Soil Mesofauna Diversity and Responses to Agro-Herbicide Toxicities in Rainforest Zone of the Niger Delta, Nigeria

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Abstract: Soil mesofauna diversity and defaunation effects of two herbicides (Atrazine and Gramoxone (Paraquat)) on microarthropods (mites and collembolans) were assessed under agro-tropical conditions in the rainforest belt of the lower Niger Delta, Nigeria. Soil samples were collected from control and treated subplots for 13 weeks with 8.5cm diameter bucket-type auger. Extraction was by the modified Bukard model of the Berlesse-Tullgren funnel. Identification was undertaken with the aid of standard keys and comparisons were made with type specimens. A total of 69 individuals of soil microarthropods were recorded. Cryptostigmata peaked in species richness and abundance. While only 3 mite species (i.e. 1 individual each) were recovered from the Atrazine-treated soil samples. Gramoxone-treated soil had 10 mite taxa belonging to Cryptostigmata and Mesostigmata. Only 1 taxon each of Cryptostigmata and Mesostigmata were encountered in the Atrazine-gramoxone treated soil, while 26 mites were recorded in the control soil samples. The soil microarthropods were apparently more susceptible to atrazine. The specific and synergistic toxic manifestations of the herbicides are discussed in relation to soil arthropod biodiversity concern in the face of emerging large-scale agro-pesticide applications to boost food security and, the challenge of achieving contemporary global objective of green economy.

Key words: Soil Microarthropods - Herbicides - Atrazine - Gramoxone - Farmland

INTRODUCTION

Soil organisms are amongst the most diverse biological communities on earth. They are usually found close to the surface and the upper thin living layer has been estimated to contain thousands of species and billions of individual organisms per hectare [1]. These organisms, also referred to as decomposer community, encompass microfauna (protozoa and nematodes), mesofauna (Collembolans, mites, protura, diplura) and macrofauna (oligochaeta and insects) [2, 3].

Mesofauna are soil organisms whose body width is 100um-2mm and occur in the litter, litter-soil interface and mostly in the topsoil, to a depth of approximately 10.0cm where organic matter is decomposed and the final products are available for crops through their roots. They account for 95% of the soil arthropod fauna [4] and play key roles in decomposition and mineralization of dead organic matter for the enhancement of soil fertility and regulation of microbial populations and largely indicate integrity of soil health.

Agricultural activities include weeding, application of pesticides, ploughing, irrigation, harvesting, burning and post-harvest collection of plant residues, etc. These activities potentially modify the properties of soil and alter the functioning of the upper soil layers [5, 6]. Removal of weeds is imperative to avoid or minimize inter-competition between the cultivated crops and weeds to enhance potential for good crop yield. Herbicide application may be preferred over weeding on large-scale farms, particularly against recalcitrant rejuvenating weeds.

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Herbicides are chemical substances used for killing circumstantial unwanted plants (weeds) or to inhibit their growth. Some herbicides are non-selective, which means that they also affect non-target organisms, or are selective in part or full, whereby they can be used for controlling the growth of specific weeds. It has long been found that herbicides cause reduction in species diversity and population density of soil microarthropods. For instance, a decrease in the population of prostigmatid, mesostigmatid mites, isonemid and oribatid mites following simazine treatment in a fallow has been recorded [7]. Long-term use of herbicides significantly reduced populations of collembolan [8]. Toxicity of hexazinone-treated plots persisted even after the herbicide had disappeared from the soil and weeds had emerged [9].

Herbicides had also been reported to have caused reduction in the rate of decomposition of dead organic matter by microarthropods. The herbicide, aldicarb, impaired the activity of decomposers by disrupting the nutrient cycle of saprophagous insects that feed on dead litter at the agro-ecosystem level, thus slowing the consumption of dead organic matter [10].

Atrazine, applied at high concentrations led to the chemical deterioration of the soil, which disrupted activity of microarthropods and prevented oviposition by the springtail (Collembola) Orchesela cinta L. [11]. Herbicides have long term effects on soil fertility, probably caused by disturbance of soil microflora and mesofauna that are responsible for certain soil processes through decomposition (www. Altavista. Comm). Population growth, poor water quality and waste management and food insecurity are some of the obvious societal problems that developing societies are grappling with [12,13]. To step up food production towards meeting goal one of the millennium development goals, large-scale agriculture production systems are increasingly becoming popular in many developing societies. And preference for pesticide use is outpacing age-long cultural pest control practices [14, 15]. Application of insecticides has attendant impact on non target taxa and some of the affected species act as natural enemies of pest [16]. This can result in surges of pest infestation [17]. Atrazine is used to stop pre-and post-emergence broad leaf and grassy weeds on major farms. It is the most widely used in conservation tillage systems, which are designed to prevent soil erosion. It does not breakdown easily after application to soil of above neutral pH and it is not water-resistant. It has the ability to leach quickly into the soil, to the depth of groundwater. By contrast, gramoxone (paraquat) N, N′-dimethyl 4,4′ bipyridinium dichloride) is adsorbed quickly and strongly by soil particles but does not leach rapidly into the soil.

Generally, the biodiversity of the Niger Delta is inadequately studied and documented, much less soil mesofauna. This study investigated species richness and diversity of soil mesofaunal assemblages in herbicide-treated and untreated plots in the humid rainforest belt of the Niger Delta, Nigeria.

MATERIALS AND METHODS

Description of Herbicides: Two categories of herbicides were used, namely: paraquat (gramoxone-bipyridilium herbicide) and atrazine (triazine herbicide). Paraquat was registered for use in 1965. It is known for its ability to cause quick destruction of plant cells and having binding affinity with inorganic minerals and rapidly reduces their bioavailability [18]. Paraquat (C₉H₉N₂), a viologen is also non-selective and used to control wide range of weeds. It does not leach fast into the soil but rather remains on soil and leaf surfaces.

Atrazine (1-chloro-3-ethylamino-5-isopropylamino-2, 4, 6 triazine) is an organic compound consisting of an s-triazine ring. It is prepared from cyanuric chloride. Atrazine (C₉H₁₆CN₃) is a colourless liquid with density of 1.87gcm-3 and it is stable in water.

Study Area: The study was conducted on a fallow farmland at Rumuagholu village (approximately N4°53′098″, E6°57′860″), in Obio-Akpor Local Government Area of Rivers State, Nigeria. Rumuagholu is an integral component of the sprawling metropolitan city of Port Harcourt, the capital of River State. Port Harcourt experiences about 180 rainy days per annum [19]. Temperature of the city ranges from 28 to 33 °C, with high relative humidity throughout the year.

Field Procedures: The experimental farmland was divided into four sub-plots of 15m x 10m each and labeled A, B, C and D. The subplots were interspersed by a space of 1m to avoid trans-boundary contamination. The soil was loamy. The test media were prepared by mixing the 5ml of each herbicide in 1l of distilled water. Similarly, a mixture (1:1) of both herbicides was prepared. Three pre-cleaned hand pump sprayers were used simultaneously to administer the treatment to the subplots. Two litres of each herbicide and the composite were sprayed on the subplots as follows: A (atrazine),
B (gramoxone), C (mixture of both herbicides); plot D was the control, untreated subplot. Soil samples were collected monthly for 4 months from each subplot; the first set of samples was collected 14 days post-treatment. The sampling campaign was undertaken with an 8.5cm diameter soil auger from depths of 0-5cm, 5.1-10.0cm, 10.1-15.0cm, 15.1-20.0cm and 20.1-25.0cm. Five replicate samples were collected from each subplot per sampling. During collection, the auger was rotated clock-wise and anti-clockwise to ensure that the soil in each depth range was fully collected. Each sample was placed in a plastic bag, labeled and taken to the laboratory for analyses in a 3-stage process (extraction, sorting and identification).

Laboratory Procedures: Extraction was carried out in the Entomology Research laboratory of the University of Port Harcourt in a modified Bukard model of the Berlese-Tullgren funnel [20]. We adopted the extraction procedure documented in Badejo [21]. Extraction lasted for 7 days and the extracts were sorted by placing them in petri-dishes under a dissecting microscope where the mites and collembolans were carefully removed. Temporary slides were prepared and identification of the taxa performed to the lowest taxonomic level possible under stereomicroscope using keys [22-26]. Identification of some of the taxa stopped at coarser level due to their conventional poor systematic status. The identified mites and collembolans were counted and recorded. Analysis of variance (ANOVA) was used to ascertain the degree of variability in species abundance among the treated and untreated soil plots as well as among the treated habitats themselves. Duncan multiple range test was used to rank the means. Species richness, community diversity, evenness and dominance were calculated as in Zabbey and Malaquias [27].

RESULTS

Sixty-nine mesofauna were recovered representing 11 species of mites and one collembolan taxon. Nine of the mites belong to Cryptostigmata and 2 were members of Mesostigmata (Table 1). Species richness in the 4 habitat types were: (untreated)-6 species of Cryptostigmata species; One Mesostigmata species; (Atrazine-treated)-3

<table>
<thead>
<tr>
<th>SPECIES</th>
<th>Untreated control</th>
<th>Atrazine</th>
<th>Gramoxone</th>
<th>Atrazine and Gramoxone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Galumna spp</td>
<td>13</td>
<td>2</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>Scheloribates yorubaensis</td>
<td>4</td>
<td>-</td>
<td>14</td>
<td>1</td>
</tr>
<tr>
<td>Scheloribates sp</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Ricthermannia nigerina</td>
<td>-</td>
<td>-</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Atropacarus sp</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Mixacarus sp</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Bellidae 1 sp</td>
<td>6</td>
<td>-</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Cephalidae 1 sp</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Mesostigmata</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Uropodidae sp</td>
<td>2</td>
<td>-</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Asca sp</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>Collembola:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cryptophagus sp</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Grand Total</td>
<td>29</td>
<td>4</td>
<td>34</td>
<td>2</td>
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<table>
<thead>
<tr>
<th>Depth range (cm)</th>
<th>Untreated control</th>
<th>Atrazine</th>
<th>Gramoxone</th>
<th>Atrazine +Gramoxone</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-5.0</td>
<td>13</td>
<td>-</td>
<td>12</td>
<td>-</td>
<td>25</td>
</tr>
<tr>
<td>5.1-10.0</td>
<td>8</td>
<td>-</td>
<td>5</td>
<td>-</td>
<td>13</td>
</tr>
<tr>
<td>10.1-15.0</td>
<td>6</td>
<td>-</td>
<td>10</td>
<td>1</td>
<td>7</td>
</tr>
<tr>
<td>15.1-20.0</td>
<td>1</td>
<td>2</td>
<td>4</td>
<td>1</td>
<td>9</td>
</tr>
<tr>
<td>20.1-25.0</td>
<td>-</td>
<td>1</td>
<td>2</td>
<td>-</td>
<td>2</td>
</tr>
<tr>
<td>Total</td>
<td>28</td>
<td>03</td>
<td>33</td>
<td>02</td>
<td>66</td>
</tr>
</tbody>
</table>
Table 3: diversity of mesofauna at different zones

<table>
<thead>
<tr>
<th>Indices</th>
<th>Control</th>
<th>Atrazine</th>
<th>Gramoxone</th>
<th>Atrazine and gramoxone</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of species</td>
<td>7</td>
<td>3</td>
<td>10</td>
<td>2</td>
</tr>
<tr>
<td>No. of individuals</td>
<td>29</td>
<td>4</td>
<td>34</td>
<td>2</td>
</tr>
<tr>
<td>Margalef diversity</td>
<td>1.782</td>
<td>1.443</td>
<td>2.552</td>
<td>1.443</td>
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<tr>
<td>Shannon-Wiener</td>
<td>0.677</td>
<td>0.452</td>
<td>0.770</td>
<td>0.301</td>
</tr>
<tr>
<td>Pilou’s evenness</td>
<td>0.802</td>
<td>0.946</td>
<td>0.770</td>
<td>1</td>
</tr>
<tr>
<td>Simpson’s dominance</td>
<td>0.275</td>
<td>0.375</td>
<td>0.244</td>
<td>0.5</td>
</tr>
</tbody>
</table>

Cryptostigmata species and 2 Mesostigmata species; (combined Atrazine and gramoxone-treated)-One species each of Cryptostigmatid and Mesostigmatid species.

One species of Collembola (Cryptophagus sp.) and 3 Cryptostigmata species were recorded in the untreated and treated (Atrazine and Gramoxone) subplots. Three species namely, *Atropacarus, Mixacarus* and *Asca* were restricted to the gramoxone-treated habitat while a taxon in the family Cephalidae that is conventionally yet to be identified to the generic level was encountered only in the untreated habitat. In the treated habitat, 11 species were recovered from gramoxone-treated samples, while only 4 species were recorded from the atrazine-treated subplot.

The 69 soil microarthropods encountered were distributed as follows: untreated plot had 28 mites and one collembolan; atrazine-treated had 3 mites and one collembolan; Gramoxone-treated, 33 mites and one collembolan; and admixture of atrazine and gramoxone-treated plot had 2 mites only (Table 1). *Galumna* sp., *Scheloribates* sp and *Cryptophagus* sp were recorded at the control, atrazine and gramoxone plots but were not recovered from the atrazine-gramoxone treated plot. *Scheloribates* sp and *Belba* sp. were recorded only at the control and gramoxone treated plots, while *Scheloribates vorubaensis* and an unidentified taxon of Uropodidae, though generally fewer in number, were recorded in the control, gramoxone and atrazine-gramoxone plots but absent in atrazine samples (Table 1).

In terms of depth profile occurrence, 0-10.cm, untreated habitat recorded 21 mites; no mite was recovered from the atrazine-treated subplot samples; 17 mites were recovered from the gramoxone-treated and while no mite was recorded from Atrazine-Gramoxone treated samples (Table 2). In the layer, 10.1-25.0cm, untreated plot recorded 7 mites; Atrazine-treated 3; Gramoxone-treated produced 16 mites; combined atrazine and gramoxone-treated 2 mites (Table 2). There were variations in species abundance in the treated and untreated soil habitats (P < 0.05), (atrazine-treated P < 0.05; gramoxone-treated P < 0.05; atrazine + gramoxone P < 0.05).

Significant variations in abundance were also recorded amongst the treated soil habitats: Atrazine Vs Gramoxone; P < 0.05; Atrazine Vs combined; P < 0.05; Gramoxone Vs combined; P < 0.05).

As indicated in Table 3, gramoxone treated plot had the highest species richness and community diversity values. The least species richness and diversity was recorded in the atrazine-gramoxone treated plot, where dominance also peaked.

### DISCUSSION

Based on taxa richness, it seems gramoxone was apparently less toxic to the soil microarthropods than atrazine. This agrees with Badejo [28] who found that atrazine herbicide greatly reduced species richness, abundance and diversity.

The high abundance of mites in gramoxone-treated plots might be related to the herbicide inability to leach easily and fast as atrazine. The former apparently dried up at the soil surface thereby making it less toxic to soil-buried mesofauna assemblages. Toxicity of atrazine has been associated with leaching into the soil where it interferes with the mechanism for oxygen production in plants which is deleterious to the growth of microarthropod populations [28]. The number of Cryptostigmatids recorded in both the treated and untreated habitats confirms earlier records that Cryptostigmatids are often the most abundant soil mites [29-31]. The similarity of species richness and abundance of collembolans in both treated and untreated plots suggests that atrazine had little or minimal effects on collembolan populations [32], even in synergy with gramoxone.

Curiously, both species richness and general diversity peaked at the gramoxone treated plot, instead of the control. It is difficult to unravel with certainty the causal reason(s) for this unexpected pattern of diversity. A plausible logic for the bizarre skewed diversity is that the soil mesofauna were unevenly distributed across the studied plots prior to treatment. That is, they were more clumped at the gramoxone plot prior to treatment. It has
long been noted that dispersion of soil invertebrates are frequently contagious (i.e. aggregated) because environmental factors are unevenly distributed and certain species tend to aggregate to produce clumped dispersion even without the influence of environmental factors [33]. Firstly, the clumped hypothesis could have been empirically validated, if pre-treatment data existed on the composition and relative abundance of the soil mesofauna. Secondly, credibility of the aggregation logic hinges on the presumption that gramoxone had no or grossly marginal mortal impact on the soil arthropods. Of less merit is the assumption that gramoxone, when applied singly, acted as an attractant to the resident mesofauna. In nature, competition, predation pressures, disturbances, environmental conditions of the habitat and structural heterogeneity of habitat are some factors underpinning diversity at different scales [34, 35].

Biological communities are characterized by few species that are very common (represented by many individuals), some species are rare, while some are represented by one or few individuals [34]. We deduced that Galumna sp., Scheloribates sp. and Cryptophagus sp. were ubiquitous in the studied area and were refractory to atrazine and gramoxone individually, but were all susceptible to the synergistic mortal effects of both herbicides. Scheloribates yorubaensis and Galumna sp. typified the common species scenario, while the rare individual circumstances was the case of the lone taxon of Uropodidae which, though, presumed to be ubiquitous, was so rare that no individual was recorded in the atrazine-treated plot.

The toxicity of atrazine probably caused vertical migration of surviving individuals to deeper depths as 3 survivors were encountered below the 10-15cm depth. Such avoidance response by deep burrowing could only confer mortal insulation on limited number of taxa that are genetically selected to survive hypoxia or anoxia conditions which characterizes deeper soil depths. The observed density of microarthropods below 0-10.0cm in the treated plots agrees with Okiwelu et al. [36] that pollution significantly reduces mesofaunal assemblages in the upper 10.0cm of soil. Presumably, oxygen concurrently had similar decreasing vertical depth gradient as the toxicants, but toxic effects of the herbicides were apparently overriding. Gbarakoro et al. [31] reported an inverse relationship of mite abundance and soil depths in an unpolluted soil habitat.

Overall, gramoxone was found to be less toxic to soil mesofauna than atrazine. There is need to appraise the short and long-term toxicological effects of pesticides under different agro-climatic settings and within a broader frame of soil biodiversity conservation. More pressing is the need to collect baseline information on soil fauna diversity to assure reliable comparative evaluation and the validity of pesticides post impact assessment. Integrating screening results into national food production policy and programmes of poor economies would largely help to preserve ecological integrity (ecological structure and functions), while enhancing robust food production, in line with current global framework of green economy for sustainable development and poverty eradication.

REFERENCES


