Changes in micromycete communities in soil in response to pollution by long-lived radionuclides emitted in the Chernobyl accident

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The effects of radionuclide pollution in soil on fungi following the accident at the Chernobyl Atomic Electric Station were investigated. Community structure was analysed using correlation analysis, resulting in the compilation of community pleaids (constellations) to describe links between fungal genera. This is one of the first times this method has been used to study fungal communities. The high levels of radioactivity from gamma-emitting radionuclides appears to favour the existence of communities dominated by melanized fungal genera. Changes in community structure over time and with depth of soil are also reported.

The catastrophe at the Chernobyl Atomic Electric Station (ChAES) caused considerable disturbance to the local ecology. Monitoring stations were set up in close vicinity of ChAES within zones of 10 and 30 km from the reactor site. Radionuclide composition of the fallout in this region was formed by products discharged from the reactor, mainly in the form of 'hot' particles derived from the fuel rods, activated particles of the building structure and those derived from condensation. At present, only long lived radionuclides remain at the site, these being dominated by \( { }^{137} \text{Cs} \), \( { }^{90} \text{Sr} \), \( { }^{239} \text{Pu} \). The composition of this pollution differs significantly from the radioactivity derived from nuclear weapons testing.

Even after some six years, the ecological consequences of the disaster are difficult to estimate. Studies should be directed to the effects of radionuclide pollution on different ecosystems, the communities of organisms supported by these ecosystems and the process of radionuclide migration in the ecosystem.

The work reported here is a study of the effects of radionuclide pollution on the community structure of soil micromycetes isolated from a zone 30 km from the accident site.

**MATERIALS AND METHODS**

In spring 1987, 10 stationary observation points were installed within the ChAES zone limits. From these, soil samples have been periodically collected at depths of 0–10 cm (1987–1991) and 0–25 cm (1990–1991), with samples taken each year. In 1986, sampling was performed sporadically. The selection of the samples at these depths was related to the nature of the radioactive pollution which, in the form of insoluble 'hot' particles, had a slow rate of movement down the soil profile.

The nature and activity of the contaminating radioactivity of the soil samples (more than 250) was determined by gamma spectrometry using a Nokia germanium detector. The nature and activity of the major pollutants from different sampling locations are given in Table 1. The first three sites were characterized by high levels of pollution, a great range of gamma irradiating radionuclides and were all on acidic soils. The least polluted site was in the vicinity of Kiev on sod-podzolic soils and had only \( { }^{137} \text{Cs} \) as the polluting radionuclide. Intermediate sites were in Novo-Shepelichi pine forest and around Chernobyl town, where three radionuclides dominated and soil pH approached 7. Radioactivity in the upper soil (0–2 cm depth) decreased by two orders of magnitude between 1987 and 1991 (three orders in the soil from Chistogalovka village).

Data on complexes of soil micromycetes were obtained from soil samples sieved onto either Czapek's or wort agar with added antibiotics. Replicate plates (pedoscopes) were incubated for 60–160 days. Quantitative and qualitative assessment of the fungal communities were made by direct observation (Zvyagintsev, Aseeva & Babjeva, 1980). Frequency of occurrence of different fungal species was derived from the quantity of soil samples. More than 1400 fungal cultures were isolated and identified as 183 species of 58 genera. The species composition of the communities isolated are given in Zhdanova et al. (1990).

The structure and degree of complexity of the micromycete communities was estimated by the construction of correlation pleaids (or constellations) (Terentjev, 1989; Borisova, 1988; Zhdanova et al., 1991). This method relies on the identification of similarities between frequency of occurrence of a particular genus (or species) of fungus at each of the sites. The correlation coefficient between frequency of occurrence of pairs of fungal species between the sites are calculated. Particular levels of correlation (r of 1.0, 0.95, 0.9 etc.) are selected and the link between genera plotted on a circular
Table 1. Characteristics of the radionuclide polluted soils of sites in the 30 km zone around the Chernobyl Atomic Electric Station (1987–1991)

<table>
<thead>
<tr>
<th>Location</th>
<th>Radioactivity Bq kg⁻¹ in soil horizons</th>
<th>Dominating radionuclides</th>
<th>Soil pH (0–2/8–10 cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(A) Novo-Shepelichi forest</td>
<td>7.8 × 10⁵–1.0 × 10⁶</td>
<td>¹³⁷Cs, ¹⁴⁴Ce</td>
<td>3.5–3.3</td>
</tr>
<tr>
<td>(B) Chistogalovka village</td>
<td>7.8 × 10⁵–2.9 × 10⁵</td>
<td>¹³⁷Cs, ¹⁴⁴Ce</td>
<td>3.9–3.2</td>
</tr>
<tr>
<td>(C) Kopachi village</td>
<td>3.2 × 10⁴–1.8 × 10⁴</td>
<td>¹³⁷Cs, ¹⁴⁴Ce</td>
<td>5.7–4.3</td>
</tr>
<tr>
<td>(D) Novo-Shepelichi pine forest</td>
<td>1.5 × 10⁵–4.1 × 10⁵</td>
<td>¹³⁷Cs, ¹⁴⁴Ce</td>
<td>4.8–4.3</td>
</tr>
<tr>
<td>(E) Chernobyl town</td>
<td>2.7 × 10⁴–4.4 × 10⁴</td>
<td>¹³⁷Cs, ¹⁴⁴Ce</td>
<td>6.1–7.0</td>
</tr>
<tr>
<td>(F) Pheophania near Kiev</td>
<td>3.7 × 10³–4.1</td>
<td>¹³⁷Cs</td>
<td>6.2–7.1</td>
</tr>
</tbody>
</table>

Fig. 1. Pleiads (constellations) constructed from correlation coefficients of 1.0 from the data in Table 3. Initially all species are arranged around the circle and lines are drawn to connect species linked at \( r = 1.0 \). The shapes derived form the pleiads of community structure. Solid circles = melanized taxa; empty circles = non-melanized taxa.

RESULTS AND DISCUSSION

The correlation pleiads in relation to level of radioactivity

Soil samples collected between 1986 and 1991 were divided...
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Fig. 2. Correlation pleiads of fungal communities in soil with different levels of radioactivity in different years. Fungus numbers in pleiads relate to the list in Table 2.

into activities between $3.7 \times 10^7$ and 37 Bq kg$^{-1}$. Figure 2 shows the community pleiads of micromycetes in 1986 at activities of $3.7 \times 10^4$ and 370 Bq kg$^{-1}$. Species of Mortierella (23), Verticillium (35), Actinomucor (34), Scopulariopsis (16), Oidiodendron (9) and Sordaria (32) were the main constituents of less polluted soil ($< 3.7 \times 10^3$ Bq kg$^{-1}$) with half of them belonging to the lightly pigmented species. Where soil radioactivity was greater than $3.7 \times 10^4$ Bq kg$^{-1}$, the majority of the species of the fungal community belonged to the dark pigmented genera, Coniochaeta (54), Drechslera (13), Aureobasidium (4) and others, forming a ‘lantern’ type pleiad (Fig. 2).

In 1987, of the soil samples of differing radioactivity from
3.7 x 10^7 to 3.7 Bq kg^-1, a structurally organized community ('star' type pleiad) was only formed in the most heavily polluted site (Novo-Shepelichi forest (A); 3.7 x 10^7 Bq kg^-1) and by dark pigmented genera of *Phoma* (38), *Melanophoma* (57), *Drechslera* (13), *Humicola* (14), *Peyronellaea* (33) and others. Communities isolated from the other soils showed linear pleiads, suggesting destruction of the fungal communities.

Between 1988–1991 the number and character of fungal communities suggests that in moderately polluted sites (3.7 x 10^4 to 3.7 x 10^6 Bq kg^-1), 'net', 'star' and 'net-star' type pleiads formed (Fig. 2). In these communities melanin containing genera of *Oidiodendron* (9), *Coniothyrium* (15), *Stachybotrys* (25), *Trichocladium* (36), *Drechslera* (13), *Llocladium* (12) and *Humicola* (14) were dominant in the formation of complexes.

**Fungal complexes in relation to location of sampling position**

Figure 3 shows correlation pleiads formed in different localities in relation to the level of radioactive pollution. In highly polluted sites (A and C), 'star net', three and four membered
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Fig. 4. Correlation pleiads of fungal communities in soil of two depth horizons in the two periods, 1987–88 and 1989–91 (sites A–F are as listed in Table 1 and ranked from highest to lowest level of pollution). Fungal numbers in pleiads relate to the list in Table 2.

In soils containing moderate and low levels of pollution (D and F), more simple communities were formed, indicated by 'simple net', 'three membered' and 'linear' pleiads. These contained a higher proportion of non-melanized fungi.

pleiads, indicating relatively stable communities, are evident. These communities consist mainly of melanized fungi (Stachybotrys (25), Ulocladium (12), Preussia (29), Plenodomus (7), Humicola (14), Aureobasidium (4), Alternaria (21) etc.).
Fig. 5. Correlation pleiads of fungal communities in soil in relation to season (sites A–F are as listed in Table 1 and ranked from highest to lowest level of pollution). Fungal numbers in pleiads relate to the list in Table 2.

(Acremonium (8), Mucor (11), Trichotheceum (26), Trichoderma (27), Actinomucor (34), P. rugulosum (39) and Fusarium (40)). These, commonly occurring fungi of this region, were rarely structural genera in the community pleiads, except for the less polluted sites. These data indicate that melanized fungi are more resistant to the effects of radionuclide pollution.

Fungal complexes formed in soil horizons of 0–2 and 8–10 cm depth

Pleiads constructed from data of frequency of occurrence of fungi at 0–2 and 8–10 cm depth from 5 sites are given in Fig. 4. In the 0–2 cm horizon, more stable and complex pleiads occur in soils of moderate and low levels of pollution. The simple ‘net’ and ‘linear’ pleiads of moderately polluted sites (C and E) in 1987–8, consist mainly of melanized fungi (Chaetomium (2), Rhizopus (5) Oidiodendron (9), Drechslera (13), Coniothyrium (15), Scopulariopsis (16), Catenularia (17), Stachybotrys (25), Paeusia (29), Scytalidium (31), Sordaria (32) and Peyronella (33)) give way to pleiads containing more non-melanized genera in 1989–91 (Gliocladium (6), Aspergillus (22), Trichoderma (27), P. funiculosum (28), Fusarium (40), Paecilomyces (44) and P. roseopurpureum (47)). In the upper soil horizon in the least polluted soil (Chistogalovka, B) correlation pleiads were absent.

In the 8–10 cm deep soil horizon of the most heavily polluted site (Novo-Shepelichi forest, A) in 1987–8 the...
complex pleiad was composed almost entirely by melanized genera. These were replaced in 1989–91 by simpler community structures composed of both melanized and non-melanized genera. In contrast, in 1989–91, the other highly contaminated soil of Chistogalovka (B), a peat bog, supported a 'lantern' type of pleiad composed almost entirely of melanized genera. In the remaining soils, simple 'net', 'three membered' and 'linear' pleiads were formed. In all cases, however, species of Fusarium (40), Mucor (11), Trichoderma (27) and Mortierella (23), common to these soils, rarely formed part of the communities illustrated by the correlation pleiads.

**Fungal complexes formed in relation to season**

Community structure of five sites at different times of the year is shown in Fig. 5. Overall, the figure shows that greatest community structure occurs in Spring, especially for the less polluted sites (C, E and F). The most highly organized communities, e.g. Chernobyl town (E) indicated by 'complex net' and Pheophania (F) indicated by 'lantern' pleiads are mainly composed of melanized fungal genera.

In general, this paper can form conclusions about the effect of radionuclide pollution on fungal community structure. The pollution occurred mainly in the form of 'hot' particles and, thus was not evenly distributed. However, it seems that there could be merit in describing soil fungal communities in the form of correlation pleiads after the method of Borisova (1988) who first used the method for leaf litter mycobiota.

In the process of studying these polluted soils, organized ('star', 'net', 'star net', 'three membered' pleiads) and disturbed ('linear' pleiads) fungal communities can be identified. For the first time, highly organized 'lantern' type pleiads have been described for soil fungi.

In relation to the fungal communities and radionuclide pollution levels, the main findings appear to be that melanin-containing genera are dominant in conditions of higher pollution loading (Zhdanova et al., 1990, 1991). It is supposed that these forms are more resistant to ionizing radiation than non-melanized forms (Zhdanova & Vasilevskaya, 1988). This is further supported by evidence from Kirilenko (1978) who showed that in these soils mainly non-melanized fungal genera occurred before the accident. In addition, there seems to be some suggestion for our data that in 1986–88, melanized forms dominated, but that later (1989–91) more non-pigmented forms were becoming part of the community structure.

The effects of changes in fungal population structure as a result of ionizing radiation on the migration of radionuclides in soil and the interaction of immobilization/mineralization has yet to be studied.

**REFERENCES**


