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Impact of the New Zealand flatworm (*Artioposthia triangulata*) on soil structure and hydrology in the UK

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Abstract

Through north west Europe, concern has been growing in recent years about the predatory nature of *Artioposthia triangulata* on indigenous earthworm species. In this study, the consequence of earthworm depletion by *A. triangulata* on soil structure and related hydrological processes is examined. Field measurements compare differences in saturated hydraulic conductivity between sites overrun by *A. triangulata* and neighbouring unaffected sites. Laboratory experiments were conducted on soil cores containing worms only, worms and *A. triangulata*, and a control with no worms or *A. triangulata*. Differences in the water release characteristic and bulk density between treatments was studied. It is concluded that in the short term, infestation by flatworms and consequent depletion of earthworms will increase infiltration. However, as macropores degenerate or are removed over time, an increased risk of surface run off may result in increased pollution and flood hazards, whilst reduced drainage and subsequent waterlogging may reduce agricultural productivity in certain soils. More research into understanding the processes is required. © 1998 Elsevier Science B.V.

Keywords: *Artioposthia triangulata*; Soil structure; Field and laboratory studies; Hydraulic conductivity; Runoff and pollution risk

1. Introduction

Artioposthia triangulata (Dendy, 1894), a recent accidental introduction to the British Isles, has proved to be a voracious predator of indigenous earthworm species (Blackshaw, 1990, 1991; Blackshaw and Stewart, 1992). Having no natural predators in the British Isles, *A. triangulata* has spread rapidly since its first sighting in Belfast in 1963 (Willis and Edwards, 1977). In recent years increasing numbers have been found in England suggesting that *A. triangulata* is populating new areas.

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The beneficial effects of earthworm activity on soil structure and hydrology have long been realised. Cast production and the excavation of burrows contribute to pedogenesis and profile development (Lee, 1985). Surface and sub-surface casting can increase the amount of water stable aggregates which, in turn, may decrease liability to soil erosion (Brussard et al., 1990). Lee (1985), and McCredie and Parker (1992) showed the porosity of soils to be increased by earthworm burrows; and Tisdall (1985) established a direct relationship between numbers of biopores and total numbers of earthworms. The importance of earthworm macropore channels on increasing infiltration rates and water flows in soils has been well demonstrated (Beven and Germann, 1982; Ehlers, 1975; Haria et al., 1994; Steenhuis et al., 1988; Van Stiphout et al., 1987). Clements et al. (1991) commented on the change in soil structure and decrease in infiltration rates in a study on the impact of twenty years absence of earthworms from a grassland site. By reducing infiltration rates and water flows in soils, risk of surface run-off is increased and the potential for increased soil erosion, agrochemical pollution, and flooding may have far reaching consequences.

In view of the threat to indigenous earthworm populations, this study assesses the indirect effects of *A. triangulata* on soil structure and related hydrological processes which may occur as a consequence of earthworm depletion.

2. Materials and methods

2.1. Laboratory study

This hydrological study complemented a three year zoological study into the activity of *A. triangulata*, initiated in November 1990, by the Department of Agriculture for Northern Ireland (DANI), in Belfast. Twenty-four black polythene bins (0.11 m^3 capacity) with 4×0.025 m diameter drain holes covered with nylon mesh and a 0.025 m layer of coarse gravel to assist drainage were filled with a mixture of peatless soil, sand and sterilized horse manure (7:2:1 ratio). A perennial ryegrass (var. "Talbot") was sown at a rate of 25 kg/hectare. On 19th November 1990 the bins were placed outdoors on a course gravel bed in six randomised blocks of four treatments, and left to settle for about 9 months. The additions of earthworms and *A. triangulata* to the treatments is described in Table 1. For the purposes of the hydrological study only Treatment 1 (control — no earthworms or *A. triangulata*), Treatment 2 (earthworms only) and Treatment 4 (earthworms and *A. triangulata*) were used.

Undisturbed soil cores (225 cm^3 volume) were taken on 6th June 1994 using a soil corer of Soil Survey and Land Research Centre (SSLRC) design. The top 0.1 m of the soil was discarded to avoid sampling the zone in which biopores created by roots play a major part. Three replicate

Table 1
Treatment description

	Treatment 1 (Control)	Treatment 2 (Earthworms only)	Treatment 3	Treatment 4 (Earthworms and flatworms)
Earthworms				
Aporrectodea juveniles	0	10	10	10
Aporrectodea caliginosa	0	10	10	10
Allolobophera chlorotica	0	10	10	10
Lumbricus terrestris	0	10	10	10
Lumbricus rubellus	0	5	5	5
Flatworms				
Artioposthia triangulata	0	0	2	2 added every 4 weeks

Earthworms were added on 16th August 1991.
Flatworms (*A. triangulata*) were added on 7th February 1992.

cores were taken below the root zone at the same depth from each of the bins for the three treatments studied. To limit changes in soil moisture, hence possible soil structural changes, and so that any earthworms trapped in the cores remained inactive during storage, the cores were sealed with close fitting plastic lids in individual plastic bags and kept at 4°C.

Water release characteristic curves of the cores were determined using the Haines tension method (Haines, 1930; Rowell, 1994). Volumetric water content changes were monitored as increasing stepwise suctions were applied to each soil core across a porous sintered glass plate. At the end of the experiment the bulk density of each core was calculated as oven dry weight/volume (Avery and Bascomb, 1974).

2.2. Field study

Situated on the Ards peninsula in County Down the field site (54°23′ N 5°33′ W; NI grid ref: J623513) was monitored regularly to map the spread of *A. triangulata*. The site was sloping agricultural land under temporary pasture on which *A. triangulata* populations had been present in one half of a field for at least the previous 2 years. A disc permeameter was used to measure, in situ, the saturated hydraulic properties of the field site with minimal soil disturbance. Ponded hydraulic conductivity measurements were taken on 9th June 1994 as described by Perroux and White (1988). Three replicate readings were taken on the area populated by *A. triangulata* that had few earthworms and also on a neighbouring part of the same field that had a healthy population of earthworms. Readings were taken on the same soil type along a line of equal topography on the assumption that hydrological variation would be governed by *A. triangulata* activity.

3. Results

3.1. Laboratory study

To compare and quantify the differences between the three treatments, all water release characteristic data were plotted as natural log (ln) water content against natural log (ln) suction (Fig. 1); the three treatments were compared using linear regression (Table 2). A difference in gradient and intercept of the regressions between Treatment 2 and the other treatments is apparent, and analysis of variance show these differences to be significant. The coefficient of determination (r^2) for Treatment 2 is lower than for the others and is perhaps because earthworm activity caused greater heterogeneity.

From the regression data, the mean water release characteristic curves for each of the three treatments were plotted (Fig. 2). The cores of Treatments 1 and 4 released more of their water at low suctions (0–25 cm H_2O), than those of Treatment 2. At any given suction from 50 to 150 cm H_2O, approximately 10% more water was held in the cores from Treatment 2 than the other treatments. For Treatment 2, this indicates fewer pores of a size corresponding to the range

Table 2
Regression data from Fig. 1 for the three treatments

		Treatment 1 (Control)	Treatment 2 (Earthworms only)	Treatment 4 (Earthworms and flatworms)
Regression		$y = -0.085x - 0.97$	$y = -0.040x - 0.89$	$y = -0.081x - 0.95$
r^2 values		0.85	0.56	0.82
S.E.	Intercept	0.0106	0.0112	0.0120
	Gradient	0.0036	0.0034	0.0037

Where y = ln water content (v/v) and x = ln suction (cm H_2O).

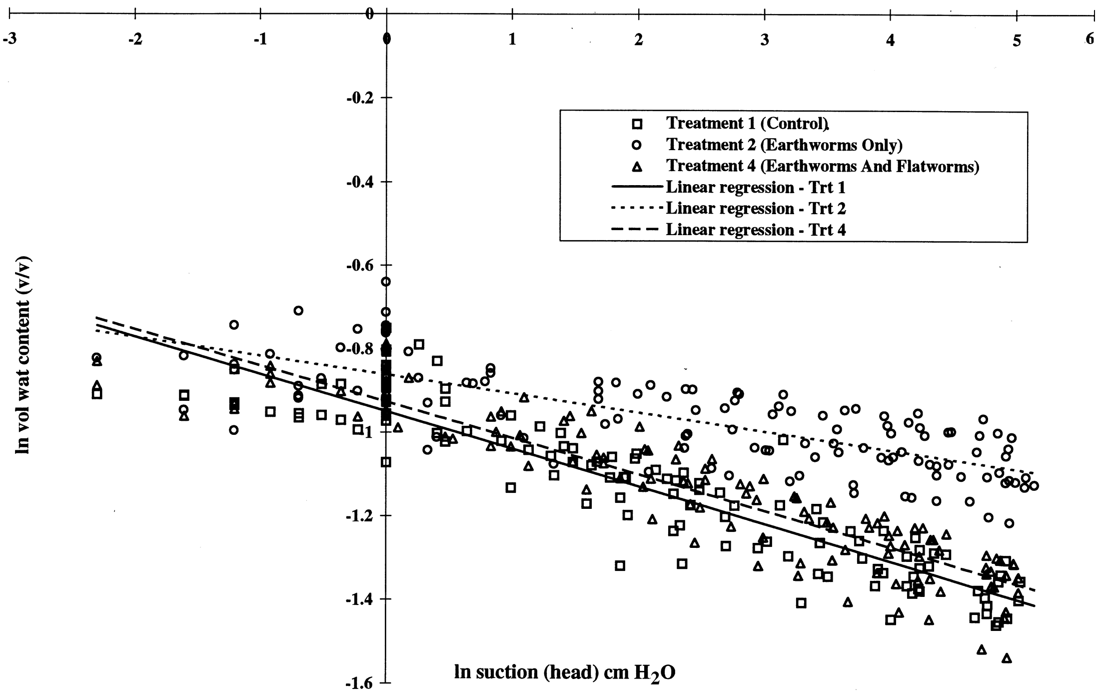

Fig. 1. Water content against suction for the three treatments.

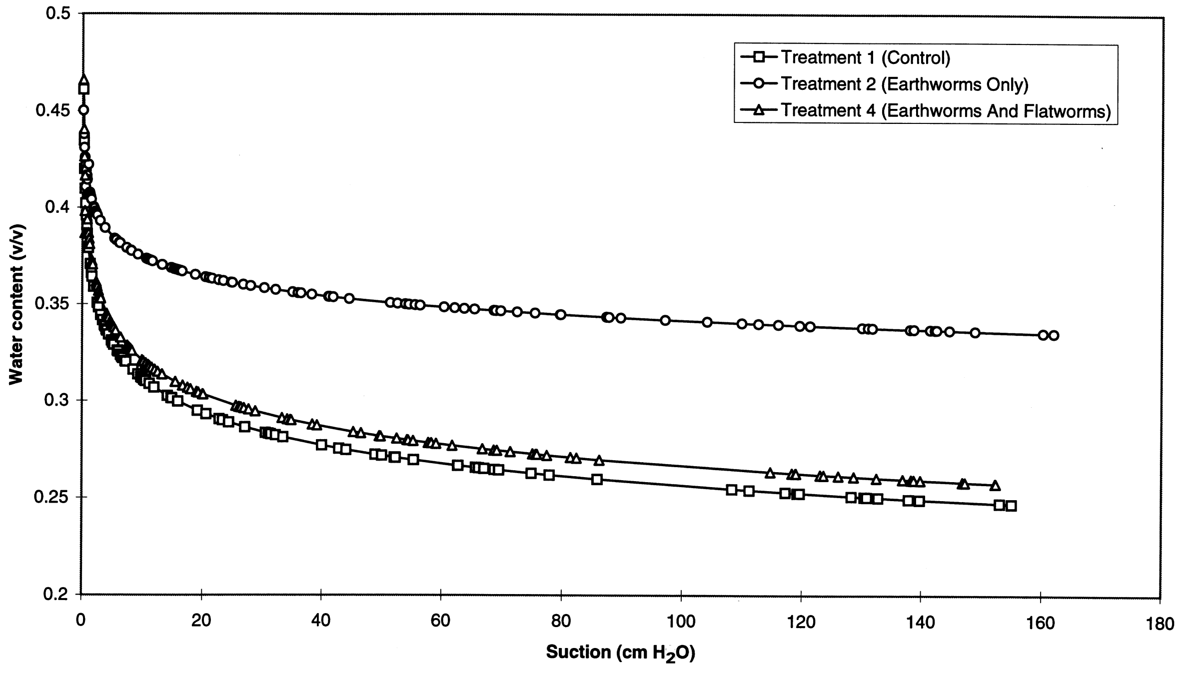

Fig. 2. Mean water release curves from regression data for the three treatments.

Table 3
Differences in bulk density (g cm^{-3}) for the three treatments

	Treatment 1 (Control)	Treatment 2 (Earthworms only)	Treatment 4 (Earthworms and flatworms)
Mean	1.072	1.325	0.999
No. of observations	6	12	12
S.D.	0.129	0.076	0.059

of suction applied.

Differences in bulk density between the three treatments are shown in Table 3. The mean bulk density of cores from Treatment 2 significantly exceeded that of the other treatments. Observations on the settling of soil within the bins showed Treatment 2 to have settled most by the end of the study. Settling in Treatment 4 and Treatment 1 was minimal, and considerably less than for Treatment 2. As the experiment was originally undertaken as a zoological study, initial measurements of bulk density were not made.

3.2. Field study

Field hydraulic conductivity data for the two sites is shown in Table 4. Significant differences were recorded, the site with *A. triangulata* present showing the highest rates of saturated conductivity.

4. Discussion

4.1. Laboratory data

Treatment 1 was a control to determine the effect of external factors on measured parameters within the experiment. The pore space in Treatment 1 was assumed to be determined by the packing of mineral particles. Hence, the differences in the water release characteristic between Treatments 1 and 2 can be put down to earthworm activity altering the original pore size distribution. Earthworm activity in Treatment 2 reduced the porosity within the range of suctions applied. This was probably a result of aggregate formation and a redistribution of finely divided particulate material by earthworms to within the larger pore spaces (Lee, 1985). In practical terms the reduction of large pore spaces by earthworms is likely to increase the water holding capacity of the soil which would be beneficial for crop growth. However, macropores beyond a certain size (about 1 mm diameter) could not effectively be studied as they would remain unsaturated at the start of the experiment using the method described. These macropores would be important for conducting water in saturated conditions and may increase infiltration rates within the soil profile during rain storms.

Table 4
Saturated hydraulic conductivity data for the field study

Saturated hydraulic conductivity (m/day)	Rep 1	Rep 2	Rep 3	Mean	S.D.
A. triangulata present	0.76	0.59	0.83	0.73	0.101
No *A. triangulata*	0.19	0.18	0.28	0.22	0.044

Treatment 4 was shown to have a very similar water release characteristic and hence pore size distribution as Treatment 1. Earthworm counts at the end of the experiment showed virtually total elimination of earthworm species after *A. triangulata* were introduced in Treatment 4. Any development in soil structure by earthworms before *A. triangulata* were introduced would then have the following two and a half years to the end of the experiment in which to break down, resulting in a structure that was not too dissimilar from Treatment 1.

Differences in bulk density between Treatments 2 and 4 are significant ($P < 0.001$). The bulk density for Treatment 2 appears to have been increased over the experimental period and can be explained by the redistribution of finely divided particulate material by earthworms to within the larger pore spaces (Lee, 1985). This hypothesis is corroborated by observations of soil settling within the bins for the different treatments, however, as initial values of bulk density were not measured, it is difficult to interpret these data conclusively.

4.2. Field data

Only a few visible macropores contribute to water flow in soils (Ela et al., 1992), perhaps because of the small percentage reaching the soil surface (Ehlers, 1975; Zachmann et al., 1987). An alternative explanation suggested by the field data from this study is that the earthworms in the burrows seal the macropores to prevent water entry and drowning; only empty burrows would conduct water. Presumably, *A. triangulata* by devouring earthworms would open up more potential pathways and so increase the saturated hydraulic conductivity of the site. The longer term consequences of *A. triangulata* infestation have yet to be investigated although this initial increase in saturated hydraulic conductivity may well be reduced drastically as the existing macropores collapse with time and are not replaced. More significantly, cultivation of fields after *A. triangulata* infestation would truncate macropores as the topsoil is turned over. In this case, the consequences would be almost immediate.

A reduction in earthworm activity may reduce saturated hydraulic conductivity and infiltration rates, inducing more extreme hydrological runoff. Catchment models have already demonstrated the sensitivity of rainfall–runoff relationships on these soil hydraulic parameters (Calver, 1988; Loague, 1992; Wright and Webster, 1991). Increased runoff may result in increased soil erosion, agrochemical pollution and flood hazards as more water passes directly overland to rivers and streams. In heavier soils where major hydrological pathways are along macropores created by earthworms, reduced drainage may mean severe waterlogging resulting in a reduction in agricultural productivity. The severity of these hydrological changes on land use and existing agricultural practices when extrapolated to catchment scale may be extreme.

The most important point of this study is to demonstrate how earthworm predation by *A. triangulata* can impact upon soil hydrological processes. The exact scale of the impact and its consequences need further research as there is a lack of basic scientific data on which to found proper environmental impact models. Hence future research needs to carried out to establish the long term impact of *A. triangulata* on in field soil water processes.

5. Conclusions

A. triangulata is a terrestrial planarian that feeds on earthworms (Blackshaw, 1991). Laboratory studies demonstrated changes in soil structure and hydrological properties, comparable to a soil lacking earthworms, resulting from an addition of *A. triangulata* to a significant worm population. Field studies showed a significant increase in saturated hydraulic conductivity at sites overrun by *A. triangulata* compared to neighbouring unaffected sites. The results highlight a poor understanding of the relationships between earthworms, macropores and water movement. The long term consequence of earthworm depletion, after burrow collapse or truncation by ploughing, may be reduced infiltration and increased surface runoff. The impact on the environment and agriculture may be significant.

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