Proc. Indian Acad. Sci. (Anim. Sci.), Vol. 97, No. 3, May 1988, pp. 239–250.

Population biology and reproductive strategy of *Dichogaster bolaui* (Oligochaeta: Octochaetidae) in two tropical agroecosystems

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MS received 24 February 1987; revised 17 October 1987

Abstract. Comparative biology of the worm *Dichogaster bolaui* (Michaelsen) in a pasture and compost pit has been reported. Important findings are: (i) restriction of more than 84% of *Dichogaster bolaui* population to upper 10 cm of the soil depth indicating surface living habit; (ii) attainment of a peak population of 12617 worms/m^2; (iii) a zero population during summer revealing environmental drasticity (soil temperature $>31°C$, soil moisture <1 g%) and yearly recolonisation of worms; (iv) habitat variation in the reproductive strategy with an unimodality in pasture and bimodality in compost pit; and (v) pre-emergence of juveniles followed by post cocoon peak indicating population survival through cocoons during summer.

Keywords. *Dichogaster bolaui*; unimodality; bimodality; reproductive strategy; life cycle; vertical stratification.

1. Introduction

There is a great paucity of information on the biology of tropical earthworms (Dash 1978; Lavelle 1978). There are about 500 species of earthworms in India (Julka 1976). Utilisation of suitable biological agents in vermitechnological programme is largely dependent on the width of our knowledge on the autecological studies of these organisms. A comprehensive programme for understanding the environmental regulation of life cycle strategy in tropical earthworms has been taken up in different agroecosystems. Dash and Patra (1977), Senapati *et al* (1979), Dash and Senapati (1980) and Sahu and Senapati (1986) have reported the activity of earthworms in lowland, upland and plain pasture ecosystems of Orissa. Impact of large herbivore grazing and thermohydric stress on tropical earthworms has been studied by Senapati and Dash (1981, 1983, 1984). Out of the 31 earthworm species reported by Julka and Senapati (1987), *Dichogaster bolaui* (Michaelsen) is the smallest with a maximum of about 40 mm in length, 1 mm in diameter and a dry weight of 7 mg with 80% of tissue moisture content. Interspecific interaction studies carried out on tropical earthworms indicate that *D. bolaui* has great potentiality in the biodegradation of organic residues (Senapati B K, Sahu S K and Pani S C, unpublished results). However, no attempt has been made to understand the orientation of life cycle strategy of detrivorous earthworms, like *D. bolaui* in different organic waste disposal sites. The present paper deals with the population biology and reproductive strategy of *D. bolaui* in two tropical agroecosystems receiving organic wastes.

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2. Study site and climate

Out of the two sites, one is an upland grazed pasture receiving kitchen wastes from Sambalpur University canteen from July–October at Jyotivihar and the other one is a dung deposit site receiving dung from a nearby farm having 50 cows and buffalows at Ainthapali (Sambalpur). Geographically the study sites are situated at 21° 25′ N latitude, 83° 52′ E longitude and about 160 m above the mean sea level. Detailed study has been made from a plot of 10 × 10 m area at both the sites, each divided into 400 subplots of 0·5 × 0·5 m^2 area. The study sites lie in the arid-humid agroclimatic belt (Lenka 1972). The climate is broadly divided into 3 seasons: winter (October–February), summer (March–mid June) and rainy (mid June–September). Climatological parameters have been measured by standard methods (Senapati *et al* 1979; Dash and Senapati 1980; Senapati and Dash 1981, 1983). Comparative characteristics of both the study sites relating to physical, chemical and biological parameters have been given in table 1. Hereafter the pasture site receiving kitchen waste and dung deposit site will be designated as pasture and compost pits, respectively.

3. Materials and methods

The present study was carried out at fortnightly intervals for about a year. At pastures site, sampling took place from July 1984 to June 1985 and from November 1985 to October 1986 at the compost pit site. The dates were fixed between 13th and 15th for the second week sampling and between 28th and 30th for the fourth week sampling every month. During each sampling, 5 random samples were taken from an area of 25 × 25 × 20 cm separately from each study site (Snedecor and Cocharane 1967; Dash and Senapati 1980). Earlier works of Dash and Patra (1977), Senapati *et al* (1979), Dash and Senapati (1980) and Senapati and Dash (1981, 1983) on tropical earthworms from various agroecosystems had standardised methods for sampling, collection, preservation and analysis of cocoons and worms. *D. bolaui* was dominant in both number and biomass (> 80%) in both the study sites. On the basis of length and clitellar development, *D. bolaui* worms were divided into 3 age classes. They were (i) juvenile (< 1 cm, non-clitellate), (ii) immature (> 1 cm but < 2 cm, non-clitellate) and (iii) adult (> 2 cm, clitellate). In the pasture, cocoons of *D. bolaui* were available during the study period and rate of reproduction was calculated from the ratio of total cocoons to adults and total juveniles to adults. Sahu and others (Sahu and Senapati 1987; Senapati B K, Sahu S K and Pani S C, unpublished results) have indicated the possibility of utilising juvenile: adult ratio in the absence of cocoon data. In the compost pit, inspite of all precautions and care, cocoons were not detected. In this changed situation the rate of reproduction was calculated from the ratio of total juveniles to adults.

4. Results

4.1 *Population size and structure*

Table 2 gives the population density and biomass of earthworms in various world agroecosystems. Table 3 shows the age structure of *D. bolaui* in two agroecosystems.

Table 1. Comparative characteristics of physical, chemical and biological parameters in two agroecosystems.

Parameter	Pasture site (1984–1985)	Compost pit site (1985–1986)
Solar radiation (average, 10^3 kJ/m^2/month)	507·19	507·19
Rain fall (total, mm)		
Winter	114·8	145·4
Summer	104·3	114·3
Rainy	1545·2	1277·9
Air temperature (°C)		
Winter	11·67–33·95	10·80–31·74
Summer	18·73–42·71	17·91–42·14
Rainy	23·76–33·91	23·51–32·85
Relative humidity (%)		
Winter	26·56–97·60	28·67–98·25
Summer	14·87–94·67	17·60–94·60
Rainy	42·40–98·19	51·74–97·93
Soil/dung moisture (g%) (at 0–10 cm depth)		
Winter	4·8–16·0	9·1–50·1
Summer	0·9–17·2	0·3–16·0
Rainy	15·5–25·3	49·7–64·6
Soil/dung temperature (°C) (at 0–10 cm depth)		
Winter	18·2–27·5	17·8–30·2
Summer	24·2–30·1	22·0–32·1
Rainy	27·1–28·8	27·0–31·1
Organic matter (g%)		
0–5 cm	10·0	80·0
6–10 cm	6·5	75·0
11–15 cm	4·0	65·0
16–20 cm	2·0	50·0
21–40 cm	1·0	40·0
Earthworm species	*Dichogaster bolaui** *Lampito mauritii*	*Dichogaster bolaui** *Perionyx excavatus*
Vegetation	*Cynodon dactylon** *Spermacocea hispida*	—

*Dominant species.

Figure 1 depicts the fortnightly density of total *D. bolaui* population in two agroecosystems.

An average population of about 1447/m^2 and 1665/m^2 was noted in the pasture and compost pit, respectively. A zero population during summer months at both the sites indicated rebuilding of worm population each year. Peak population (nos/m^2) of 8038 in the pasture and 12617 in the compost pit noted in this study is the highest density reported so far. However, the highest value for worm biomass (g live wt/m^2)

Table 2. Population density (nos/m^2) and biomass (g live wt/m^2) of earthworms in various world agroecosystems.

Habitat	Population density	Population biomass	Locality	Extraction method	Reference
Savana					
Low laying wet savana	180–340	39–57	Lamto (Ivory coast), Africa	H	Lavelle (1977)
Grass savana	202		Lamto (Ivory coast), Africa	H	Lavelle (1978)
Shrub savana	350		Lamto (Ivory coast), Africa	H	Lavelle (1978)
Shrub savana	400		Lamto (Ivory coast), Africa	H	Lavelle (1978)
Grasslands					
Natural grasslands					
Pasture (base-rich grassland)	389–470	52–110	Westmoorland, UK	H	Svendsen (1957)
Pasture (base-rich grassland)	390	56	Bardsey Island	H	Reynoldson *et al* (1955)
Pasture (base-rich grassland)	481–524	112–120	N Wales	H	Reynoldson (1955)
Pasture (upland protected)	122–387	20–78	Sambalpur, Orissa, India	H and WS	Senapati and Dash (1981)
Pasture (lowland protected)	64–800	6–60	Berhampur, Orissa, India	H	Dash and Patra (1977)
Human interfered grasslands					
Pasture (upland grazed)	75–272	12–70	Sambalpur, Orissa, India	H and WS	Senapati and Dash (1981)
Pasture (upland grazed)	0–140	0–26	Jyotivihar, Orissa, India	H	Pradhan and Mishra (1986)
Arable land Paddy field (upland)	32–1399	2–62	Sambalpur, Orissa, India	H and WS	Pani and Senapati (unpublished results)
Paddy field (lowland)	0–246	0–25	Sambalpur, Orissa, India	H and WS	Pani and Senapati (unpublished results)
Organic waste deposit sites					
Pasture receiving kitchen waste	0–8038	0–66·2	Jyotivihar, Orissa, India	H and WS	Sahu and Senapati (1986)
Farmyard manure garden	15–625	–	Bangalore, Karnataka, India	H	Kale and Krishnamoorthy (1982)
Dung deposit site	0–12617	0–51·4	Sambalpur, Orissa, India	H and WS	Present work
Kitchen waste deposit site	600	–	Rajgangpur, Orissa, India	H	Julka and Senapati (1987)
Wash basin waste receiving site	50–500	–	Jyotivihar, Orissa, India	H	Julka and Senapati (1987)
Straw thatched roof drain site	800	–	Ladukhai, Orissa, India	H	Julka and Senapati (1987)

H, Hand sorting; WS, wet sieving.

Table 3. Age structure of *D. bolaui* in two agroecosystems.

	Pasture site (1984–1985)				Compost pit site (1985–1986)			
Month (week)	Juvenile worms (J)	Immature worms (I)	Adult worms (A)	Total worms (TW)	Juvenile worms (J)	Immature worms (I)	Adult worms (A)	Total worms (TW)
Jul. (IV)	1193	1466	372	3031				
Aug. (II)	1582	5585	871	8038				
(IV)	1208	2571	644	4423				
Sep. (II)	78	3242	1132	4452				
(IV)	238	120	676	1034				
Oct. (II)	118	473	474	1065				
(IV)	0	40	80	120				
Nov. (II)	—*	—	—	—				
(IV)	0	0	39	39	361	1579	199	2139
Dec. (II)	—	—	—	—	1207	4777	554	6538
(IV)	0	0	39	39	268	1894	211	2373
Jan. (II)	—	—	—	—	17	233	24	274
(IV)	0	0	39	39	41	95	36	172
Feb. (II)	—	—	—	—	0	0	17	17
(IV)	0	0	39	39	0	0	0	0
Mar. (II)	—	—	—	—	—	—	—	—
(IV)	0	0	0	0	0	0	0	0
Apr. (II)	—	—	—	—	—	—	—	—
(IV)	0	0	0	0	0	0	0	0
May (II)	—	—	—	—	—	—	—	—
(IV)	0	0	0	0	0	0	0	0
Jun. (II)	0	40	80	120	—	—	—	—
(IV)	118	473	119	710	23	98	63	184
Jul. (II)					342	308	116	766
(IV)					315	1570	233	2118
Aug. (II)					2514	8823	1280	12617
(IV)					387	1548	212	2147
Sep. (II)					240	491	228	959
(IV)					59	123	111	293
Oct. (II)					29	93	134	256
(IV)					239	206	156	601

*Sampling not done.

was reported from the base rich grasslands (table 2). Population structure constituted 11–39% of juveniles, 12–73% of immatures and 11–100% of adults during 1984–1985 study period at the pasture. In the compost pit the population structure comprised 6–45% of juveniles, 34–85% of immatures and 9–100% of adults during 1985–1986 study period. This shows that the youngest age group i.e. juveniles forming the smallest component of the total population, indicate rapid transformation and/or high mortality and/or discontinuous reproduction resulting in an unstability in the age structure. In the compost pit total worm population showed one peak during December II week 1985 with 6538 worms/m^2 and another peak during August II week 1986 with 12617 worms/m^2 (table 3). The higher peak is associated with rainy season and lower peak with the postrainy season. This peak population value is about 57% higher than the highest density (8038/m^2) of *D. bolaui* noted in the pasture site. Higher nutrient quality and longer activity period might be the cause for increased population density in the dung pit.

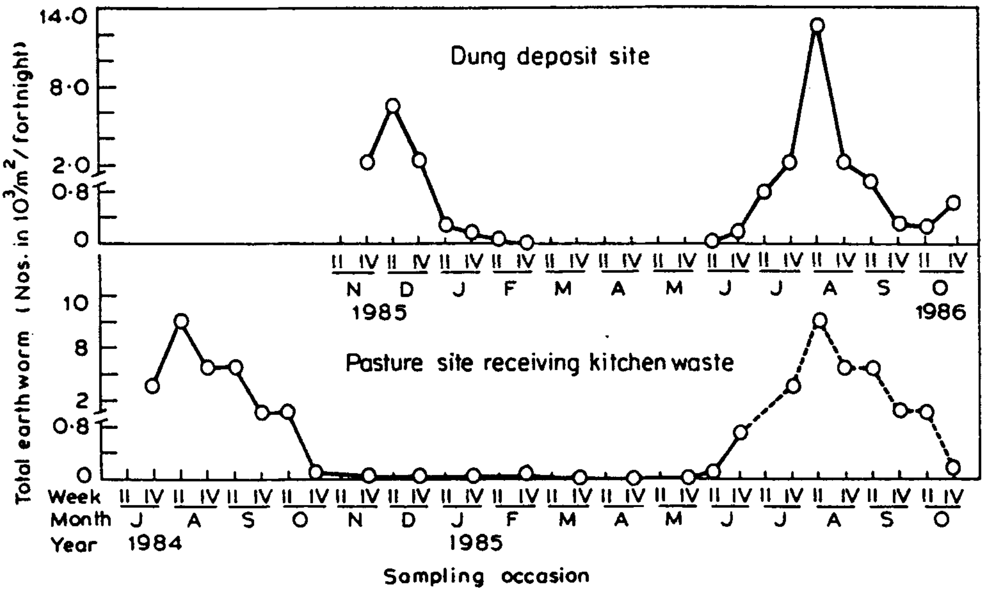

Figure 1. Fortnightly density of total *D. bolaui* population in two agroecosystems.

Table 4. Correlation coefficient values of different environmental parameters with total *D. bolaui* density.

Parameter	Total *D. bolaui* worm density: Pasture site	Total *D. bolaui* worm density: Compost pit site
Solar radiation	−0·458[a]	−0·526[b]
Rainfall (total)	0·177[c]	0·158[c]
Relative humidity (average)	0·598[d]	0·325[a]
Air temperature (average)	0·091[c]	−0·077[c]
Soil temperature (0–10 cm, average)	0·324[c]	0·014[c]
Soil moisture (0–10 cm, average)	0·719[e]	0·468[b]

[a, b, d, e] Significant at 0·2, 0·05, 0·02 and 0·01 respectively. [c] Not significant at 0·2.

4.2 *Population distribution and environmental regulation*

Table 4 gives the correlation coefficient values of different environmental parameters with total *D. bolaui* density and figure 2 shows the vertical distribution of *D. bolaui* population in two agroecosystems studied.

Environmental parameters fluctuated more drastically at the pasture compared to the compost pit. Soil moisture and solar radiation showed a positive and negative correlation with the total monthly worm density, respectively for both the sites (table 4). About 84 and 16% of the total worms were stratified at 0–10 and 11–15 cm of soil depth at the compost pit site whereas 96 and 4% of the worms remained at 0–10 and 11–15 cm of soil depth at the pasture site. Juvenile and immature worms were mostly restricted to 0–5 cm of soil depth. Thus the whole population was mostly confined to upper 10 cm of the soil profile indicating highest degree of exposure to the environ-

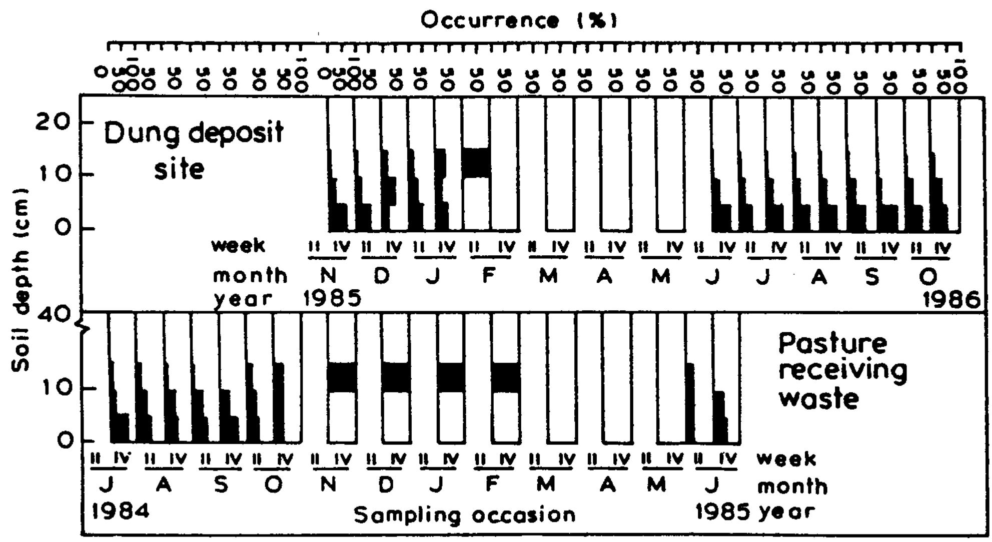

Figure 2. Vertical distribution of *D. bolaui* population in two agroecosystems.

mental fluctuations. Dynamics of total worms (nos/m^2/fortnight) showed unimodal and bimodal form of population peak at pasture and compost pit site, respectively (table 3, figure 1). Diapause coils of worms were obtained during November–February in the pasture site and during February in the compost pit site. However these diapause coils were not available after February indicating death and destruction of the diapaused worms resulting in zero population during summer months. Thus there is a possibility of yearly recolonisation of the worms to the study sites from the surrounding wet habitats and/or due to hatching of cocoons survived through summer stress.

4.3 *Reproductive strategy*

Table 5 gives the rate of reproduction and figure 3 shows the life cycle of *D. bolaui* in two agroecosystems.

The cocoon of *D. bolaui* is lemon yellow, slightly oval in shape and measures about 2 mm in length and 1·25 mm in width with a distinct ornamentation at the hatching side. Usually 1–2 juveniles hatch out from the cocoon and the incubation period is about one week. Although cocoons were obtained from the pasture site, they were not available from the compost pit site. Deep coloration of the dung along with high organic matter (>70%) provided a very inappropriate background for cocoon identification. In the pasture site the cocoons were available from June IV week till October II week (table 5). The peak density of 4956 cocoons/m^2 was noted during II week of September 1984 when density of adult worms were 1132/m^2. Thus the rate of reproduction (total cocoon: total adult) came to be around 4·38. The ratios of total cocoons to adults and total juveniles to adults in all the sampling occasions did not show significant difference at 0·05 level of significance ($t = 0{\cdot}22$, $n = 16$) indicating the use of juvenile: adult ratio as an alternate method of calculating rate of reproduction in the absence of cocoon. Emergence pattern of the worm was unique because the

Table 5. Rate of reproduction in *D. bolaui* at two agroecosystems.

	Pasture site (1984–1985)			Compost pit site (1985–1986)
	Total cocoons	Rate of reproduction		Rate of reproduction
Month (week)	(TC)	TC/A	J/A	J/A
Jul. (IV)	0	0·00	3·21	
Aug. (II)	76	0·09	1·82	
(IV)	645	1·00	1·88	
Sep. (II)	4956	4·38	0·07	
(IV)	915	1·35	0·35	
Oct. (II)	78	0·17	0·25	
(IV)	0	0·00	0·00	
Nov. (II)	—	—	—	
(IV)	0	0·00	0·00	1·81
Dec. (II)	—	—	—	2·18
(IV)	0	0·00	0·00	1·27
Jan. (II)	—	—	—	0·71
(IV)	0	0·00	0·00	1·14
Feb. (II)	—	—	—	0·00
(IV)	0	0·00	0·00	0·00
Mar. (II)	—	—	—	—
(IV)	0	0·00	0·00	0·00
Apr. (II)	—	—	—	—
(IV)	0	0·00	0·00	0·00
May (II)	—	—	—	—
(IV)	0	0·00	0·00	0·00
Jun. (II)	0	0·00	0·00	—
(IV)	39	0·33	0·99	0·37
Jul. (II)				2·95
(IV)				1·35
Aug. (II)				1·96
(IV)				1·83
Sep. (II)				1·05
(IV)				0·53
Oct. (II)				0·22
(IV)				1·53

J, Juvenile; A, adult.
'*t*' test between TC/A and J/A in pasture site not significant at 0·05 level.

cocoon peak (September II week, 1984) was observed after the juvenile peak (August II week, 1984). Pre emergence of juveniles followed by post cocoon peak might be an indication of population survival through cocoons during summer. The rate of reproduction (total juvenile: total adult) of *D. bolaui* at the compost pit site, reached 2·18 during December II week and 2·95 during July II week indicating two reproductive peaks. Thus two peaks in the compost pit and single peak in the pasture site indicated bimodality and unimodality of *D. bolaui* earthworm, respectively. The time lag between the emergence of juvenile from the cocoon and their transformation into adult till production of cocoons, is known as the duration of life cycle. Considering the peak rate of reproduction, peak juveniles and peak population the probable duration for completion of *D. bolaui* life cycle might be about 4–5 months in the pasture site and 4–8 months in the compost pit site (figure 3). The expected duration that an individual is supposed to live is known as life span.

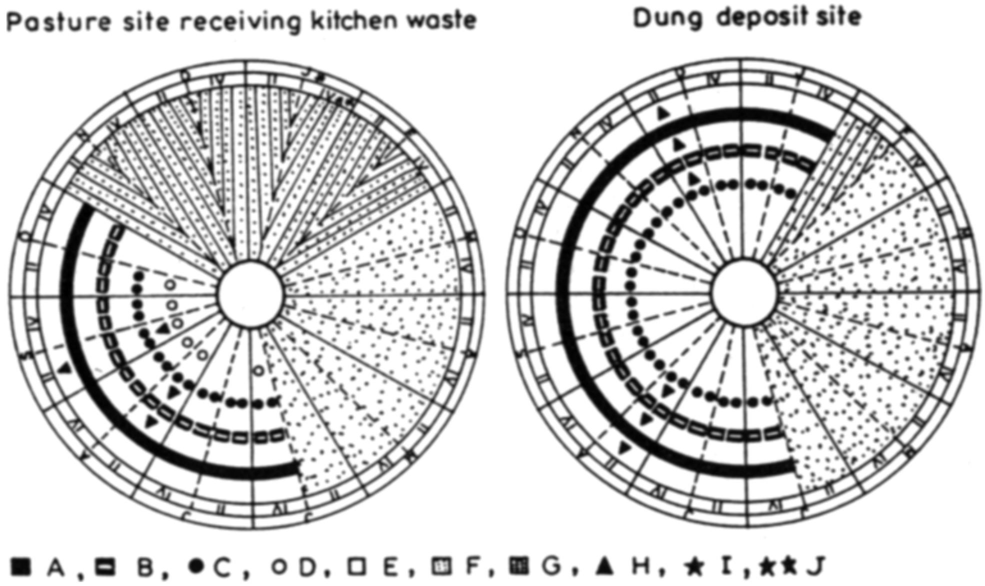

Figure 3. Life cycle of *D. bolaui* in two agroecosystems.
(A, Adult; B, immature; C, juvenile; D, cocoon; E, active period; F, worms not available; G, inactive period; H, peak number; I, month; J, week).

Since *D. bolaui* population reached zero level and showed annual recolonisation of worms, so the duration of the life cycle might be equal to the life span. This needs verification in laboratory culture.

5. Discussion

5.1 *Population distribution, size, structure and environmental regulation*

D. bolaui is a cosmopolitan species (Gates 1972; Julka and Senapati 1987). In India the worms show peregrinity (wide occurrence) (Stephenson 1923; Bahl 1950). However, excepting taxonomic details and places of collection, very little information is available on the ecology of this widely distributed worm. Sahu and Senapati (1986) first published the details of population biology and secondary production of the worm from a pasture ecosystem. Population density of $12617/m^2$ for *D. bolaui* reported in the present work is the highest among the previously reported values for earthworms in various world agroecosystems (table 2). Body size, surface living habits and organic rich substrate might be the causes for maximum density of *D. bolaui* worm. In a continuously reproducing population, relationship among the density of juvenile, immature and adult is of distinct vertical pyramidal type. Because of discontinuity and unstability, vertical pyramidal structure is not very much distinct.

Studies on the horizontal and vertical distribution of earthworms have been made by Dowdy (1944), Gerard (1967), Bouche (1972), Rundgren (1975), Dash and Patra (1977), Senapati *et al* (1979), Dash and Senapati (1980) and Sahu and Senapati (1986). Stratification to upper 10 cm of soil depth along with single population peak in the pasture and two population peaks in the compost pit showed that *D. bolaui* is a surface living earthworm. Bimodality of *D. bolaui* at compost pit site might be an indication of favourable environmental factors like soil temperature, moisture and organic matter (table 1). Dash and Senapati (1980) and Senapati and Dash (1981) have reported that population survival in *Octochaetona surensis* (Michaelsen) earthworm was possible for two reasons: (i) migration of worms to a depth of > 20 cm during summer and (ii) prevalence of minimum soil moisture of about 3 g%. So the field population of *O. surensis* never became zero. But the conditions with *D. bolaui* were different in both pasture and compost pit site where the worm never migrated below 15 cm of soil depth and field soil moisture decreased to extreme values (< 1 g%) resulting in worm mortality. These could be probable reasons for zero population of *D. bolaui*.

5.2 *Reproductive strategy*

Reproductive strategy of a few species has been studied from both temperate and tropical habitats. Among the species of earthworms whose reproductive biology and life cycle have been worked out are *Eisenia foetida* (Savigny), *Allolobophora longa*, Ude, *A. caliginosa* (Savigny), *Lumbricus terrestris*, Linnaeus, *L. rubellus*, Hoffmeister, *Bimastos zeteki* (Smith and Gittins), *Eudrilus euginiae* (Kinberg), *Milsonia anomala*, Omedo, *Drawida calebi* Gates, *D. willsi*, Michaelsen, *Lampito mauritti* Kinberg and *Ochtochaetona surensis* (Michon 1954; Avel 1959; Murchie 1960; Satchell 1967; lavelle 1977, 1978; Hartenstein *et al* 1979; Senapati *et al* 1979; Dash and Senapati 1980; Senapati 1980; Pani 1986). Discontinuous mode of reproduction has been advocated for surface living earthworms (Satchell 1967; Rundgren 1977; Dash and Senapati 1980). Previous studies on tropical earthworms (*D. calebi, L. mauritii* and *O. surensis*) have revealed single peak and prolonged emergence pattern, whereas *D. bolaui* showed a single and sudden emergence pattern in the pasture. A double population peak following sudden emergence has been observed from the compost pit. Among the tropical earthworms known, the incubation period is about 7 days in *D. bolaui*, 15 days in *D. willsi* and 30 days for *M. anomala, D. calebi, L. mauritii* and *O. surensis*. A life cycle of about 12–20 months have been reported for *D. calebi, L. mauritii, O. surensis* and *M. anomala*. *D. bolaui* exhibited a very brief life cycle of about 4–5 months in pasture ecosystem whereas it was around 4–8 months in the compost pit site. Population survival through cocoons had been advocated by Wilcke (1952) and Murchie (1960) and has been reported for the first time in *D. bolaui*. This is an unique attribute of its epigeic (surface living) nature. Intraspecific variation of reproductive strategy with change in the habitat conditions indicate a flexibility. Thus *D. bolaui* having an adult size measuring about 4 cm in length and weighing 7 mg dry weight, with epigeic habit, high population density, reproductive rate and environmental resistance, comparatively short life cycle and life span period indicate the possibility of utilising this earthworm in biotechnology particularly in vermicomposting and also vermiculture. Comparative role of *D. bolaui* worms in the decomposition of various organic wastes are in progress. This type of study will be helpful in developing vermitechnology programme and also in the management of the decomposer fauna like earthworms in tropical agroecosystems.

Acknowledgements

The authors express their sincere thanks to Sri J P Lath for providing field facility and to Prof. M C Dash for constant encouragement and laboratory facilities. BKS acknowledges receipt of a research grant from the University Grants Commission, New Delhi. SKM is thankful to the Council of Scientific and Industrial Research, New Delhi for a fellowship.

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