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Sublethal effects of iron and manganese soil pollution on *Orchesella cincta* (Collembola)

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With 6 figures

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1. Introduction

Blast-furnace plants expel large quantities of iron and manganese carrying dust, which results in soil pollution (Joosse & van Vliet 1982, 1984). Until now, little attention has been paid to the effects of iron and manganese on soil-dwelling animals. These metals appear to be relatively harmless, because they have essential functions in many physiological processes. Only at extremely high doses negative effects on mammals and birds are reported (Underwood 1977; Venugopal & Luckey 1978).

Studies on isopods, however, have shown that moderately increased concentrations of iron and manganese in the food already cause a decrease of food consumption and growth and an increase of the metabolic rate (van Capelleveen 1983; Joosse & van Vliet 1984). The consumption of litter and decomposer fungi by animals such as isopods, earthworms, springtails and oribatid mites ameliorates the conditions for the decomposition process (Mason 1977). So a decrease of the amount of food consumed by soil-dwelling animals could result in a decrease of the decomposition rate of the litter.

An interaction between iron and manganese occurs in the uptake of these metals by mammals and isopods as a result of competition for absorption sites at the gut epithelium. An increase of the concentration of one metal in the food results in a decrease of the concentration of the other metal in the animals (Underwood 1977, 1979; Venugopal & Luckey 1978; van Capelleveen 1983; Joosse & van Vliet 1984).

Springtails are capable of storing heavy metals in the gut epithelium (Humbert 1977). When the animals moult, they expel the old gut epithelium as a gut pellet containing the stored metals, before the renewal of the gut epithelium. As a consequence of this mechanism the springtails have been shown to excrete about 43% of the absorbed lead (Joosse & Buker 1979; Joosse & Verhoef 1983; van Straalen *et al.* 1985).

In the present study the effects of iron and manganese on the feeding activity and the growth of a springtail species are described and the consequences of these effects for the functioning of the soil ecosystem are discussed. The uptake and excretion of iron and manganese is studied and the factors influencing these processes are discussed.

2. Materials and methods

Samples of the species *Orchesella cincta* (L.) (Collembola) were collected from leaf litter in June 1983 at Wijk aan Zee, a polluted site near a blast-furnace plant (Hoogovens), and in August 1983 at the Boswachterij Roggebotzand, an unpolluted forest. Both sites are in the Netherlands. Samples of springtails and *Pleurococcus* spp. (green algae), which is one of their main food items, were taken at both sites in April 1983 for analysis of metal concentrations in the field. A sample of *Pleurococcus* was also taken in April 1983 at the Amsterdamse Bos, an unpolluted forest southwest of Amsterdam.

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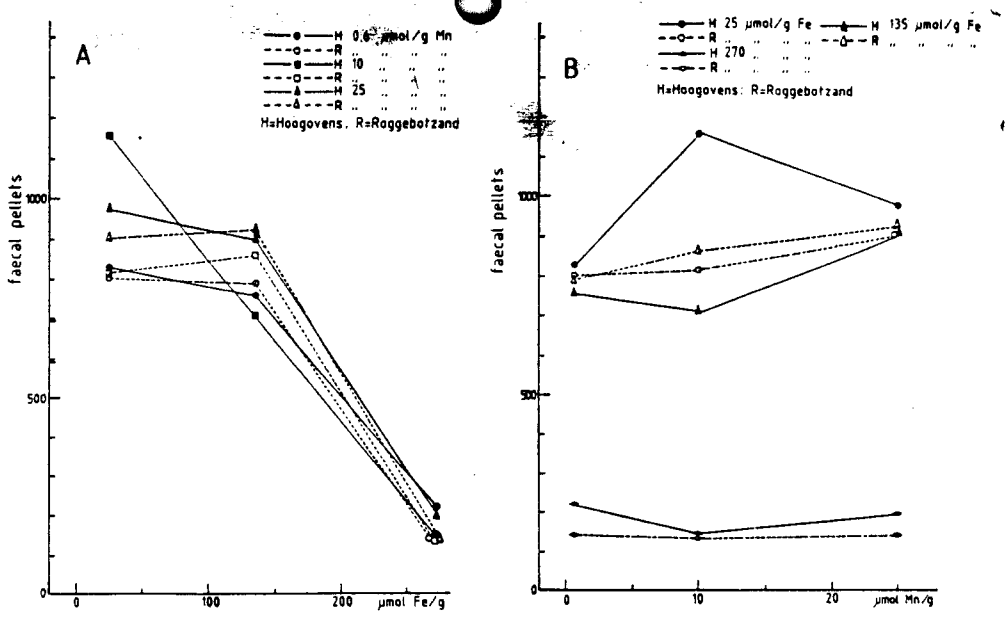


Fig. 2. Effect of iron (A) and manganese (B) in the food on the feeding activity (number of faecal pellets produced) of *O. cincta*. Only the mean of each experimental group is shown.

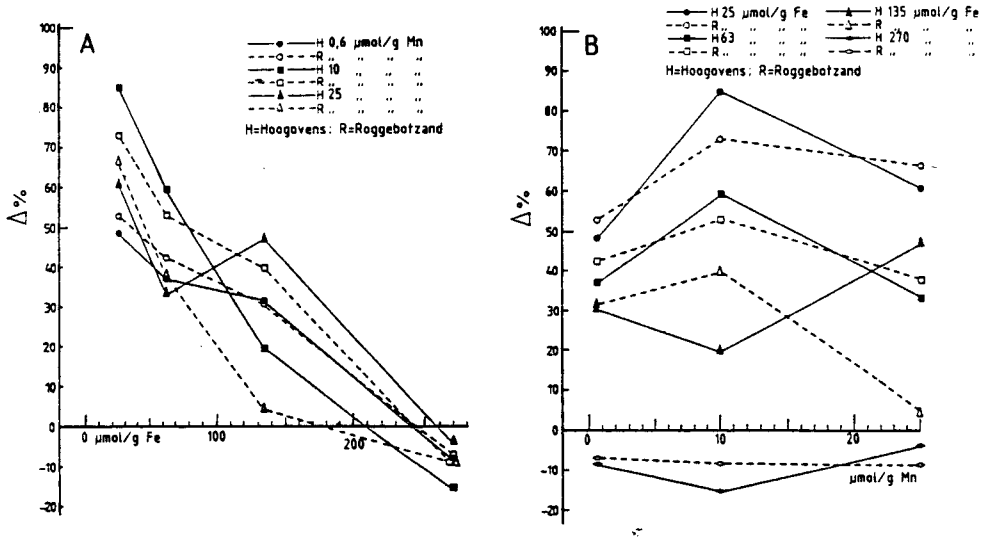
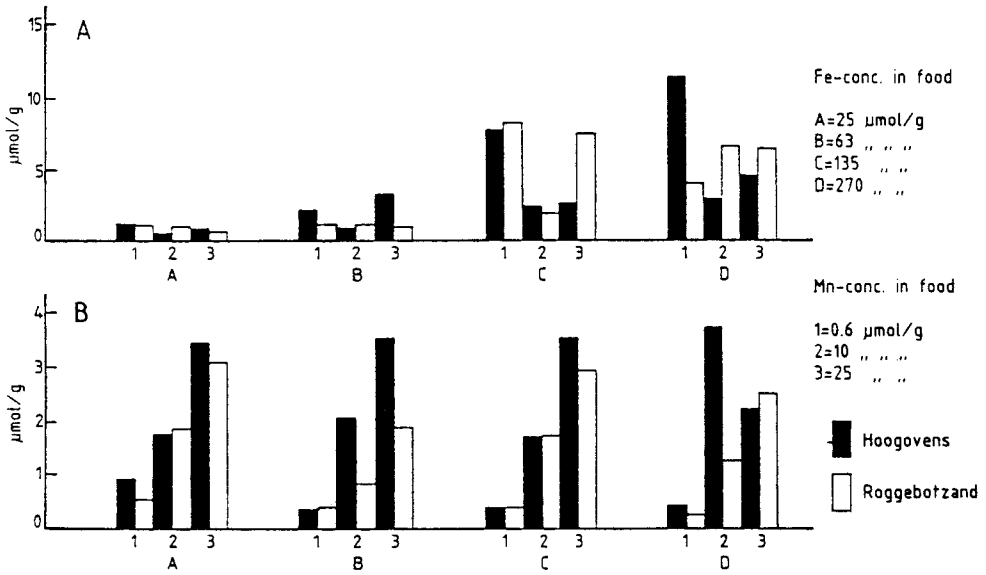


Fig. 3. Effect of iron (A) and manganese in the food on the growth (in %) of *O. cincta*. Only the mean of each experimental group is shown.

With increasing manganese concentration in the food the manganese concentration in the animals increases (sig., $p < 0.001$; Fig. 4b). The iron concentration in the food has no effect on the manganese concentration in the animals (Fig. 4b). A nearly significant difference ($p = 0.057$) exists between both populations: the manganese concentration in animals from Wijk aan Zee is higher.

The concentrations of iron and manganese in the animals are much lower than in the food. *O. cincta* does not concentrate iron and manganese.



F 4. Concentration of iron (A) and manganese (B) in *O. cincta* (in μmol/g dry mass) at the end of the experiment. Only the mean of each experimental group is shown.

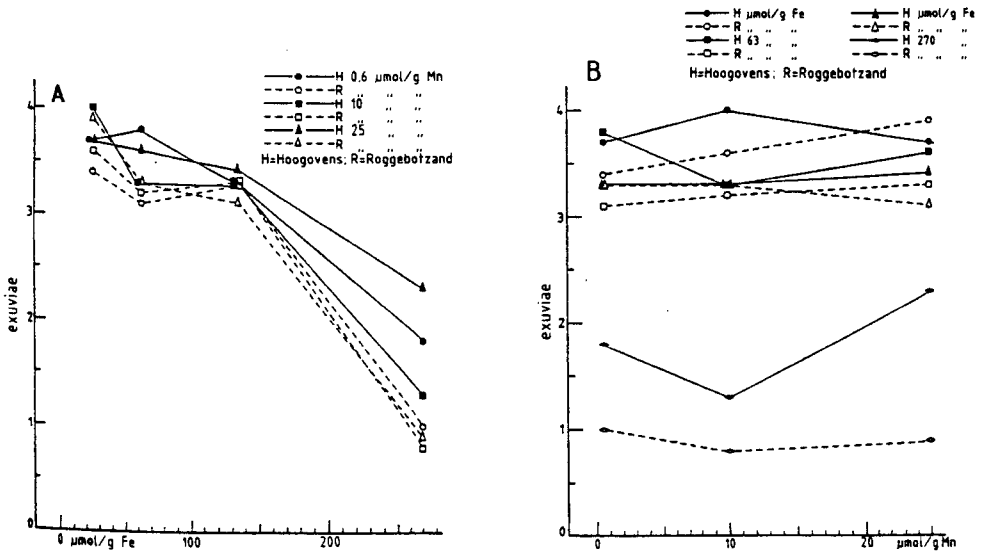


Fig. 5. Effect of iron (A) and manganese (B) in the food on the moulting frequency (number of exuviae produced) of *O. cincta*. Only the mean of each experimental group is shown.

Iron causes a decrease of the moulting frequency, especially at a concentration of 270 μmol · g^{-1} dry mass (sig., $p < 0.001$; Fig. 5a). No effect of manganese on the moulting frequency has been found (Fig. 5b). A difference exists between both populations (sig., $p = 0.003$; Fig. 5a, b): the animals from Wijk aan Zee moult more frequently. This difference already exists at unpolluted food and increases with increasing iron concentration in the food. At 270 μmol Fe · g^{-1} dry mass the difference is 50—100%.

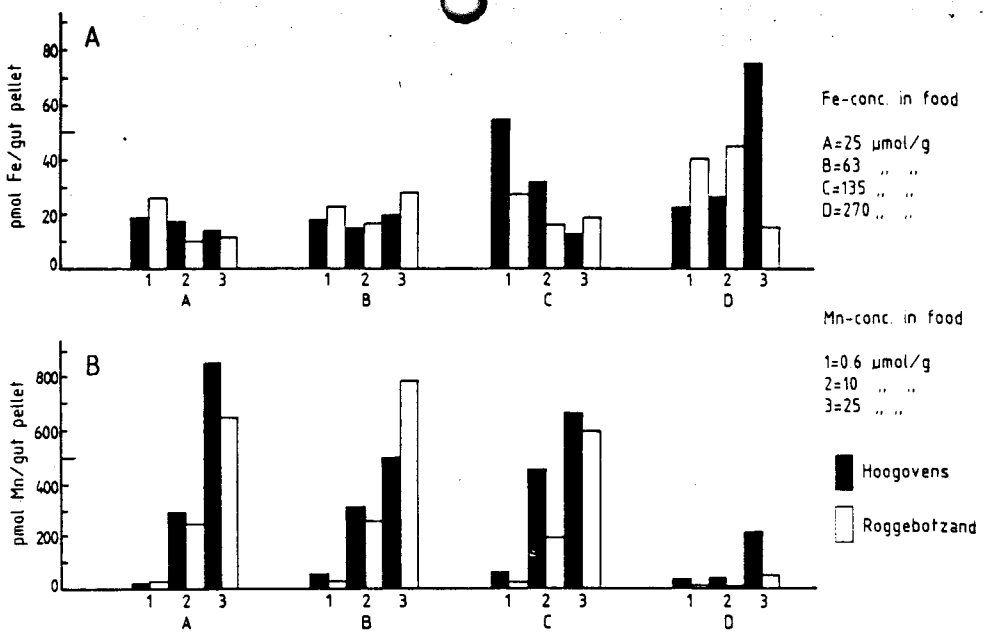


Fig. 6. Content of iron (A) and manganese (B) in a gut pellet (in pmol/gut pellet) of *O. cincta* feeding on food polluted with iron and manganese. Only the mean of each experimental group is shown.

The iron content of a gut pellet increases with increasing iron concentration in the food (sig., $p = 0.009$; Fig. 6a). No effect of manganese on the iron content of a gut pellet has been found. The manganese content of a gut pellet increases with increasing manganese concentration in the food (sig., $p < 0.001$; Fig. 6b). The manganese content of a gut pellet has been found to be decreased by the iron concentration in the food (sig., $p < 0.001$), especially at a concentration of $270 \mu mol\ Fe \cdot g^{-1}$ dry mass. There is a significant difference ($p = 0.019$) between gut pellet contents of manganese with higher contents in gut pellets from the Wijk aan Zee animals. Notwithstanding the usually higher iron concentration of the food, the manganese content of a gut pellet is much higher than the iron content of the same gut pellet. When the concentrations of iron and manganese in the food are equal ($25 \mu mol \cdot g^{-1}$ dry mass), the manganese content (range: 640—1,014 pmol/gut pellet) is 50—80 times higher than the iron content (range: 8—19 pmol/gut pellet) of the same gut pellet.

4. Discussion

Within the range of concentrations used in the experiment, iron has been found to decrease the feeding activity of *Orchesella cincta*, especially when the food concentration exceeded $135 \mu mol \cdot g^{-1}$. No effect of manganese has been found. Both metals have been shown to decrease the food consumption by isopods (VAN CAPELLEVEEN 1983). Iron also causes a decrease of the growth, whereas manganese has no effect on the growth. Other metals, such as copper and lead have also been shown to impair the growth of springtails (BENGTSSON *et al.*, 1983; JOOSSE & VERHOEF 1983). A decrease of the feeding activity and the growth occurring in the field as a result of iron pollution could have consequences for the functioning of the soil system. In addition to *Pleurococcus*, fungi are an important food source for *O. cincta* (VEGTER 1983). The consumption of fungi by springtails has been shown to increase the metabolic activity of these fungi (HANLON & ANDERSON 1979; PARKINSON *et al.* 1979; HANLON 1981). Field experiments have shown that Collembola increase the litter decomposition rate (VERHOEF & DE GOEDE 1985). Therefore, a decrease of the amount of food consumed in a period by springtails could result in a decrease of the litter decomposition rate.

The concentrations of iron and manganese in the springtails are far below the concentra-
ons in the food. Similar results have been found in springtails feeding on fungi polluted with
ad and copper (BENGTSSON *et al.* 1983). The springtails absorb relatively more manganese
ıan iron. Vertebrates, on the other hand, absorb more iron than manganese: 5—15%
· 3—4% of the amount present in the food (UNDERWOOD 1977). Hence the metal uptake
: springtails is low, especially for iron. Two phenomena may account for this low iron
ptake. In the first place iron absorption may be regulated by the gut epithelium. This
as been found to occur in mammals (UNDERWOOD 1977). Available information on insects
arvae of the blowfly *Lucilia cuprina*) also supports this explanation (WATERHOUSE & STAY
955). Secondly, the possibility exists that iron absorption is low as a result of physico-
ıemical conditions in the gut, such as the *p*H. At a low *p*H iron is much more soluble than
t a high *p*H, because at a low *p*H it occurs as Fe^{2+} and at a high *p*H as Fe^{3+}. HUMBERT
974) has shown that the hind gut of the springtail species *Sinella coeca* has a *p*H of about
.0. In the experiment described here, the metals were added to the food as sulphate. When
ıe *p*H in the gut is high, iron will occur mainly as Fe^{3+} and Fe(III)sulphate is insoluble.
'his has been shown to occur in mammals (VENUGOPAL & LUCKEY 1978).

Moulting is the most significant pathway for heavy metal excretion by springtails.
pringtails are able to store metals in the gut epithelium (HUMBERT 1977), which is expelled
s a gut pellet at every moult. The manganese content of a gut pellet is much higher than
ıe iron content, whereas in the food and the animals the iron concentration is usually
igher. So iron excretion is low compared to manganese excretion (and lead excretion (VAN
TRAALEN *et al.* 1985)). The iron excretion of vertebrate animals is also low compared to
ıanganese excretion (UNDERWOOD 1977).

Pollution of the food with manganese causes a reduction of the iron uptake. Such an
ıteraction is usually caused by a competition for absorption sites at the gut epithelium
UNDERWOOD 1977, 1979; VENUGOPAL & LUCKEY 1978). In *O. cincta* the relation between
·on and manganese is nonlinear instead of linear, which is usually found. The highest
eduction of the iron uptake occurs at a concentration of $10 \mu mol\ Mn \cdot g^{-1}$ dry mass in the
ood. In contrast with the results of JOOSSE & VAN VLIET (1984) and KHANDELWAL *et al.*
1984) no effect of the iron in the food on the manganese concentration in the animals has
een found. The cause of this may be that iron possibly occurs in the gut in an insoluble
ɔrm as a result of a high *p*H.

The manganese concentration in animals from the polluted site is possibly regulated at
higher level. Similar observations made by WIESER & MAKART (1961) showed that the
opper concentration in isopods from sites polluted with copper is 2—3 times higher than
n isopods from unpolluted sites, even after they have been grown for six years at unpolluted
ood. The moulting frequency of animals from the polluted site was also higher even when
he animals were feeding on unpolluted food. The largest difference was found at a concen-
ration in the food of $270 \mu mol\ Fe \cdot g^{-1}$ dry mass. This difference could mean that these
nimals are adapted to a higher concentration of metals in the environment, which enables
he animals from the polluted site to excrete a greater amount of metals in the same period.
'he adaptation of plants to metal pollution has been documented by BRADSHAW & MCNEILLY
1981) and similar observations have been made on animal populations (WIESER & MAKART
961; BRYAN & HUMMERSTONE 1971; BROWN 1976; VAN CAPELLEVEEN 1983; JOOSSE &
'AN VLIET 1984; JACOBSON 1985). Further research has to be done to answer the question
vhether the differences between the springtail populations are genetically based.

5. Zusammenfassung

[Sublethale Wirkungen von Eisen- und Mangan-Immissionen in den Boden auf Collembolen der Art *Orchesella cincta*]

Sublethale Wirkungen von Eisen und Mangan auf zwei Populationen der Collembolen-Art *Or-
hesella cincta* (L.) wurden untersucht. Tiere von einem von Industrierauch beeinflußten und einem
ınbeeinflußten Standort wurden mit Grünalgen (*Pleurococcus* spp.) gefüttert (die mit Eisen und

Mangan „verunreinigt" waren). Danach mindert Eisen die Freßaktivität und das Wachstum der Collembolen, während Mangan wirkungslos bleibt. Die Konsequenzen dieser Wirkungen für die Funktion des Boden-Ökosystems werden diskutiert. Die Metallkonzentrationen in den Tieren nehmen mit steigenden Metallkonzentrationen in der Nahrung zu. Mangan erniedrigte die Eisenaufnahme, während umgekehrt Eisen keinen Einfluß auf die Manganaufnahme hatte. Tiere aus dem Immissionsgebiet scheiden in gleicher Zeit mehr Metall aus als solche in dem immissionsfreien Gebiet. Faktoren, die die Aufnahme und Ausscheidung von Eisen und Mangan beeinflussen, werden diskutiert.

Schlüsselwörter: Collembola, Eisen, Mangan, Boden-Verunreinigung (Pollution), Toleranz, Toxizität, Aufnahme, Ausscheidung, Wechselwirkung, Differenzierung.

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Synopsis: *Original scientific paper*
NOTTROT, F., E. N. G. JOOSSE & N. M. VAN STRAALEN, 1989. Sublethal effects of iron and manganese soil pollution on *Orchesella cincta* (Collembola). Pedobiologia **30**, 45—53.
Sublethal effects of iron and manganese were studied in two populations of the springtail species *Orchesella cincta*. Animals from a polluted and an unpolluted site were fed on green algae polluted with iron and manganese. Iron decreases the feeding activity and the growth, whereas manganese has no effect. The consequences of these effects for the functioning of the soil ecosystem are discussed. Body metal concentrations increase with increasing metal concentration in the food. Manganese decreases iron uptake, whereas iron has no effect on the manganese uptake. Animals from the polluted site excrete a greater amount of metal in the same period. Factors influencing uptake and excretion of iron and manganese are discussed.
Key words: Collembola, iron, manganese, soil pollution, tolerance, toxicity, uptake, excretion, interaction, differentiation.