JEB
Journal of Environmental Biology

Journal Website : www.jeb.co.in
E-mail : editor@jeb.co.in
ISSN: 0254-8704 (Print)
ISSN: 2394-0379 (Online)
CODEN: JEBIDP

Influence of organic wastes on the biology of epigeic earthworm, *Perionyx excavatus* during different seasons

Pulikeshi M. Biradar* and Vijaykumar A. Biradar
Department of P.G. Studies in Zoology, Karnatak University, Pavate Nagar, Dharwad –580 003, India
*Corresponding Author E-mail: pulikeshi123@rediffmail.com

Publication Info

Paper received:
27 May 2014

Revised received:
04 November 2014

Re-revised received:
01 February 2015

Accepted:
20 March 2015

Abstract

Epigeic earthworm, *Perionyx excavatus* were cultured on a variety of organic wastes amended with cattle manure in different seasons to know the influence of different organic waste-diets and seasonal environmental factors on life activities of epigeic earthworm, *Perionyx excavatus*. Results showed that growth and reproductive strategies of *P. excavatus* varied with different organic waste-diets and seasons. Growth, maturity and reproduction of worms in all waste-diets were significantly more during monsoon followed by winter and summer seasons. All agricultural and garden organic wastes served as a source of balanced diet for this worm during all three seasons. Further, mixed organic waste and soft (straw-based) wastes appeared more congenial for overall life activities of this worm than that of hard (pod-based) wastes ($P<0.001$, $P<0.05$).

Key words

Organic wastes, Epigeic earthworm, *Perionyx excavatus,* Seasons

Introduction

Epigeic earthworms are surface feeders known to enhance the rate of organic manure (vermicompost) production through biodegradation/ mineralization process in vermiculture and vermicomposting technology. They can be easily cultured in any non-toxic organic waste residues, which have nutritional value to recycle macro and micronutrients. Earthworms have been cultured successfully in different organic wastes such as sewage sludge (Dominguez *et al.,* 2000; Plana *et al.,* 2001), brewery waste (Manivannan *et al*., 2004; Nogales *et al.,* 2005), winery waste (Fernandez *et al.,* 2009) processed crop residue wastes (Bansal and Kapoor,2000), waste from paper industry (Kaur *et al.,* 2010), waste from super market and restaurants (Chirashree Ghosh, 2004), horticultural residues from dead plants, yard waste (Suthar, 2007), coffee pulp (Garg *et al*., 2006), food and animal wastes (Aira and Dominguez, 2008) and olive cake (Nogales *et al.,* 2008). Reports of these authors revealed that significant variations in growth and reproduction of epigeic earthworms were observed with respect to different organic wastes under which earthworms were cultured in uncontrolled environmental conditions.

It has also been known that the available nutrients and environmental factors (Norgrove and Hauser, 2000; Dominguez, 2004; Chaudhari *et al.,* 2012) influence the reproductive activities of many earthworms. Similarly, species composition and population density of earthworms in field also varied with many abiotic environmental factors such as various meteriological factors (Singh *et. al.,* 2004; Monroy *et al.,* 2006), physico-chemical properties of soil (Ndegwa *et al.,*2000; Sinha *et al.,* 2008), food type (Aira and Dominguez,2009) and microbial property of soil (Tiunov and Scheu, 2000; Darke and Horn, 2007; Lazcano *et al.,* 2008). Different responses of epigeic earthworms with nutritionally varied organic wastes under changing climatic conditions promoted us to undertake the present research work. The present work deals with the influence of different agricultural and garden organic wastes on the biology (growth and reproduction) of epigeic earthworm, *Perionyx excavatus* under the prevailing environmental conditions.

Materials and Methods

Agricultural and garden wastes collected from fields in quantity enough for experimental works were dried and grouped into straw-based [*Triticum aestivum* (wheat straw), *Sorghum* *vulgare* (jowar husk), *Oryza sativa* (rice straw), *Dicanthium annulatum* (grass straw), *Leucaena leucocephala* (subabul waste), *Parthenium hyesteroporus* (parthenium waste)], pod-based [*Cajanus cajane* (redgram pod husk), *Phaseolus mungo* (blackgram pod husk), *Phaseolus radiata* (greengram pod husk)] and Mixed organic waste (general waste). Simultaneously, urine-free pure cattle manure collected from cattle shed was dried and powdered to get 0.2 mm particle size. Each agricultural and garden waste was dried and chopped in to 1 – 2 cm length in size and was mixed with equal amount (1:1 v/v) of powdered cattle manure. Pure cattle manure (control) and all other mixed organic waste-diets were sprinkled with tap water to impart 75- 80% moisture and it was kept for one week for thermal stabilization and initiation of microbial degradation.

Culture beds in triplicates were prepared by transferring each waste-diet to round plastic containers (156 cm^3 volumes with 35 cm^2 surface areas) with pin-holed lid for ventilation and prevention of predators. One week aged five juveniles of *P. excavatus*, hatched from cocoons laid by stock culture maintained in cattle manure under room environmental conditions, were inoculated in each culture container after noting their weight. Experiments were set up with the onset of each season [monsoon (June – September), winter (October – January) and summer (February - May)] and continued for 16 weeks duration in each season. The prevailing mean room temperatures during the experimental period during monsoon, winter and summer seasons were 25.92 – 27.71ºC, 22.71 – 27.28 ºC and 26.92 – 35.42 ºC and with corresponding percent relative humidity in the range of 65.64 – 84.35 %, 48.00 – 77.57 % and 29.14 – 76.78 % respectively. Cultures with cattle manure alone served as control for experimental sets. Culture containers were sprinkled with tap water so as to maintain moisture of about 75 - 80% (Singh *et. al.,* 2004) and scarcity of food was avoided by addition of respective stabilized waste-diet. Weekly observations were made and recorded with respect to weight of worms, attainment of sexual maturity and number of cocoon produced. Weights of the worms were noted and growth rate (mg / day / g live weight of worm) was calculated. Statistical significance of the data was obtained for variance by ANOVA (Scheffe's pair-wise comparision).

Results and Discussion

Growth and reproductive strategies of *P. excavatus* varied with waste-diets and seasons (Tables 1–3). Enhanced reproductive activities of the worms were noticed during monsoon > winter > summer season in all the waste-diets. All agricultural and garden organic wastes served as a source of balanced diet for normal life activities of this worm during all the three seasons. Further, soft (straw-based) wastes appeared more congenial for overall activities of the worms than hard (pod-based) wastes.

During monsoon season, there were no significant differences in growth and reproduction of worms cultured in different waste-diets from that of cattle manure (Table 4). Biomass of worm cultured in all waste-diets including pure cattle manure (control) increased gradually and consistently up to the end of experiment and gained more or less same weight at the end of 16th week. Growth rate increased steeply during pre-clitellar stage irrespective of diet and it was observed peak just one week prior (4th week) to the attainment of maturity and commencement of cocoon production (5th week) in almost all waste-diets.

Worms attained sexual maturity on the 5th week and at this stage each worm weighed 100 – 150 mg in all the waste diets during this season. Cocoon production by worms was more in general waste and straw-based diets and lesser in pod-based diets than in control (Table 1). Though cocoon production / worm / week in various diets was not significantly different from that of control but the cumulative number of cocoons per worm during 16 weeks was higher in general waste and straw-based wastes and lower in pod-wastes and equal in subabul waste than in control. Parthenium waste though, was straw-based waste-diet but it did not support the life processes of the worm in like other diets.

During winter, activities of the worms in all waste-diets were lesser than control (Table 2). The weight of worms cultured in different waste-diets increased gradually up to 6 – 7 weeks and later it was almost stagnant in majority of the diets unlike control. It was lesser in general waste, straw and pod-based diets than in control. Weight of the worms was almost similar in all the waste diets except grass straw (f=4.69, $P<0.05$) and wheat straw (f=7.70, $P<0.001$) where it was significantly lesser than in cattle manure (Table 4). Like biomass, growth rate was also significantly lesser in grass straw (f=8.26, $P<0.001$) and wheat straw (f=11.87, $P<0.001$) than in control cattle manure (Table 4).

All worms attained sexual maturity during 5th week in pod-based waste-diets and in control, during 5-6 weeks in general waste and most of the straw-based waste-diets. Rate of cocoon production / worm / week was maximum in control followed by general waste, subabul, redgram pod husk, greengram pod husk, rice straw, blackgram pod husk, grass straw, wheat straw, jowar husk. In parthenium waste it was significantly (f= 5.60, $P < 0.05$) lesser than control.

During the summer season, more biomass and lesser cocoons by the worms were noticed in all the waste-diets as compared to control (Table 3). The life activities of worm in all waste-diets during summer season notably varied from that of monsoon and winter seasons. In general, the biomass of worms in almost all waste-diets was more than in winter and it was almost equal to monsoon season. Biomass of worms though was not significantly different (Table 4), it was more in general waste, grass straw, subabul waste, jowar husk, redgram pod husk and greengram pod husk than control. Whereas, growth rate was significantly lesser only in diets of general waste (f=10.09, $P < 0.001$) and grass straw (f= 6.35, $P < 0.001$) than in control cattle manure (Table 4).

Table 1 : Biomass, growth rate and cocoon production of *P. excavatus* in various organic waste-diets during monsoon season

Variables	Cattle manure (control)	General waste	Grass straw	Rice straw	Wheat straw	Jowar husk	Subabul waste	Redgram pod husk	Greengram pod husk	Blackgram pod husk	Parthenium waste
Mean biomass (mg) of worm at 16th week	230.50 ±60.33	228.03 ±12.15	239.60 ±18.08	236.60 ±21.61	214.56 ±17.17	222.06 ±15.60	253.20 ±21.70	228.40 ±17.10	252.66 ±29.48	257.46 ±15.41	256.20 ±15.70
Maximum growth rate in mg day^{-1} gm^{-1} (at weeks)	1011.27 ±82.59 (5th)	1119.69 ±32.92 (4th)	1428.31 ±43.57 (4th)	1055.15 ±40.68 (4th)	1204.14 ±45.37 (4th)	1118.83 ±46.47 (4th)	1138.51 ±39.61 (4th)	710.29 ±37.31 (4th)	653.92 ±30.66 (4th)	1271.53 ±54.51 (4th)	1445.01 ±39.16 (4th)
Mean growth rate mg d^{-1} g^{-1}	646.62 ±237.93	631.46 ±258.00	751.52 ±334.67	577.72 ±212.79	609.99 ±267.97	644.84 ±265.73	646.34 ±229.69	539.06 ±139.98	485.49 ±133.47	693.26 ±276.00	672.56 ±320.07
Biomass (mg) of worm at sexual maturity	129.63 ±19.75	146.00 ±19.02	170.76 ±20.81	129.29 ±16.10	151.03 ±12.65	144.30 ±21.94	147.90 ±19.95	100.36 ±17.85	096.10 ±16.05	167.30 ±18.85	172.70 ±19.16
Maturity week (s)	5th	5th	5th	4-5	5th	5th	5th	5th	5th	5th	5th
Mean cocoon rate	5.01 ±3.60	7.20 ±4.20	5.73 ±3.60	5.47 ±3.72	5.23 ±3.67	5.20 ±2.55	4.95 ±3.75	4.16 ±1.89	3.93 ±2.03	3.28 ±2.00	3.40 ±1.88
Cumulative cocoon number/worm at 16th week	60.20 ±10.81	86.46 ±11.01	68.80 ±12.00	65.66 ±11.50	62.80 ±15.71	62.46 ±12.38	59.46 ±10.86	50.00 ±9.00	47.20 ±6.00	39.40 ±11.00	40.86 ±4.50

Data are Means ± SE (five earthworms were used for each analysis)

Table 2 : Biomass, growth rate and cocoon production of *P. excavatus* in various organic waste-diets during winter season

Variables	Cattle manure (control)	General waste	Grass straw	Rice straw	Wheat straw	Jowar husk	Subabul waste	Redgram pod husk	Greengram pod husk	Blackgram pod husk	Parthenium waste
Mean biomass (mg) of worm at 16th week	238.53 ±17.94	211.76 ±23.27	164.56 ±17.44	197.16 ± 23.25	151.00 ±16.71	193.20 ±19.60	201.16 ±19.50	227.00 ±17.13	187.10 ±15.70	205.46 ±17.60	185.73 ±18.29
Maximum growth rate in mg day^{-1} gm^{-1} (at weeks)	1051.14 ±21.77 (4th)	913.56 ±38.02 (5th)	587.19 ±39.03 (4th)	783.21 ±26.92 (5th)	599.52 ±19.84 (6th)	818.47 ±51.80 (6th)	792.41 ±24.81 (6th)	840.84 ±19.35 (7th)	1014.82 ± 25.61 (4th)	1098.86 ±52.24 (4th)	1122.67 ±21.68 (5th)
Mean growth rate mg d^{-1} g^{-1}	613.05 ±219.30	590.53 ±217.01	426.90 ±121.71	531.35 ±177.56	387.11 ±128.19	524.56 ±185.89	513.67 ±168.60	530.21 ±195.42	533.03 ±219.61	620.27 ±239.62	593.48 ±280.20
Biomass (mg) of worm at sexual maturity	140.93 ±15.40	144.51 ±16.23	091.83 ±16.05	119.30 ±17.16	105.56 ±16.21	142.50 ±22.95	119.93 ±17.52	086.16 ±15.25	129.56 ±19.02	134.80 ±14.61	164.61 ±19.12
Maturity week (s)	5th	6th	5-6	5th	6th	6th	5-6	5th	5th	5th	5-6
Mean cocoon rate	4.15 ±3.39	3.65 ±1.10	2.84 ±2.58	3.07 ±1.56	2.71 ±1.85	2.12 ±1.10	3.51 ±3.43	3.25 ±2.75	3.23 ±2.58	2.85 ±1.96	1.64 ±0.89
Cumulative cocoon number/ worm at 16th week	49.80 ±8.55	40.20 ±6.00	31.20 ±4.00	33.80 ±11.00	29.86 ±9.50	23.40 ±8.00	42.20 ±5.00	39.13 ±10.50	38.80 ±11.00	34.26 ±9.71	18.06 ±15.50

Data are Means ± SE (five earthworms were used for each analysis)

Earliest (6th week) sexual maturity was observed in control, while it was delayed in general waste, rice straw, subabul waste (6–7 weeks), grass straw, wheat straw, jowar husk, redgram pod husk, greengram pod husk (7–8 weeks), Parthenium waste (8 – 10 weeks) and blackgram pod husk (12– 14 weeks). Cocoon production was lesser in all the waste-diets than in control and was delayed in this season as compared to monsoon and winter seasons. It was significantly lesser in grass straw (f=19.52, $P < 0.001$), wheat straw (f= 28.77, $P < 0.001$), greengram pod husk (f= 4.79, $P < 0.001$), parthenium waste (f= 20.10, $P<0.001$) and blackgram pod husk (f= 8.59, $P < 0.001$) than in control (Table 4). Cumulative number of cocoons was significantly lesser only in grass straw (f=6.74, $P<0.05$), wheat straw (f= 13.42, $P<0.001$), and parthenium waste (f=10.66, $P<0.001$) than in control (cattle manure).

Table 3 : Biomass, growth rate and cocoon production of *P. excavatus* in various organic waste-diets during summer season

Variables	Cattle manure (control)	General waste	Grass straw	Rice straw	Wheat straw	Jowar husk	Subabul waste	Redgram pod husk	Greengram pod husk	Blackgram pod husk	Parthenium waste
Mean biomass (mg) of worm at 16th week	211.13 ±16.23	242.43 ±17.15	250.73 ±16.60	229.86 ±19.55	228.76 ±18.46	340.83 ±22.35	267.40 ±20.91	320.76 ±21.95	301.76 ±16.15	174.83 ±25.00	229.66 ±20.30
Maximum growth rate in mg day^{-1} gm^{-1} (at weeks)	938.52 ±22.48 (6th)	571.42 ±23.76 (6th)	650.69 ±32.14 (6th)	996.01 ±33.61 (6th)	959.34 ±28.16 (7th)	712.51 ±43.87 (8th)	981.30 ±41.78 (6th)	862.78 ±30.54 (7th)	1005.00 ±27.88 (7th)	994.68 ±43.79 (6th)	783.10 ±19.11 (6th)
Mean growth rate mg d^{-1} g^{-1}	592.89 ±208.90	394.48 ±122.08	431.86 ±126.31	581.73 ±217.47	643.68 ±211.29	536.42 ±135.93	558.96 ±213.69	655.98 ±190.91	696.06 ±246.22	642.76 ±211.50	559.28 ±142.68
Biomass (mg) of worm at sexual maturity	169.30 ±18.95	118.66 ±16.81	140.59 ±17.00	147.98 ±15.25	154.46 ±17.54	186.15 ±18.05	179.03 ±15.96	181.99 ±18.35	183.10 ±20.05	156.85 ±22.45	144.28 ±16.10
Maturity week (s)	6th	6-7	7-8	6-7	7-8	7-8	6-7	7-8	7-8	12-14	8-10
Mean cocoon rate	4.71 ±2.49	3.90 ±2.71	1.36 ±0.58	2.74 ±2.37	0.22 ±0.21	2.13 ±2.29	2.90 ±2.26	3.57 ±3.69	2.68 ±1.61	0.40 ±0.17	0.65 ±0.60
Cumulative cocoon number/ worm at 16th week	51.86 ±9.50	39.06 ±8.08	13.60 ±2.40	27.46 ±4.16	2.06 ±1.52	23.53 ±6.02	29.00 ±5.00	32.20 ±7.00	26.86 ±7.50	1.20 ±1.00	5.26 ±3.51

Data are Means ± SE (five earthworms were used for each analysis)

Variations in growth and reproduction of worms in different waste-diets even during favourable (monsoon) season might be due to palatability because of variation in chemostimulants rather than the level of nutrients present in the waste-diets (Chaudhari and Bhattacharjee, 2002; Aira and Dominguez, 2008). Different species of earthworms have differentiated themselves in the microniche due to their differential preferences towards organic matter (Gunadi and Edwards, 2002; Dominguez *et al.,* 2010). Similarly, *P. excavatus* being selective feeder and breeder also showed differential preference to different waste-diets. Although, the nature of available waste-diet influences worm activity (Suthar, 2007). Enhanced growth and reproduction of worms in general waste, grass straw, rice straw, wheat straw and jowar husk than in cattle manure (control) during favorable (monsoon) season might be attributed to the release of ameliorative chemostimulants present in these wastes. Bansal and Kapoor (2000) and Suriyanarayanan *et al.* (2010) also reported enhancement in productivity of earthworms due to addition of additives such as cereals and gram wastes to the cattle dung rather than dung alone. Enhanced life activities of worms in all waste-diets during monsoon season than during winter and summer seasons might be due to synergetic influence of diets and favorable environmental conditions of the season. Loh *et al*. (2005) also mentioned the intrinsic nature of *Eudrilus eugeniae* and *Eisenia fetida* for the production of cocoons in laboratory populations.

Among two (winter and summer) adverse seasons, in all waste-diets, lesser biomass during winter season than during summer season might be due to the production of more cocoons in the former due to diverting of conserved energy for their cocoon formation. Delayed maturity in some waste-diets during winter and in all waste diets during summer season might be due to the influence of unfavorable factors of the season rather than nutritional status of diets. Steep increase in growth rate during pre-clitellar period may be due to more feeding activity of worms before maturity than during post-clitellar period. Pulikeshi *et al.* (2008) mentioned more rate of composting during pre-clitellar stage (up to 7th week) than post-clitellar stage in *Eisenia fetida*. Similarly, Manivannan *et al*. (2004) and Loh *et al*. (2005) mentioned acceleration in growth of hatchling *Eudrilus eugeniae* up to 7th week when reared on cassava peels and on animal waste products respectively.

More production of cocoons in general waste and straw-based wastes than in pod-based wastes during monsoon could be attributed to easy availability of nutritive constituents by quick reduction of these soft natured wastes and congenial conditions of the season respectively. Low production of cocoons by worms in pod-based (hard) waste-diets might be due to presence of tannin / lignin contents which cannot be easily degraded to release nutrients. Tripathi and Bharadwaj (2004) and Aira and Dominguez (2008) also reported palatability by *Lampito mauritii* on the texture and chemical nature of organic wastes. Chaudhari and Bhattacharjee (2002) and Pulikeshi and Amoji (2003) reported variations in cocoon production by earthworms with quality of food provided. In the present study, parthenium waste, though was straw (soft) based waste-diets, appeared least palatable as judged by least activity of worms, which could be due

Table 4 : Seasonal variations ('f' and 'p' values) in biomass, growth rate and cocoon production of *P. excavatus* grown in various organic waste- diets from that of control (cattle manure)

Seasons	Cattle manure (control)	General waste	Grass straw	Rice straw	Wheat straw	Jowar husk	Subabul waste	Redgram pod husk	Greengram pod husk	Blackgram pod husk	Parthenium waste
Monsoon	Biomass	0.02	0.70	0.03	0.00	0.08	0.68	0.32	0.14	0.53	0.36
	Growth rate	0.05	0.96	0.68	1.42	0.98	0.02	2.20	3.35	0.24	0.06
	Cocoon rate	2.05	0.30	0.01	0.03	0.39	0.00	0.49	0.73	2.41	1.76
	Cumulative cocoon number	0.82	0.08	0.05	0.06	0.03	0.16	1.48	1.33	5.41	1.85
Winter	Biomass	0.27	4.69*	0.71	7.70**	1.36	1.14	0.55	1.46	0.28	0.76
	Growth rate	0.08	8.26**	1.26	11.87**	1.42	1.94	0.37	0.56	0.01	0.08
	Cocoon rate	0.21	1.37	0.92	1.12	3.54	0.69	0.49	0.55	1.31	5.60
	Cumulative cocoon number	0.04	1.13	0.56	1.55	1.88	0.01	0.29	0.07	0.32	0.63
Summer	Biomass	0.84	0.18	0.74	0.50	0.96	0.00	0.73	0.22	1.77	0.71
	Growth rate	10.09**	6.35**	0.02	0.44	0.77	0.19	0.75	1.53	0.31	0.26
	Cocoon rate	0.51	19.52**	3.42	28.77**	6.38	1.25	0.70	4.79**	8.59**	20.10**
	Cumulative cocoon number	0.02	6.74*	0.47	13.42**	2.99	1.48	1.05	1.12	4.33	10.66**

** $P < 0.001$, * $P < 0.05$

to presence of 'Parthenin' substance present in it. Among pod-based wastes, blackgram pod husk appeared least preferred diet due to the presence of more amount of lignin / tannin content in it. Less production of cocoons in all waste-diets than in control during winter and summer seasons was attributed to direct effect of adverse environmental factors of the seasons through fibro-porous nature of these waste diets. Further, reduction in reproductive activities of the worms in all waste diets during summer than during the winter season might be due to still more adverse effect of climatic conditions. Pulikeshi *et al.* (2008) have also been reported reduced activities of *Eisenia fetida* during summer season because of decreased neurohumor levels. Maximum cocoon production (7.20 / worm / week) was observed during the present investigation in most palatable diet (general waste) during favorable (monsoon) season was much lesser than that reported by various researchers at controlled temperature 25 ºC. This variation may be due to more nutritional status of the diets and / or no fluctuations of environmental factors under controlled conditions. Among all waste-diets during the monsoon season, enhanced worm activities observed in general waste-diet might be due to the presence of variety of nutritive constituents from different organic wastes.

From the foregone discussion, it can be concluded that growth and reproduction in all organic waste-diets were higher during monsoon > winter > summer season. Hence, monsoon is extraordinarily congenial for the culture of *P. excavatus* for commercial production of vermimass / vermiprotein and vermicompost. Straw-based wastes appeared to be more palatable than pod-based wastes during favourable (monsoon) season. Parthenium waste was the least preferred waste-diet for this worm.

Acknowledgments

The authors acknowledge with thanks the financial assistance extended by the UGC, New Delhi and the host department for providing necessary facilities to carry out this work.

References

Aira, M. and J. Dominguez: Optimizing vermicomposting of animal wastes: Effects of dose of manure application on carbon loss and microbial stabilization. *J. Environ. Manag.,* **88,** 1525-1529 (2008).

Aira, M. and J. Domínguez: Microbial and nutrient stabilization of two animal manures after the transit through the gut of the earthworm, *Eisenia fetida* (Savigny, 1826). *J. Hazard. Mater.,* **161,** 1234–1238 (2009).

Bansal, S. and K.K. Kapoor: Vermicomposting of crop residues and cattle dung with *Eisenia foetida*. *Biores. Technol.*, **73,** 95-98 (2000).

Chaudhari, P.S. and G. Bhattacharjee: Capacity of various experimental diets dung with *Eisenia foetida*. *Biores. Technol.*, **73,** 95-98 (2002).

Chaudhari, P.S., T.K. Pal, S. Nath and S.K. Dey: Effect of five earthworm species on some physico-chemical properties of soil. *J. Environ. Biol*., **33,** 713-716 (2012).

Chirashree, G.: Integrated vermi-pisciculture- an alternative option for recycling of solid municipal waste in rural India. *Biores. Technol.*, **93,** 71-75 (2004).

Darke, H.L. and M. A. Horn: As the worm turns: The earthworm gut as a trasnsit habitat for soil microbial biomass. *Annu. Rev. Microbial*., **61**, 169-189 (2007).

Domínguez, J.: State of the art and new perspectives on vermicomposting research. In *Earthworm Ecology,* (Ed.: *C.A. Edwards*), 2nd Edn. CRC Press, pp. 401–424 (2004).

Domínguez, J., C.A. Edwards and M. Webster: Vermicomposting of sewage sludge: Effect of bulking materials on the growth and reproduction of the earthworm, *Eisenia andrei*. *Pedobiologia,* **44,** 24–32 (2000).

Dominguez, J., M. Aira and M. Gomez-Brandon: Vermicomposting: Earthworms enhance the work of microbes. In: Microbes at Work. (Eds.: H. Insam, I. Franke-Whittle and Gobernam), *Boca Raton, FL Springer, Berlin. pp. 94-115* (2010)

Fernández-Bayo, J.D., R. Nogales and E. Romero: Effect of vermicomposts from wastes of the wine and alcohol industries in the persistence and distribution of imidaclo-prid and diuron on agricultural soils. *J. Agric. Food Chem.,* **57,** 5435–5442 (2009).

Garg, P., A. Gupta and S. Satya: Vermicomposting of different types of wastes using *Eisenia fetida:* A comparative study. *Biores. Technol.*, **97,** 391-395 (2006).

Gunadi, B. and C.A. Edwards: The effect of multiple application of different organic waste on the growth, fecundity and survival of *Eisenia foetida* (Savigny) (Lumbricidae). *Pedobiologia,* **31**, 199-209 (2002).

Kaur, A., J. Singh, A.P. Vig, S.S. Dhaliwal and P.J. Rup: Composting with and without *Eisenia fetida* for conversion of toxic paper mill sludge into soil conditioner. *Biores. Technol.,* **101**, 8192-8198 (2010).

Lazcano, C., M. Gomez-Brandon and J. Dominguez: Comparison of the effectiveness of composting and vermicomposting for the biological stabilization of cattle manure. *Chemosphere,* **72,** 1013-1019 (2008).

Loh, J.C., Y.C. Lee, J.B. Liang and D. Tan: Vermicomposting of cattle and goat manure by *Eisenia fetida* and their growth and reproduction performance. *Biores. Technol.* **96**, 111-114 (2005).

Manivannan, S., P. Ramamurthy, K. Parthasarathi and L.S. Ranganathan: Effect of sugar industrial wastes on the growth and reproduction of earthworms. *J. Exp. Zool. India*, **7,** 29-37 (2004).

Monroy, F., M. Aira,, J. Domínguez and A. Velando: Seasonal population dynamics of *Eisenia fetida* (Savigny, 1826) (Oligochaeta: Lumbricidae) in the field. *C.R. Biol.,* **329,** 912–915 (2006).

Ndegwa, P.M., S.A. Thompson and K.C. Das: Effects of stocking density and feeding rate on vermicomposting of biosolids. *Biores. Technol.,* **71**, 5-12 (2000).

Nogales, R., C. Cifuentes and E. Benitez: Vermicomposting of winery wastes: A laboratory study. *J. Environ. Sci. Hlth., Part B,* **49,** 659–673 (2005).

Nogales, R., M. Saavedra and E. Benitez: Recycling of wet olive cake “Alperujo” through treatment with fungi and subsequent vermicomposting. *Fresenius Environ. Bull.,* **17,** 1822–1827 (2008).

Norgroove, L. and S. Hauser: Production and nutrient content of earthworm casts in a tropical agri-silvicultural system. *Soil Biol. Biochem.,* **32**- 1651-1660 (2000).

Plana, R., C. Pérez, J. Domínguez, S. Mato and F. Aguilera: Development of a semi-industrial scale experimental organic wastes biodegradation reactor. In: Recycling and Reuse of Sewage Sludge (Eds.: R.K. Dhir, M.C. Limbachiya and M.J. McCarthy). Thomas Telford, London, pp. 351– 362 (2001).

Pulikeshi, M.B. and S.D. Amoji: Influence of organic wastes and seasonal environmental factors on growth and reproduction of *Eisenia fetida*. *J. Environ. Biol.,* **24,** 81-89 (2003).

Pulikeshi, M. Biradar, S.D. Amoji and G. Harsha: Life cycle of the epigeic earthworm, *Eisenia fetida* as influenced by seasonal environmental factors. *J. Exp. Zool. India*, **11,** 405-409 (2008).

Singh, N.B., A.K. Khare, D.S. Bhargava and S. Bhattacharya: Optimum moisture requirement during vermicomposting using *Perionyx excavatus*. *App. Ecol. Environ. Res.,* **2,** 53-62 (2004).

Sinha, R.K., G. Bharambe and D. Ryan: Converting waste land into wonderland by earthworms: A low-cost nature's technology for soil remediation: A case study of vermiremediation of PAH contaminated soil. *The Environmentalist*, *UK*, **28,** 466-475 (2008).

Suriyanarayanan, S., A.S. Mailappa, D. Jayakumar, K. Nathakumar, K. Karthikeyan and S. Balasubramania: Studies on the characterization and possibilities of reutilization of solid wastes from a waste paper based paper industry. *Global J. Environ. Res.,* **4,** 18-22 (2010).

Suthar, S.: Vermicomposting potential of *Perionyx sansbaricus* (Perrier) in different waste material. *Biores. Technol.*, **98,** 1231-1237 (2007).

Tiunov, A.H. and S. Scheu: Microbial communities in soil litter and casts of *Lumbricus terrestris* (Lumbricidae): A laboratory experiment. *App. Soil Ecol.,* **14,** 17-26 (2000).

Tripathi, G. and P. Bharadwaj: Comparative studies on biomass production, life cycles and composting efficacy of *Eisenia foetida* (Savigny) and *Lampito maruitti* (Kinberg). *Biores. Technol.*, **92,** 275-283 (2004).