SOME ENVIRONMENTAL FACTORS AFFECTING EARTHWORM POPULATIONS AND SWEET POTATO PRODUCTION IN THE TARI BASIN, PAPUA NEW GUINEA HIGHLANDS

C.J. Rose* and A.W. Wood†

ABSTRACT

Populations of the earthworm Pontoscolex corethrurus *were measured in mounded sweet potato cultivation (*Ipomoea batatas *(L.), Lam.), and mean values for the trial blocks ranged from 93 to 302 individuals per m² (46.5 to 127.7 g fresh weight). Populations were higher on a drained peaty clay soil than on a drier, less organic alluvial soil. Mean sweet potato yields per block ranged from 324 to 776 g dry matter of tuber and 286 to 497 g dry matter of topgrowth per m². Soil moisture content was negatively correlated with crop production. There was no correlation between crop production and earthworm population for the whole trial, but mounds with less than 43 g of earthworm freshweight per m² showed a positive and significant correlation with topgrowth production. In one block of the trial with a peaty clay soil, tuber production was negatively correlated with worm yield. In another block with an alluvial soil, topgrowth yields were positively correlated with worm yields. Weekly rainfall was positively correlated to earthworm population.*

INTRODUCTION

Interest in earthworms and sweet potato production developed from observations on village pigs (*S. scrofa papuensis*) at Piwa Agricultural Station near Tari. Tethered pigs ate considerable quantities of earthworms when foraging in old sweet potato gardens, and these were thought to account for a high proportion of total protein intake. The importance of earthworms is also asserted by the Huli people of Tari who transfer them to areas of low earthworm population to improve the quality of pig foraging. Swamp lands are considered most suitable for uncontrolled pig foraging, partly because of their high earthworm populations.

Research on earthworm populations in cultivated areas has been largely connected with their beneficial effects on the break-down of organic matter and on aeration and soil structure (Edwards and Lofty 1977: ch. 8). In Papua New Guinea little research on earthworms has been reported apart from a study concerning the influence of earthworms on microrelief features in lowland areas (Haantjens 1965; Lee 1967).

A trial was carried out to observe earthworm populations under sweet potato cultivation, to identify the species of earthworm present, and to investigate any relationships between edaphic and climatic conditions and crop and earthworm yields. The trial was conducted at Piwa Agricultural Station in the Tari Basin, Southern Highlands Province (*Figure 1*).

* Piwa Agricultural Station, Department of Primary Industry, Tari, Southern Highlands Province, Papua New Guinea.
Present Address: Tropical Pig Breeding and Research Centre, P.O. Box 766, Goroka, E.H.P., P.N.G.

† Department of Geography, University of Papua New Guinea.
Present Address: P.O. Box 426, Ingham, Queensland, 4850, Australia.

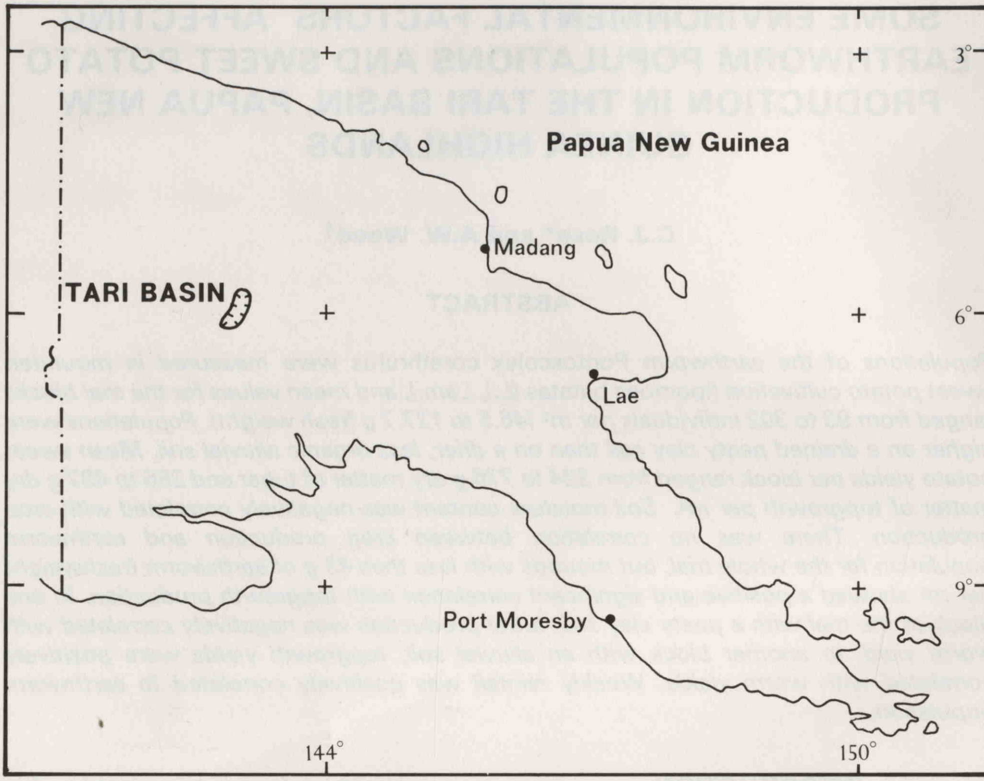


Figure 1.—**Location of the Tari Basin**

The Tari Basin is one of a series of intermontane valleys in the New Guinea Highlands between 1,500 and 2,000 m. These valleys are characterised by the intensive cultivation of sweet potato which forms the staple for the high human and pig populations (Brookfield 1964).

THE STUDY AREA

Piwa is situated 3.0 km south east of Tari at a height of 1,620 m, adjacent to an undrained swamp. The soils are typical of the intensively cultivated lowland parts of the Tari Basin. The climate is representative of the New Guinea Highlands with an annual rainfall of 2,693 mm, well distributed throughout the year, and no month registering less than 155 mm. Temperatures vary little during the year and mean monthly maxima range from 22.8 to 24.4°C and mean monthly minima from 12.5 to 14.0°C (McAlpine, Keig and Short 1975).

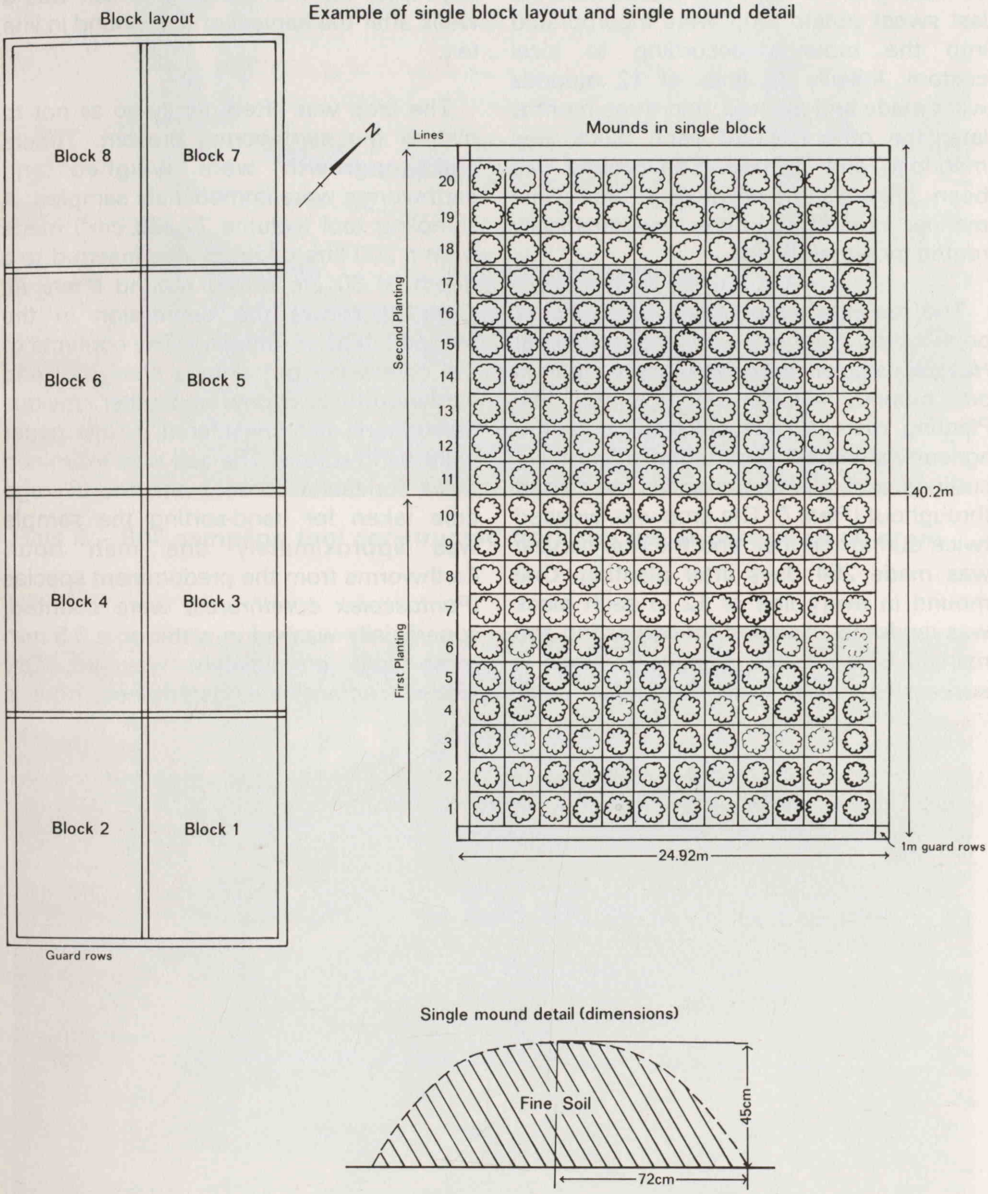
There are two main soil types in the Agricultural Station: peaty clay soils on the low lying, drained swampland; and less organic alluvial soils nearer the Piwa River. The peaty clay soils are very dark brown in colour, high in organic matter and usually wet due to a high water table. The alluvial soils are lighter in colour, drier, and commonly overlie sandy alluvial with rounded river gravels at a depth of about one metre.

METHODS

The trial was conducted on 0.70 ha, divided into eight blocks each measuring 22.92 by 38.20 m. Each block consisted of 240 mounds which were arranged in 20 straight lines of 12 mounds separated from adjacent blocks by a one m wide 'guard' row (*Figure 2*).

Individual mounds were composed of topsoil taken from an area of 3.65 m² and

Figure 2.— **Layout of blocks and mounds**



the completed mounds were 45 cm high and 144 cm in diameter. Compost consisting of the vines and weeds from the last sweet potato crop were incorporated into the mounds according to local custom. Initially 10 lines of 12 mounds were made and planted, and three months later the other half of each block was mounded and planted. The ground had been previously cultivated in the same manner and had been systematically rooted by tethered pigs.

The mounds were planted with sweet potato cuttings of one variety (local name: *Habare*) using six bunches of three cuttings per mound, (49,340 cuttings per ha). Planting material was collected from the agricultural station, and uniform length of cuttings and planting practice was used throughout (*Plate I*). The crop was weeded twice during the trial, and the first harvest was made 254 days after planting. One mound in every line of 12 in each block was randomly allocated for harvesting and marked with a stake. Marked mounds in successive lines were harvested each week for twenty weeks. The first harvest of the second planting was taken at 238 days after the first planting, which was a week after the harvest of the mound in line ten.

The crop was lifted gently so as not to disturb the earthworms present. Tubers and topgrowth were weighed and earthworms were immediately sampled. A sampling tool (volume 77,328 cm^3) made from a 200 litre oil drum was inserted to a depth of 30 cm in the mound (*Plate II*). *Plate III* shows the depression in the mound left after sampling. The contents of the core were put onto a steel tray and earthworms, cocoons, and other obvious macrofauna not considered in this paper were hand-sorted. The soil was examined twice for fauna content and the average time taken for hand-sorting the sample was approximately one man hour. Earthworms from the predominant species (*Pontoscolex corethrurus*) were counted, superficially washed in water on a 0.5 mm mesh and immediately weighed. Dry matter content was determined from a

Plate I.—**Planting sweet potato cuttings in a mound**

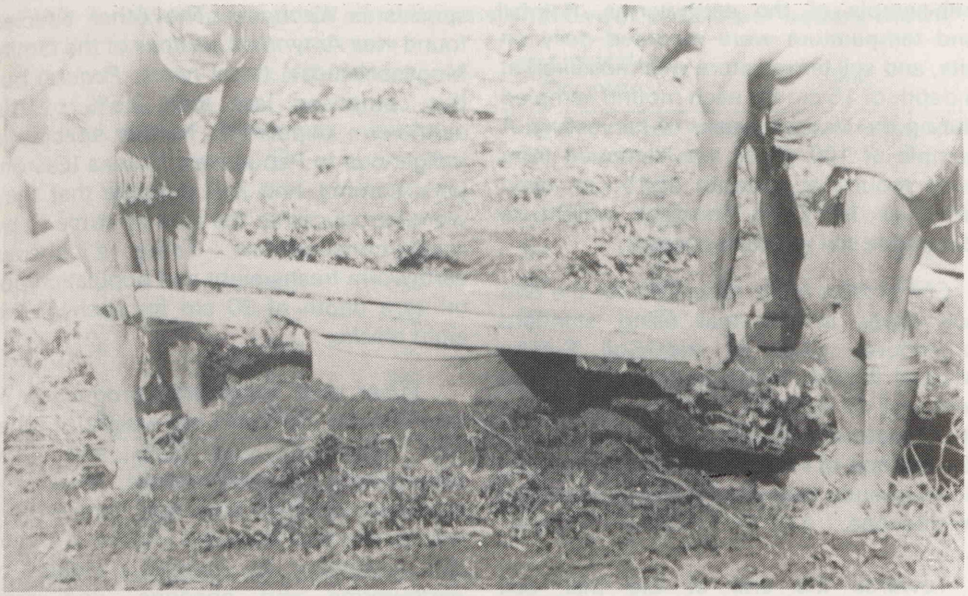


Plate II.—**Soil sampling tool constructed from the upper part of an oil drum**

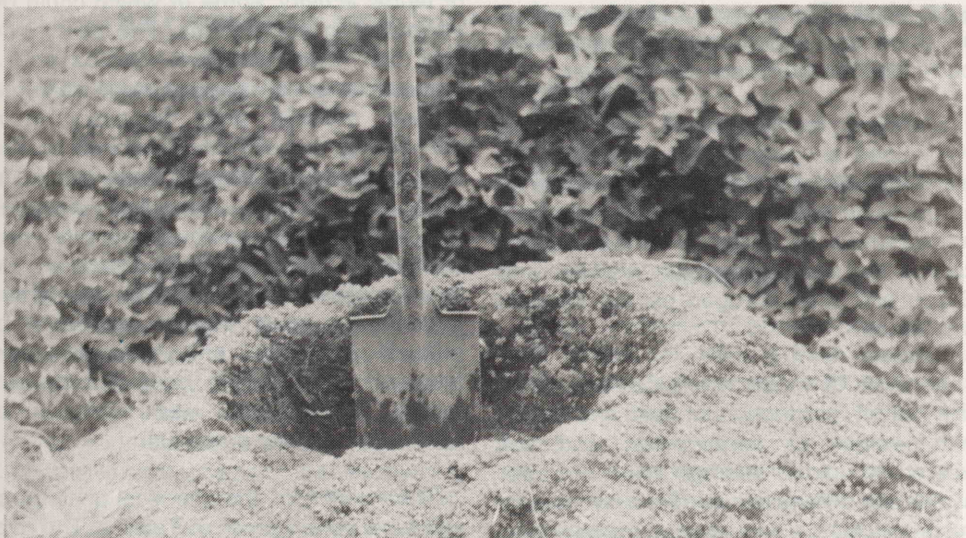


Plate III.—**Depression left in the ground after sampling** sub-sample of the earthworms. Rainfall and temperature were recorded daily on site, and soil temperature was measured at a depth of 15 cm for each mound sampled during the last ten weeks of harvesting. A sample of 100 g soil was removed from each mound at a depth of 15 cm, oven dried at 105°C to constant weight to determine soil moisture content.

Soil profiles were described for the two soil types in the trial using standard procedures given in the Soil Survey Manual (USDA 1951), and samples were removed for analysis. Samples for making thin sections were also taken according to the method of FitzPatrick (1970), and were subsequently examined under a polarizing microscope.

Towards the end of the trial, soil samples were taken from block 5 (peaty clay soil) and block 6 (alluvial soil). Samples were taken at a depth of 15 cm from twenty mounds selected at random in each block. These were bulked together, air dried and riffled, and analyses were performed on duplicate sub-samples.

Standard techniques of soil analysis were used as given in Black (1965). The exchangeable cations were determined by ammonium acetate extraction; available phosphorous by Olsen's method; organic carbon by the method of Walkley and Black; and total nitrogen by the Kjeldahl procedure.

Analysis of variance was carried out on dry matter production of leaf and tuber, wet weight of earthworms, and soil moisture and temperature. Least significant differences between two means were calculated for various probabilities. Appropriate linear regressions and correlations were calculated.

RESULTS

The predominant species of earthworm found was identified as being *Pontoscolex corethrurus*, of the family Glossoscolecidae. The local name for this species is *Kaungoe*. The other species found was *Amynthas corticus* of the family Megascolecidae, (local name, *Pedere*) but this comprised less than 0.5% of the earthworm population. Neither species is indigenous to Papua New Guinea (Easton, pers. comm.), and it is possible that they were introduced to the area by cattle or by road construction. *Table 1* shows earthworm freshweight and population per m² at a depth of 30 cm for each of the eight blocks.

Tuber and topgrowth production is also shown. The oven dry weight of tuber and topgrowth was 32% and 18% respectively of fresh weight. Mean soil moisture content and soil temperature results are also included. *Figure 3* shows the variation in rainfall, yields of earthworms and cocoons, and crop production for the whole area over time.

The soil thin sections showed evidence of faunal activity, some of which could be attributed to earthworms. The peaty clay soil in thin section indicated a predominance of opaque dark coloured organic material with numerous interconnecting, smooth sided channels coated with iron oxides. Some of these contained roots and others re-worked material, probably from earthworms. A few earthworm cocoons were observed. No faecal material was found. The alluvial soil contained a much higher proportion of mineral material, and channels and passages were again coated with iron oxides. There was less evidence of earthworm activity in this soil.

The results of the chemical analysis of soil samples are given in *Table 2*. The peaty clay soil is highly organic with a high cation exchange capacity and low pH. The alluvial soil is less organic and less acid. Levels of calcium, magnesium and potassium are low for both soils whereas available phosphorus is moderate to high.

The majority of earthworms were adults and there appeared to be little variation in

Table 1.— **Average yield of earthworms and sweet potato per square metre***

Block No.		EARTHWORMS Fresh weight (g)	EARTHWORMS Number	SWEET POTATO (Dry matter) Tuber (g)	SWEET POTATO (Dry matter) Leaf (g)	SOIL Soil moisture (%)	SOIL Temperature (ºC)
1		78.7	181	415	331	171.6	21.1
2		77.4	152	551	329	138.1	21.5
3		78.8	180	324	286	164.3	21.6
4		100.5	226	480	394	129.1	21.4
5		127.7	302	585	434	103.3	21.5
6		59.8	130	670	418	84.7	21.4
7		84.0	187	621	497	91.4	21.2
8		46.5	93	776	417	94.8	21.2
LSD	0.05	15.5	—	308	55	8.6	NSD
	0.01	20.3	—	405	73	11.4	—
	0.001	25.9	—	518	93	14.8	—

NSD = No significant difference between means

LSD = Least significant difference

* The yield of earthworms was estimated from a sub-sample extrapolated to the total volume of a mound (which occupied a ground area of 3.65 m²). The total volume of the mound was calculated by considering the mound as a ½ elipsoid with formula $\frac{\frac{4}{3} \times 3.14\, b^2 a)}{2}$ where *b* is the height of the mound from the base to the highest point on the surface, and *a* is the radius of the base.

size between individuals. A linear regression between weight of earthworms and number of earthworms was significant at the 1% level (*Figure 4a*). Oven dry matter of earthworms was constant at 21% of fresh weight. It was found that rainfall registration in the week preceding harvest was a significant factor affecting earthworm yield (*Figure 4b*). When earthworm populations were grouped into four classes on the basis of wet earthworm weight per m² (0-42, 43-87, 88-130, 131-173 g), the first group with less than 43 g was significantly correlated with production of topgrowth (*Figure 4c*). There was no significant correlation for the other groups. Examination of data from block 5 indicated a negative and significant correlation between earthworms and tuber yield (*Figure 4d*). A positive and significant correlation between earthworms and topgrowth production was found in block 6 (*Figure 4e*). Soil moisture was negatively correlated with crop production.

DISCUSSION

Mean earthworm populations ranged from 93 per m² (46.5 g fresh weight) in block 8 to 302 per m² (127.7 g fresh weight) in block 5 (*Table 1*). The highest population was in block 5 on the peaty clay soil, and was significantly lower on the alluvial soil. There appears to be a relationship between earthworm population and soil organic matter content, and this agrees with the findings of El-Duweini and Ghabbour (1965) for Egyptian soils. However, there is no relationship between earthworm populations and soil moisture content in the different blocks. The moisture content is far higher than recorded by El-Duweini and Ghabbour (1965), who also associated

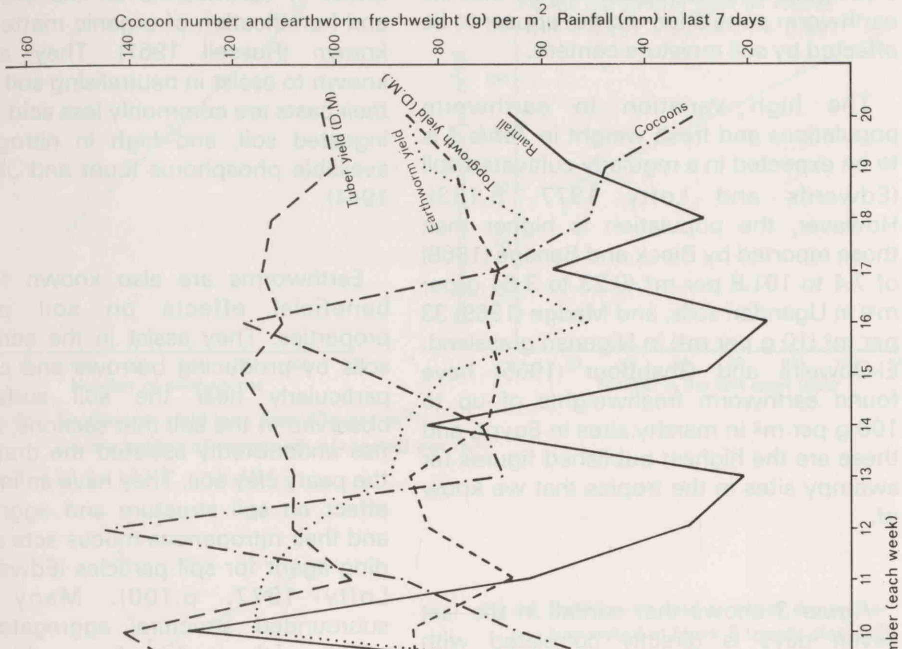
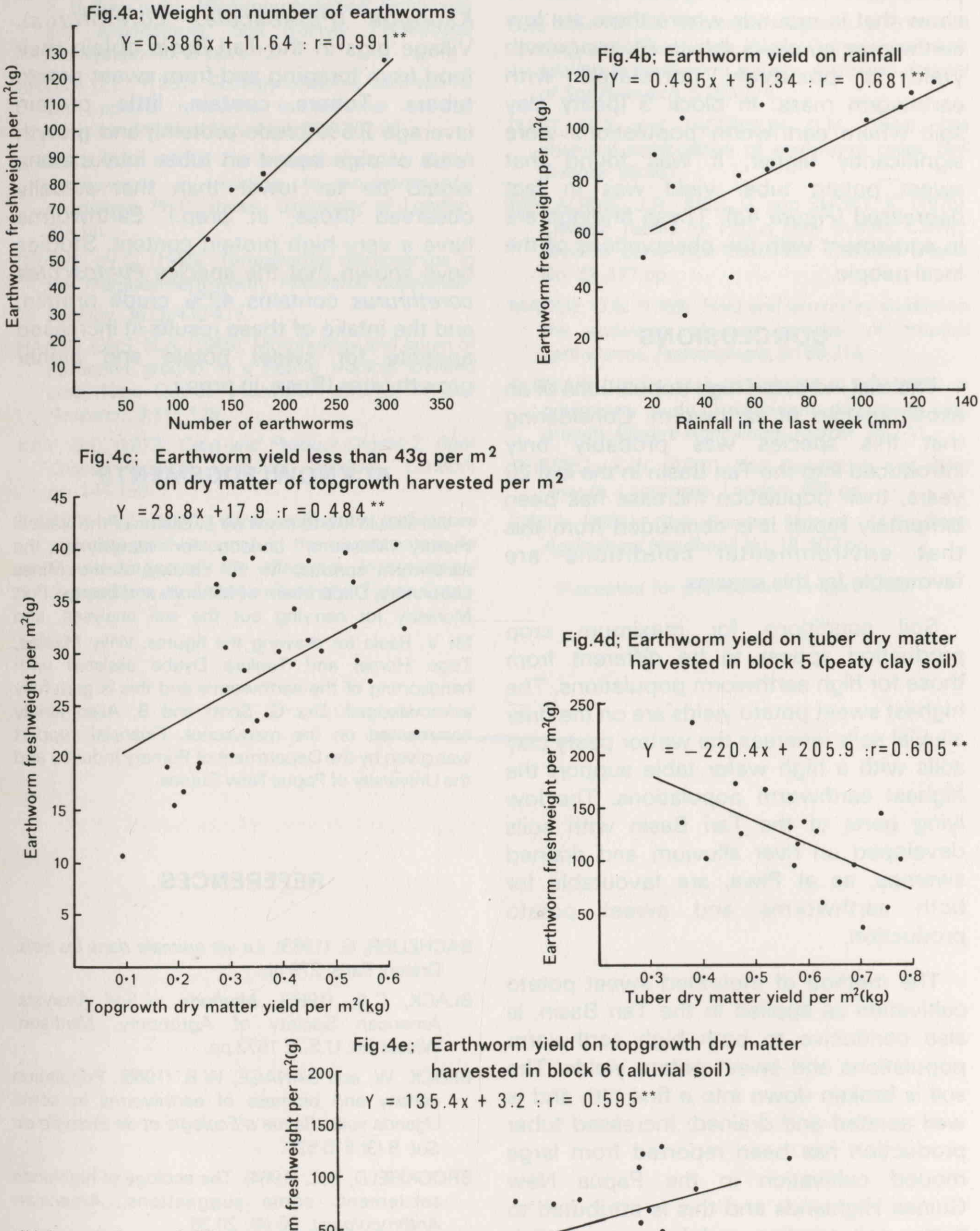


Figure 3. Yields of earthworms, sweet potato dry matter and rainfall during the trial

Table 2.—**Chemical analysis of soil samples**

	AIR DRY MOISTURE (%)	LOSS ON IGNITION (%)	pH	EXCHANGEABLE CATIONS (mEq 100g⁻¹ Soil)				CATION EXCHANGE CAPACITY (mEq 100g⁻¹ Soil)	AVAILABLE P (ppm)	NITROGEN (%)	ORGANIC CARBON (%)
				Ca	Mg	Na	K				
PEATY CLAY SOIL											
Profile topsoil	19.7	42.1	4.0	1.4	0.8	0.4	0.3	49	37	0.99	21 5
Block 5	13.7	24.8	5.2	3.6	0.8	0.1	0.2	34	22	0.70	10.6
ALLUVIAL SOIL											
Profile topsoil	14.5	19.8	5.1	2.4	0.6	0.2	0.1	29	17	0.58	7.5
Block 6	14.0	22.1	5.4	1.9	0.6	0.1	0.2	32	19	0.63	8.5

Figure 4.— **Linear regression relationships**



** Indicates significance at P<0.01

an increase in water content from 15-34% with an increase in numbers and average weight of adult *A. caliginosa*. It is probably because of the high moisture content of these soils and the regular rainfall that the earthworm population did not appear to be affected by soil moisture content.

The high variation in earthworm populations and fresh weight in *Table 1* is to be expected in a regularly cultivated soil (Edwards and Lofty 1977, p.123). However, the population is higher than those reported by Block and Banage (1968) of 7.4 to 101.8 per m² (0.23 to 3.64 g per m²) in Ugandan soils, and Madge (1969) 33 per m² (10 g per m²) in Nigerian grassland. El-Duweini and Ghabbour (1965) have found earthworm freshweights of up to 100 g per m² in marshy sites in Egypt, and these are the highest published figures for swampy sites in the tropics that we know of.

Figure 3 shows that rainfall in the last seven days is directly correlated with earthworm yields in the top 30 cm of the mound. This could be caused by the earthworms rising above a fluctuating water table, and is particularly likely to occur in the peaty clay soils with a high water table. This phenomenon of worms coming to the surface in wet weather is well known and has been described by Gates (1961) for various species in India. Cocoons do not show a similar relationship with rainfall, but were more abundant in the second half of the trial (*Figure 3*). Soil temperatures were steady at around 21°C and this appears to be the optimum temperature for both cocoon development (Gerard 1960) and for earthworm activity (Grant 1955) although these workers were studying other earthworm species. The acidity of the peaty clay soils (pH 5.2) does not appear to have affected earthworm populations, and it is likely that the species *Pontoscolex corethrurus* is adapted to an acid environment. Bachelier (1963) notes that certain tropical species of *Megascolex* are numerous in acid soils of pH 4.5 to 4.7.

The differences in chemical properties for the peaty clay soil between the profile topsoil and that in block 5 (*Table 2*) could be attributable to earthworm activity. The effect of earthworms on the breakdown and humification of organic matter is well known (Russell 1961). They are also known to assist in neutralising soil pH, and their casts are commonly less acid than the ingested soil, and high in nitrogen and available phosphorus (Lunt and Jacobson 1944).

Earthworms are also known for their beneficial effects on soil physical properties. They assist in the aeration of soils by producing burrows and channels particularly near the soil surface, as observed in the soil thin sections, and this has undoubtedly assisted the drainage of the peaty clay soil. They have an important effect on soil structure and aggregation, and their nitrogenous mucus acts as a binding agent for soil particles (Edwards and Lofty 1977, p.100). Many small, subrounded structural aggregates were seen on the soil surface, which were smooth, shiny and light greyish brown in colour. These were probably worm casts. Puttarudriah and Sastry (1961) suggested that *Pontoscolex corethrurus* had an adverse effect on soil structure in India by creating an impermeable pan through which some roots could not penetrate. This is unlikely to occur under mounded cultivation.

Mean sweet potato tuber yields vary considerably from 324 to 776 g of oven dry matter per m², and topgrowth from 286 to 497 g. Soil moisture content was negatively correlated with crop production (tuber $r = -0.89$ ($P < 0.01$), leaf $r = -0.87$ ($P < 0.01$)) (*Table 1*). According to Kay (1973), a sandy loam reasonably high in organic matter would seem to be the optimum soil for sweet potato production and soils very rich in humus normally result in lower yields. This could be the reason for the differences in yields between the peaty clay soil and the alluvial soil.

In general, there is no relationship between earthworm population and crop production. However, *Figures 4c* and *4e* show that in mounds where there are low earthworm numbers (block 6), topgrowth yield is positively correlated with earthworm mass. In block 5 (peaty clay soil) where earthworm populations were significantly higher, it was found that sweet potato tuber yield was in fact depressed (*Figure 4d*). These findings are in agreement with the observations of the local people.

CONCLUSIONS

The trial indicated high populations of an exotic species of earthworm. Considering that this species was probably only introduced into the Tari Basin in the last 20 years, their population increase has been extremely rapid. It is concluded from this that environmental conditions are favourable for this species.

Soil conditions for maximum crop production appear to be different from those for high earthworm populations. The highest sweet potato yields are on the drier alluvial soils whereas the wetter peaty clay soils with a high water table support the highest earthworm populations. The low lying parts of the Tari Basin with soils developed on river alluvium and drained swamps, as at Piwa, are favourable for both earthworms and sweet potato production.

The method of mounded sweet potato cultivation as applied in the Tari Basin, is also conducive to both high earthworm populations and sweet potato yields. The soil is broken down into a fine tilth and is well aerated and drained. Increased tuber production has been reported from large mound cultivation in the Papua New Guinea Highlands and this is attributed to better soil aeration and less compaction (Kimber 1970). In drier soils with less organic matter, increased aeration and improved drainage by mounding may well depress earthworm activity, although this cannot be proved in this study.

The Huli people attribute increased pig populations and growth rates specifically to the introduction and multiplication of *Kaungoe* (*Pontoscolex corethrurus*). Village pigs in the Tari Basin obtain their food from foraging and from sweet potato tubers. Tubers contain little protein (average 2.5% crude protein), and growth rates of pigs based on tuber intake alone would be far lower than that actually observed (Rose, in prep.). Earthworms have a very high protein content. Studies have shown that the species *Pontoscolex corethrurus* contains 42% crude protein, and the intake of these results in increased appetite for sweet potato and higher growth rates (Rose, in prep.).

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