# EARTHWORM AND ENCHYTRAEID POPULATIONS IN A 13-YEAR-OLD AGROFORESTRY SYSTEM

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ABSTRACT

Quarterly sampling of the Tikitere trial in 1986–87 gave estimates of average earthworm populations of 378, 283, 150, 0, and 1 earthworms/m$^2$ in plots containing 0, 50, 100, 200, and 400 **Pinus radiata** D. Don/ha 13 years after planting. These are lower than published values for the same plots of 547, 435, 304, 389, and 287 earthworms/m$^2$ estimated 2 years after planting. Both soil pH and pasture productivity have fallen in the intervening period. Populations of Enchytraeidae averaged 10 000–64 000/m$^2$, being most abundant at 50 **P. radiata**/ha. The declining earthworm populations and soil pH indicate significant changes in soil biological activity which may influence post-harvest management.

**Keywords:** agroforestry; rotations; Oligochaeta; soil pH; pasture; **Pinus radiata**.

## INTRODUCTION

Agroforestry systems can improve land-use profitability, shelter animals or crops, provide fuelwood, or aid soil conservation (Bilbrough 1984; Pimentel *et al.* 1986). The work reported here is part of the assessment of various combinations of pastoral agriculture and populations of *Pinus radiata* at the joint Ministry of Agriculture and Fisheries/Forest Research Institute trial established on pumice soil at the Tikitere Forest Farming Research Area near Rotorua. The experiment has previously been described in detail (Hawke *et al.* 1980; Percival *et al.* 1984).

Earthworms play important roles in the cycling of plant nutrients, the turnover of organic matter, and maintenance of soil structure, and may advantageously be introduced to pastures from which they are absent (Stockdill 1982). If pasture is to be maintained under an agroforestry regime it is desirable that earthworm populations persist. Further, when a subsequent crop is planted, presence of earthworms would be expected to be beneficial to at least the lower tier.

McMillan (1981) gave estimates of earthworm populations for the Tikitere Forest Farming Research Area for 1975–76, in the 2 years after the trial was established. This paper reports on their status midway through the trial when canopy closure had occurred in the highest planting density. Among the Oligochaeta, the distribution of Enchytraeidae often complements that of Lumbricidae (Wallwork 1970) so the abundance of the two groups has been estimated in parallel.

## MATERIALS AND METHODS

The Tikitere Forest Farming Research Area, located 18 km north-east of Rotorua, was planted in September 1973, and McMillan (1981) described conditions relating to earthworms in 1975–76. Intraplot population variability was such that more meaningful results were obtained from multiple samples of one trial replicate than from single samples from all replicates. The present sampling utilised McMillan's five experimental plots, now at their final *P. radiata* stocking densities, with four randomly allotted points on a 25 point grid being sampled on each of the four sampling occasions, 13–15 October 1986, 15–18 January, 7–8 April, and 13–15 July 1987. The topography of all areas sampled was flat or easy rolling. The status of the tree and pasture components of the plots about this time is summarised in Table 1.

TABLE 1–Characteristics of the plots

| Tree population (final stems/ha) | 0 | 50 | 100 | 200 | 400 |
|---|---|---|---|---|---|
| Plot | E | L | G | I | H |
| Space between tree rows (m) | – | 14.2 | 7.1 | 7.1 | 3.55 |
| Area of sampling grid ($m^2$) | 2200 | 2400 | 2400 | 2400 | 1000 |
| Mean diameter breast height (cm)* | – | 45.6 | 47.7 | 42.7 | 37.0 |
| Mean tree height (m)* | – | 18.1 | 19.1 | 20.1 | 22.1 |
| Pasture productivity (kg DM/ha)* | 9922 | 8515 | 5891 | 1265 | c. 300 |
| Litter ($g/m^2$) (mean of four quadrats on four dates) | 0 | 17 | 74 | 321 | 1199 |
| Soil dry bulk density ($T/m^3$) (July 1987) | | | | | |
| 2.5–10 cm | 0.95 | 1.00 | 0.94 | 0.99 | 1.03 |
| 12.5–20 cm | 1.02 | 1.04 | 0.95 | 1.06 | 1.05 |
| Soil pH (October 1986) | | | | | |
| 0–10 cm soil depth | 5.5 | 5.2 | 5.2 | 5.3 | 5.2 |
| 10–20 cm | 5.3 | 5.3 | 5.4 | 5.4 | 5.6 |
| 20–30 cm | 5.5 | 5.5 | 5.4 | 5.5 | 5.7 |
| 30–40 cm | 5.7 | 5.6 | 5.6 | 5.6 | 5.7 |

* Data are for 1986; trees pruned to an average height of 5.9 m.

At each sampling point a 0.1-$m^2$ quadrat was handsorted (Lee 1985) for earthworms to 40 cm soil depth, with the fauna of each 10 cm depth increment being separated. Following Martin (1986), the earthworms were placed directly into 10% ethanol, transferred to 4% formaldehyde the same night, and 1–2 weeks later counted and stored in 70% ethanol; after 24 hours in 70% ethanol the collections were blotted dry and weighed for biomass assessment.

Cores for extraction of Enchytraeidae were taken using a corer 51 mm in diameter, with 0–25 and 25–50 mm depths being sampled. Ten replicate cores were collected, two or three being adjacent to each of the four earthworm sampling points. Extraction was carried out using Baermann funnel extractors heated by 60-watt light bulbs such that the water temperature reached 45°C over the 3-hour extraction period; cores were retained in their protective plastic rings throughout extraction. Specimens were counted under a stereo-microscope.

Soil moisture contents (expressed as percentage dry weight) were determined after drying overnight at 105°C, and soil pH measurements were made on 1 : 2.5 water suspensions which stood overnight. *Pinus radiata* litter was collected from the quadrats and dried at 85°C; only intact needles were collected (L horizon) the other strata (F and H horizons) being treated as part of the soil for assessing animal abundance. Soil bulk density determinations were made in July 1987, using 10 replicate 91-mm-diameter rings for each depth and plot, distributed as for Enchytraeidae cores.

In this paper the plot lettering follows that of the trial, whereas McMillan (1981) used the designations A–E to apply to increasing *P. radiata* densities. However, for a given tree density the same plot was sampled in both 1975–76 and 1986–87.

## RESULTS

### Site Conditions

With increasing tree density, pasture productivity declined while needle litter increased (Table 1) and at 200 *P. radiata*/ha the grass/weed turf mat could almost be rolled back like a carpet. Terrestrial Amphipoda, characteristic of native forests rather than introduced grassland, were found in two of the 16 quadrats examined at 200 *P. radiata*/ha and in all 16 quadrats at 400 stems/ha. No significant differences occurred in soil bulk density (Table 1). Soil acidity at 0–5 cm (Table 2) increased with time ($p < 0.01$) but analysis of variance of data in Table 2 did not show the trend from 5.78 at 0 stems to 5.52 at 400 stems to be significant.

TABLE 2–pH of 0-5 cm soil at five tree densities at intervals during the trial

| Tree population (stems/ha) | 1975 October | 1977 October | 1979 October | 1986 October | 1987 January |
|---|---|---|---|---|---|
| 0 | 5.9 | 5.7 | 5.7 | 5.9 | 5.7 |
| 50 | 5.7 | 6.0 | 5.5 | 5.4 | 5.7 |
| 100 | 6.0 | 6.0 | 5.9 | 5.4 | 5.5 |
| 200 | 5.9 | 5.7 | 6.2 | 5.1 | 5.2 |
| 400 | 5.9 | 5.7 | 5.8 | 5.1 | 5.1 |

### Earthworm Populations

There were no changes in species from those recorded by McMillan (1981) viz, *Aporrectodea caliginosa* (Savigny), *Lumbricus rubellus* Hoffmeister, *Octoclasion cyaneum* (Savigny). *Octoclasion cyaneum* was represented by only a few individuals. Population estimates are given in Table 3.

With only four replicates in each plot data variability was high and, despite observed climatic differences (Table 4), analysis of variance of log transformed data showed that there were no over-all significant differences between the sampling times. However, the same analysis of variance showed the mean abundance of total earthworms to be significantly lower in the 200 and 400 *P. radiata*/ha plots than in the other plots. Earthworm weight showed a similar trend.

Earthworm numbers and their biomass were highly significantly correlated with pasture herbage yield and also with soil pH in the 0–5 cm soil depth, but non-signifi-

TABLE 3–Populations of earthworms under five densities of *P. radiata* on four sampling occasions; values are means of four replicates; over-all means and standard errors for each *P. radiata* density and date are also given

| Tree population (stems/ha) | | Sampling date: October 1986 | January 1987 | April 1987 | July 1987 | Mean |
|---|---|---|---|---|---|---|
| 0 | Total earthworms/m² | 483 | 310 | 330 | 390 | 378 ± 65 |
| | Earthworm weight (g/m²) | 142 | 73 | 132 | 164 | 128 ± 24 |
| | *A. caliginosa*/m² | 401 | 278 | 302 | 330 | 328 |
| | *L. rubellus*/m² | 82 | 32 | 28 | 60 | 50 |
| 50 | Total earthworms/m² | 293 | 130 | 215 | 493 | 283 ± 46 |
| | Earthworm weight (g/m²) | 135 | 50 | 82 | 183 | 113 ± 20 |
| | *A. caliginosa*/m² | 206 | 83 | 205 | 415 | 227 |
| | *L. rubellus*/m² | 87 | 47 | 10 | 75 | 55 |
| 100 | Total earthworms/m² | 253 | 48 | 128 | 168 | 150 ± 10 |
| | Earthworm weight (g/m²) | 101 | 18 | 39 | 92 | 63 ± 16 |
| | *A. caliginosa*/m² | 201 | 41 | 109 | 130 | 120 |
| | *L. rubellus*/m² | 52 | 7 | 19 | 38 | 29 |
| 200 | Total earthworms/m² | 0 | 0 | 0 | 0 | 0 |
| 400 | Total earthworms/m² | 0 | 5 | 0 | 0 | 1.25 ± 1.25 |
| | Earthworm weight (g/m²) | 0 | 0.4 | 0 | 0 | 0.1 ± 0.1 |
| | *A. caliginosa*/m² | 0 | 5 | 0 | 0 | 1.25 |
| | *L. rubellus*/m² | 0 | 0 | 0 | 0 | 0 |
| Mean | Total earthworms/m² | 206 ± 54 | 99 ± 33 | 136 ± 42 | 210 ± 60 | – |
| | Earthworm weight (g/m²) | 76 ± 18 | 28 ± 9 | 51 ± 16 | 88 ± 24 | – |

TABLE 4–Environmental conditions during the sampling period; moisture data is mean of five plots with differing tree populations

| | Monthly rainfall* (mm) | Mean daily 10 cm soil temperature* (°C) | Mean soil moisture on sampling occasions (% dry weight): 0–10 cm | 10–20 cm |
|---|---|---|---|---|
| August 1986 | 214.3 | 6.5 | – | – |
| September | 109.0 | 8.8 | – | – |
| October | 84.9 | 12.7 | 37.2 | 27.3 |
| November | 98.5 | 14.1 | – | – |
| December | 102.7 | 16.2 | – | – |
| January 1987 | 120.1 | 19.2 | 15.1 | 13.4 |
| February | 26.1 | 17.4 | – | – |
| March | 267.9 | 14.0 | – | – |
| April | 116.4 | 12.4 | 30.4 | 33.2 |
| May | 81.2 | 9.6 | – | – |
| June | 74.4 | 7.1 | – | – |
| July | 35.4 | 5.7 | 33.2 | 26.3 |

*Rainfall and temperature data for Tikitere supplied by M. Hawke, Ministry of Agriculture and Fisheries.

cantly with soil pH at 0–10 cm although on three sampling occasions 80% of earthworms were at this depth (Tables 2 and 5). There was no relationship between earthworm numbers or biomass and litter.

TABLE 5–Average percentage vertical distribution of earthworm numbers on each sampling occasion

| Depth (cm) | Sampling date | | | |
|---|---|---|---|---|
| | October 1986 | January 1987 | April 1987 | July 1987 |
| 0–10 | 81 | 27 | 98 | 99 |
| 10–20 | 16 | 47 | 1 | 1 |
| 20–30 | 3 | 20 | 1 | – |
| 30–40 | – | 4 | – | – |
| 40–50 | – | 2 | – | – |

## Enchytraeidae Populations

Analysis of variance of log transformed enchytraeid populations showed significant ($p < 0.001$) treatment and time effects. Over-all, there was a sixfold difference between treatments, with the lowest and highest occurring at 0 and 50 *P. radiata*/ha respectively (Table 6). The 50 *P. radiata*/ha plot had the pH closest to the pasture situation, and showed some accumulation of dark, organic matter in the upper 3–8 cm of the soil profile.

At the five tree densities the mean enchytraeid and earthworm populations (Tables 3 and 6) were not significantly correlated. However, the mean populations of the two groups at the various sampling dates were significantly correlated ($r = +0.977^*$), with the lowest populations being found in January. Low soil moisture was probably responsible for these low January values.

TABLE 6–Populations of Enchytraeidae (number/m² in 0–5 cm soil) under five densities of *P. radiata* on four sampling occasions; values are means of 10 replicates; overall means ± standard errors for each *P. radiata* density and date are also given

| Tree population (stems/ha) | Sampling date | | | | Mean |
|---|---|---|---|---|---|
| | October 1986 | January 1987 | April 1987 | July 1987 | |
| 0 | 16 643 | nil | 3 818 | 22 125 | 10 647 |
| 50 | 113 221 | 832 | 53 258 | 88 697 | 64 002 |
| 100 | 49 684 | 538 | 5 972 | 29 370 | 21 391 |
| 200 | 45 768 | 979 | 33 335 | 76 998 | 39 270 |
| 400 | 49 831 | 4 552 | 41 412 | 29 027 | 31 206 |
| Mean | 55 029<br>± 8 031 | 1 380<br>± 391 | 27 559<br>± 4 543 | 49 243<br>± 7 844 | – |

# DISCUSSION

The earthworm population has declined markedly since McMillan's (1981) sampling in 1975–76 (547, 434, 304, 389, and 287 earthworms/m$^2$ in the five treatments), and reflects the decline in pasture production over the period reported by Percival *et al.*

(1984). It seems likely that at the end of the rotation there may be very few worms present in plots carrying more than 50 *P. radiata*/ha. Wallwork (1976) reported that high polyphenol content of litter inhibits decomposition and that acid conditions are inimical to lumbricid earthworms although the correlation between pH at 0–10 cm and earthworm abundance in this study was not significant. Mice have been shown to feed on earthworms in *P. radiata* forests (Badan 1986), but it was not possible to assess the impact of this on earthworm populations at Tikitere.

The distribution of Enchytraeidae is not readily explained. Unfortunately neither Styles (1967) in his survey of *P. radiata* litter fauna at a Kaingaroa Forest site nor McColl (1974) working under *P. radiata* near Reefton included earthworms, Enchytraeidae, or Amphipoda in their surveys. The populations of Enchytraeidae reported here are greater than most of those New Zealand populations summarised by Yeates (1986).

The method of forest harvest may affect both soil animals (Bird & Chatarpaul 1986) and plant nutrient availability (Ballard 1978). However, the declining earthworm abundance found in this trial and the increase in acidity associated with *P. radiata* plantings indicate significant changes in soil biological activity which may influence post-harvest management.

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