported that *E. fetida* was unable to survive in cattle solids with pH of 9.5 and electrical conductivity of 5.0 dS m^{-1}. After three weeks all of the earthworms died in fruit wastes probably because of the low pH 4.1 ± 0.1 (Table 1). According to Edwards (1998) the optimal NH_4 content for breeding *E. fetida* was below 500 mg kg^{-1}.

In the experiment the earthworms died after 2 weeks in the fresh cattle solids although the moisture content, pH, electrical conductivity, C/N ratio, NH_4 and NO_3 contents were suitable for the growth of *E. fetida* (Table 1). Probably after two weeks the fresh cattle solids became anaerobic. In anaerobically-digested cattle solids alcohol, ammonia, acetic acid and methane gas are produced which could be lethal to the earthworms (Frederickson & Knight 1988). Aerobically-digested organic wastes are essential for the growth of earthworms (Neuhauser et al. 1988). Precomposting of cattle solids may also be important for earthworm growth since cattle solids can contain toxic components (Gunadi et al. 2002).

According to Neuhauser et al. (1980a, b) and Jefferies and Audsley (1988), the growth patterns of *E. fetida* in animal wastes are logistic; where the growth of earthworms becomes slower when specimens attain maturity. The growth of *E. fetida* in the first substrates (batch cultures) of this experiment also followed a logistic growth pattern. There were two different growth patterns in the growth of *E. fetida* in the cattle solids and pig solids (Fig. 1). The growth of earthworms in the separated cattle solids and in the pre-composted cattle solids had similar patterns. The same applied to the growth pattern of *E. fetida* in the growing-finish pig solids and sow pig solids. The growth of earthworms in the pig solids was faster than that in the cattle solids, which is comparable with the results of Edwards et al. (1985).

In the first substrates the growth of *E. fetida* in pig solids was about twice as fast as in cattle solids, but the time before the earthworms started to produce cocoons was longer in pig solids (8 weeks) than in the cattle solids (6 weeks). Moreover the *E. fetida* in the pig solids produced fewer cocoons per earthworm and produced fewer hatchlings per cocoon than in the cattle solids (Table 2).

The growth of *E. fetida* in separated cattle solids, pre-composted cattle solids, growing-finish pig solids, and sow pig solids after second and third substrate additions (continuous cultures) until the end of the experiment after 37 weeks did not follow a logistic growth pattern (Figs. 2a, 2b, 2c and 2d) as it did after the first addition (batch cultures). The body weight of *E. fetida* after the second and third substrate additions increased from around 350 mg to 500 mg and stabilized at around 400 mg. This result differed from pre-composted cattle solids in which the growth of *E. fetida* reached a peak of around 500 mg and 400 mg after the second and third additions. After reaching these peaks, the growth of *E. fetida* decreased until body mass was about 100 mg. The most plausible explanation for this is that pre-composted separated cattle solids might have decreased in quality in terms of nutrient availability for earthworm growth. Gunadi et al. (2002) reported that separated cattle solids, that had been pre-composted for various times (0, 1, 2, 3, 4 and 5 weeks), could inhibit the rate of growth and number of cocoons and hatchlings produced by *E. fetida*. In the control with no new substrate added earthworms died earlier (after 35 weeks) in pre-composted cattle solids than in non-composted separated cattle solids (Figs. 2a and 2b).

The maximum individual biomass of *E. fetida* was about 1200 mg in the second substrate addition using growing-finish pig solids and this agreed with results of Edwards et al. (1985). However, earthworms in the control with no new addition of growing-finish pig solids were able to survive until 60 weeks with decreasing body weight from around 600 mg to 100 mg (Fig. 2c). Although the growth rates of the earthworms were greater in the pig solids, their mortality was more than in the cattle solids (Tables 2 and 3). Gates (1972) reported that the maximum life expectancy of *E. fetida* was about 5 years with an average life expectancy at 18–28° C of about 600 days. The average life span dropped to about 500 days for isolated individuals that could not copulate (Gates 1972).

It can be concluded that the continuous culture of earthworms (with new substrates addition) in the laboratory is important since the role of vermicomposting, as a part of waste management systems, is mostly in continuous condition. The single kinds of organic waste can be fatal for *E. fetida* (e.g. for nursery pig solids, vegetable wastes, fresh cattle solids, and fruit wastes) due to the high electrical conductivity, high NH_4 content, high moisture content, or low pH. The multiple additions of substrates can prolong the fecundity of *E. fetida*, but there is a tendency of decreasing of the weight of *E. fetida* after 60 weeks of the experiment.

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