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THE EFFECTS OF EARTHWORMS AND THE NEW ZEALAND FLATWORM, *Artioposthia triangulata*, ON SOIL STRUCTURE AND HYDROLOGY - A REVIEW.

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CONTENTS:

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ABSTRACT

Earthworms are described generally and their effects on soil structure and hydrology reviewed. The effect on soil strucrure is through burrowing, which increases soil porosity and hydraulic conductivity, and cast production, which contributes to pedogenesis and profile development as well as increasing soil organic matter levels and the number of water stable aggregates. The chemical content of the soil is altered by localised increases in nitrogen and carbon levels and heavy metals may be re-distributed within the soil and food chain. Soil hydrology is influenced by the number, the size, and the distribution of earthworm burrows and other macropores. These, in turn, are affected by agricultural practices and extreme soil conditions (eg. waterlogging).

The New Zealand flatworm, *Artioposthia triangulata*, is a recent introduction to the British Isles and has been found to be a voracious predator of indigenous earthworm species. Its distribution and spread, and its effects upon indigenous earthworm populations are reviewed in this paper.

1. INTRODUCTION

There are approximately 3000 species of Earthworm, found in all but the driest and coldest areas of the world. The majority are soil dwellers and their interaction with this environment is perhaps one of the most notable and important in the animal kingdom. They are extremely important to the maintenance of soil structure, which in turn is important in agriculture, horticulture and for natural processes such as drainage. For years people have noted the beneficial effects of Earthworms and they have been actively encouraged into farmland and gardens as well as being extensively used for compost production and breakdown of waste products.

They have many natural predators, most notably birds, yet their populations have never been seriously threatened, even though numbers have fallen due to modern agricultural practices. However, a new imported predator called the New Zealand Flatworm, *Artioposthia triangulata* (Dendy, 1894) is now posing a threat to the indigenous earthworm population of the British Isles.

2. EARTHWORMS

2.1. Description

The 'basic design' of earthworms changes little from species to species. Cylindrical in shape, they consist of two concentric tubes: the body wall and the gut. These are separated by a fluid-filled cavity called the coleum (Lee,K.E. 1985).

Earthworms spend the majority of their life span underground and are injured or even killed by exposure to light, especially ultra-violet wavelengths, however, they do come up to the soil surface to feed at night. Their principle food sources are decaying plant and animal matter, both from the soil surface and below, and micro-organisms in the soil. Due to their lack of mobility they tend to remain in localised areas close to a source of food (Lee, K.E 1985). Earthworms can be split into two categories based on their feeding habits: *detritivores* which feed on the biological debris present on or near the soil surface and *geophages* which feed below the surface, ingesting large quantities of soil, usually of high organic matter content.The first group are the humus formers and the latter the humus feeders. These categories were first defined by Perel (1977). Surface feeders tend to take the plant and animal litter below the surface before ingesting it, presumably to avoid predation. They therefore contribute to the distribution of organic matter through the soil profile (Zachmann & Linden, 1989). Sub-surface feeders feed on dead roots and soil micro-organisms. Both therefore increase the organic matter content of the soil (Lee, 1985).

There are three general types of worm burrows:

1. 'More or less permanent refuges in underlying soil horizons of species that feed on soil litter. These are usually vertical for most of their length, sometimes branching near the top to several entrances.'

2. 'More extensive burrows of geophagous species that forage for food in subsurface horizons. These are predominantly horizontal, but have some vertical components and some openings to the soil surface. They may extend deep into the soil.'

3. 'More or less vertical burrows made by earthworms that live near the surface as they retreat to enter a resting state in deep soil horizons during dry or cold seasons, or return to surface horizons when conditions permit them to resume an active life.'

(Lee, 1985).

Seasonality in earthworm activity was noted by Kretschmar, (1991), who reported a complete lethargy and lack of activity during the summer months. This may be temperature related or be due to the fact that earthworm activity is limited when soil water potential falls below a particular limit. The latter is a consequence of the hydraulic pressure exerted by the coleomic fluid which governs the efficiency of the earthworms hydraulic skeleton.

2.2. Effect on soil structure and chemistry.

Physical effects on soil structure by earthworms is through excavation of burrows and production of casts. Cast production below the surface contributes to pedogenesis whilst surface casts contribute more to profile development. Casts consist of mixed organic/inorganic materials ingested from the soil by the earthworm and broken down in the gut. They are generally made up of the smaller particles of the soil from which they originate (Lee, 1985; Shiplato & Protz, 1988). Casts are soil aggregates and therefore the total amount of soil matrix that they make up, their stability, and the fragments into which they break down are all important in terms of soil structure (Lee, 1985). Both surface and sub-surface casting increase the amount of water stable aggregates which, in turn, may decrease liability to erosion. In field and laboratory experiments a higher proportion of earthworms led to an increase in the size of the water stable aggregates (Brussard ea al., 1990).

Burrows influence soil porosity and hydraulic conductivity (Lee, 1985; Shiplato & Protz, 1988). There may be an increase in soil-air volume of approximately 8 - 30 % due to earthworm burrowing activity. It was also found that the hydraulic conductivity (K) of a saturated soil decreased by 80% when vertical earthworm burrows in soil cores were artificially blocked at each end (Lee, 1985). Burrowing activity is affected by several factors. Apart from the seasonality in general earthworm activity noted by Kretzschmar (1991) burrowing is also affected by soil compaction, soil bulk density and soil saturation (McCredie & Parker, 1992). In experiments measuring burrowing activity using a measure of casting activity, it was found that activity increased up to a compaction pressure of 250 Kpa from which point soil stength and bulk density were the limiting factor. The burrowing activity slowed earlier in a completely saturated compacted soil as a consequence of the hydraulic pressures involved (Kretzschmar, 1991). In soils such as heavy clays Earthworm channels and other macropores make good access paths for plant roots (Tisdall, 1985; Lodgson & Linden, 1992).

Earthworms also affect the chemical content of soils. Breakdown of surface plant and animal litter and deposition below the surface increases the humus content of the soil. The organic matter content of soil containing no earthworms is greatly reduced as the plant and animal surface litter is not incorporated (Clements et al., 1991).This is also important in terms of the nitrogen and carbon cycle. The carbon content of casts is about 1.5-2.0 times greater than the soil, whilst the nitrogen content is about 1.5-1.7 times greater. This is because earthworms have an inability to digest most of the plant material they ingest. The increased C:N ratio also reflects their efficiency as protein producers (Lee, 1985). The thin layer of soil surrounding an earthworm burrow is affected by mucus and nitrogenous waste as well as the increased access of air. The mucus may have strong bonding properties, whilst the high nitrogen and carbon content of the waste means a localised increase in nitrogen and carbon value (Lee, 1985; Shiplato & Protz, 1988). However the nitogen is not in a form which can be immediately utilised by plants. Digestion of micro-organisms that fix atmospheric nitrogen also means a conversion of nitrogen in one form to produce nitrogen in a different form in the soil (Lee, 1985).

The accumulation and distribution of heavy metals and radioactive elements, both in the soil and the more general ecosystem is also affected. Heavy metal pollutants may build up in large quantities in the soil where they are ingested by earthworms and then build up in the worms tissues. They are then passed along the food chain when the earthworms affected are preyed upon (Lee, 1985).

2.3. Hydrology associated with Earthworms

Agricultural practice has major effects on Earthworm channels and thus the influence they have on soil properties (Zachmann et al., 1987; McCredie & Parker, 1992; Edwards, 1991). In conventional agricultural practice the earthworm channels are constantly destroyed by ploughing and other cultivation techniques (Bicki & Guo, 1989). Within four years of no-tillage practice the number and percentage of earthworm channels nearly doubled in the Ap horizon (20cm soil depth), (Ehlers, 1975). Ehlers, (1975) also found that Ap horizon burrows in the tilled plot were unable to take in irrigation water whereas in the no-till plot, earthworm burrows reaching the surface transported water deep into the profile. This was because any earthworm burrows in the tilled plot were short, horizontally directed channels which were blocked with loose soil aggregate. These blockages create a barrier to the free movement of water and therefore allow it to move into the matrix of the upper soil layer. Zachmann et al., (1987), found that infiltration in the top 5 cm of the soil was greater in a tilled plot. However, more water by-passed the soil matrix at 19 cm in a no-till plot because earthworm burrows had not been disturbed and were more continuous.

The water moving down the burrows in the no-till plot was in a tension free state (the water was dyed blue and this colour was not shown in the soil matrix around the burrows). It was therefore concluded that the burrows must reach the surface and the water be in a tension free state for Earthworm burrows to have an effect on soil hydrology (Ehlers, 1975). However Quisenburry & Phillips, (1978) found that flow occurred in macropores which are not open to the surface, though to a lesser extent. This is because water building up below the tilled layer (smearing of the macropore entrances at the surface of the untilled layer reduces hydraulic conductivity) will eventually reach a potential of close to zero. Some of this water then enters the relatively few remaining macropores and the film becomes thicker as more water moves into the pores. Movement of water at zero tension down the pores is governed by gravitational potential (Thomas & Phillips, 1979).

It was found that only a small fraction of total earthworm burrows dominate deep displacement of water and solutes in the soil. This is due to the small percentage actually reaching the soil surface (Ehlers, 1975; Zachmann et al., 1987). Beven and Germann, (1990) concluded that the most important macropores in terms of soil hydrology were between 1mm and 1cm in diameter (i.e. the range including worm and root channels). Smaller pores were prone to large capillary forces whilst in larger ones the maximum flow rates exceeded normal rainfall amounts. They also concluded that although macropores contributed to only a small proportion of total porosity and for only short periods at a time (i.e. immediately after saturation of the matrix following rainfall), they were of great importance in terms of the volume of water and solutes moved. The importance of large pores on water movement and infiltration was shown by Dixon and Peterson, (1971). Steenhuis et al., (1988) demonstrated the importance of macropore flow on the hydrology of shallow hard-pan soils where the macropores allow transport through the otherwise impermeable clay layer.

Urbanek & Dolezal found that in a drained clay soil the maximum depth of any earthworm burrow was 1.15m, with the majority having their end points at 0.4 - 1.1m (in the impermeable sub soil). These vertical channels ended in spherical voids, some of which contained living worms (The permanent channels used as 'living quaters' as described by Lee, 1985). These, it was concluded, did not contribute substantially to soil water movement as they ended in an impermeable layer with no continuous hydraulic connection. However if such channels connected with a field drain, macropore flow occurred and with greater ease than normal movement through the soil matrix (Haria et al, 1994). The flow was reduced by any form of clogging (Urbanek and Dolezal).

The topographical aspect of earthworm burrows was discussed by Trojan & Linden (1992). They found that burrow openings in depressions transported more water than those opening on ridges or those surrounded by worm casts.

3. NEW ZEALAND FLATWORM

3.1. Description

Artioposthia triangulata was first described by Dendy in 1894:

" Body, when at rest, broad and very much flattened, but at the same time long and strap-shaped; often with a more or less pronounced median dorsal ridge; flattened or even concave below; with thin translucent margins. When crawling, very active, and capable of great elongation, becoming correspondingly narrowed at the same time; tapering gradually in front and behind, but broader towards the posterior extremity; more or less triangular in cross-section. Eyes as usual in this genus; numerous, but very small, and rarely in more than single series; continued round the horse-shoe-shaped anterior tip.

The dorsal surface has a dark purplish-brown colour for the median two-thirds, or thereabouts, of its breadth. This colour shades off rather abruptly into a translucent marginal band of pale-yellowish colour, peppered with numerous minute specks of dark grey. In this posterior portion of the body there may be a very narrow mid-dorsal stripe of darker colour. The anterior tip is pale pinkish-yellow. The ventral surface is pale-yellowish, thickly peppered with minute grey specks."

The New Zealand flatworm is an hermaphrodite and is therefore capable of asexual reproduction. Although its normal means of reproduction is by copulation followed by cross-fertilization (Froelich, 1955) its hermaphrodite nature means that new colonies may grow from a single specimen (Blackshaw and Stewart, 1992). Egg capsules are 4.5 - 8.5 mm long and 3 - 6 mm wide (Willis and Edwards, 1977). Between 2 and 10 young (average 6) may emerge from a single capsule (Blackshaw and Stewart, 1992). They are found on the soil surface in association with the resting places of inactive adults between March and October. Young adults are light pink in colour and 25 - 40mm long (Willis and Edwards, 1977).

Adults are nocturnal, resting in damp protected places by day (e.g. under stones, boxes or sacks). They do not burrow themselves although they can be found in the soil between 25 - 30cm in small but deeply defined chambers. (Willis and Edwards 1977). They are thought to get down to this depth using already existing cracks and channels and have been found to be able to escape from a knotted plastic bag by elongation, and hence narrowing, of the body (Blackshaw and Stewart, 1992). They feed at night, seemingly only locating earthworms by trial and error. It has been found in laboratory experiments that specimens can go without food for up to a year (Blackshaw and Stewart, 1992), re-absorption of redundant body tissues such as the reproductive organs making this possible once fat reserves have been used up (Reynoldson, 1983). However mortality during this period may be temperature dependent. The flatworm does seem to be temperature sensitive and temperatures above 20°c may be fatal (Blackshaw and Stewart, 1992). This would seem to be the main limiting factor on their spread and distribution.

The flatworm moves by extension of its body and secretes large quantities of mucus which aid this movement. The mucus may also make the worm unpalatable to predators and indeed *A. triangulata* has no natural predators in the British Isles (Blackshaw and Stewart, 1992). The mucus also has a high concentration of neuropeptide (Curry et al., 1991) which may kill or paralyse earthworms on contact. Certainly partially eaten earthworms always die, whilst a brief non-feeding contact may also cause death.

3.2. Location/Spread

Although originating from New Zealand, there are few published records of *A. triangulata* in that country. It is confined to the South Island, principally the forests and sheltered areas of Canterbury Plain.

The first sighting of the worm in the British Isles was in 1963 when two separate specimens were found in Belfast. 30 more records from all the province counties except Fermanagh, had been gathered by 1977 (Willis and Edwards, 1977). Since then, and with increased public awareness, regular sightings have been recorded and the New Zealand Flatworm is believed to be wide spread within Northern Ireland.

The first sighting in Scotland was at The Royal Botanic Gardens, Edinburgh in 1965. Figures released by Biological Recording in Scotland (BRISC) recently, show that from 81 records in July 1991 the number has jumped to 437. (The latest figure breaks down as follows: 386 in domestic back gardens; 22 in nurseries/garden centres; 15 in National Trust gardens; 7 in botanic gardens; 7 on farms).

Although *A.triangulata* is most prevalent in Scotland and Northern Ireland there have been some sightings in The Republic of Ireland (Blackshaw and Stewart, 1992) and increasing numbers found in England (the first sighting was in 1965 in Cumbria). This suggests that the New Zealand Flatworm is slowly progressing further south and populating new areas. It has been found in a range of different land types especially agricultural land and horticultural holdings such as garden centres and nurseries where it lives in the root ball of potted plants. It is believed to be transported to new areas in this way (Blackshaw and Stewart, 1992).

It is thought to have arrived in the British Isles from New Zealand in either stored Daffodil bulbs or Rose bushes. Indeed the first sighting in the Isle of Man was by a specialist rose grower who associated it with imported plants from New Zealand. There are imports of both roses and Daffodil bulbs from the Canterbury area of New Zealand to Northern Ireland and Scotland (Blackshaw and Stewart, 1992).

3.3. Hydrology associated with Flatworms

New Zealand flatworms have very little effect on the structure and hydrology of soils. They mainly live on the surface and only go below ground to feed. By following prey down macropores they may block certain bypass routes and re-cycling of earthworms may increase organic matter content, but the effect on hydrology and structure will be so small as to be negligable.

4. EFFECTS OF FLATWORMS ON EARTHWORMS

4.1. Effect of flatworms on earthworms

Once located the Flatworm adheres to its prey with its anterior end and coils around it until its mouth is also in position. Digestive enzymes are then secreted which dissolve the earthworm tissues which are taken up through the pharynx (Willis & Edwards, 1977).

In an experiment studying fertiliser affects on earthworm populations in a particular site, Blackshaw (1989), observed that the population declined to a point where no individuals could be retrieved using formalin sampling techniques. Previous data showed that earthworm numbers were not greatly affected by the fertiliser used and since *A. triangulata* was found to be present on the site the decline was attributed to the alien worms (Blackshaw, 1989).

Further experimentation found that surface-feeding earthworm species were the first to be decimated because this is the preferred preying area of the flatworms (Blackshaw, 1989 & 1990). The rate of decimation was then quantified. It was calculated that a flatworm population of $6.5/m^2$ would consume a 'typical' grassland earthworm population of $475/m^2$ in one year. This figure is likely to be lower in the field as the experiment was laboratory based and thus not subject to other factors that may come into play under field conditions (Blackshaw, 1991).

In a field study a relationship between the population densities of earthworms and their flatworm predators was found to exist, suggesting that flatworm populations are supported by the earthworm populations on which they prey (Blackshaw, 1990). In another study it was found that the number of earthworms attacked was related to the size of the flatworms and a predator size to prey number attacked ratio was calculated (Blackshaw, 1991).

4.2. Effect of lack of earthworms on soil structure

In a study assessing the impact of 20 years absence of earthworms on a grassland soil, it was found that bulk density was dramatically increased as was shear strength, penetrability and depth of leaf litter. There was a reduction in soil organic matter content, initial infiltration rate, pH and soil moisture content (Clements et al., 1991). Some of these changes occurred very rapidly whilst others were more long-term: bulk density changes did not become measurable for ten years (Clements et al., 1991).

5. CONCLUSIONS

The role of earthworms in soil production and structure is therefore evident and also their importance in terms of soil hydrology. The full effects of flatworms on earthworm populations and thus the knock on effect for soil structure has yet to be quantified on a large scale or in a range of conditions. However from the work that has been done in the various areas associated with this topic, it would seem that *A. triangulata* may seriously affect earthworm populations and therefore be detrimental to both soil structure and hydrology over a large area.

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