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Review

Carbaryl toxicity prediction to soil organisms under high and low temperature regimes

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ABSTRACT

Many studies on risk assessment of pesticides on non-target organisms have been performed based on standardized protocols that reflect conditions in temperate climates. However, the responses of organisms to chemical compounds may differ according to latitude and thus predicting the toxicity of chemicals at different temperatures is an important factor to consider in risk assessment. The toxic effects of the pesticide carbaryl were evaluated at different temperature regimes, which are indicative of temperate and tropical climates and are relevant to climate change predictions or seasonal temperature fluctuations. Four standard organisms were used (*Folsomia candida*, *Eisenia andrei*; *Triticum aestivum* and *Brassica rapa*) and the effects were assessed using synergistic ratios, calculated from EC/LC_{50} values. When possible, the MIXTOX tool was used based on the reference model of independent action (IA) and possible deviations. A decrease on carbaryl toxicity at higher temperatures was found in *F. candida* reproduction, but when the mixtox tool was used no interactions between these stressors (Independent Action) was observed, so an additive response was suggested. Synergistic ratios showed a tendency to synergism at high temperatures for *E. andrei* and *B. rapa* and antagonism at low temperatures for both species. *T. aestivum* showed to be less affected than expected (antagonism), when exposed to both low and high temperatures. The results showed that temperature may increase the deleterious effects of carbaryl to non-target organisms, which is important considering both seasonal and latitude related differences, as well as the global climate change context.

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1. Introduction

Standardized ecotoxicological tests have been conducted under strict limits on abiotic factors such as temperature, simulating temperate regions (Smit and Van Gestel, 1995; Martikainen and Krogh, 1999), while risk assessment for tropical and cold temperate climates is often carried out through extrapolations from these data (De Silva et al., 2009).

Factors such as organic matter, soil moisture, UV radiation and temperature can differ widely according to the planet region. In temperate regions, soils are seasonally cold, characterized by a low biological activity (Robertson and Grandy, 2006). Whereas, tropical regions are characterized by high moisture and temperatures that cause a fast turnover of organic compounds and organic matter in soil (Ayanaba and Jenkinson, 1990; Trumbore, 1993). Fate and transport of pesticides, toxicity and exposure routes may differ between these regions, mainly due to the temperature (Bourdeau et al., 1989; Laabs et al., 2002). So risk assessment based on these standardized tests may not be representative of tropical and cold temperate regions.

Besides differences in latitude, seasonal fluctuations and global climate change can also lead to different temperature regimes, which may therefore influence the fate and transport of chemicals in the environment.

The high temperature favors the volatilization and degradation of some organic chemicals in soil (Viswanathan and Krishna Murti, 1989; Martikainen and Krogh, 1999), and on the other hand degradation of pesticides occur slowly at lower temperatures (Topp et al., 1997), favoring its stability in the environment (Viswanathan and Krishna Murti, 1989).

Regarding the terrestrial environmental compartment, the increase in temperature may affect the structure and dynamics of plant communities (Aerts et al., 2006) and crops (Blum et al., 1994; Ortiz et al., 2008), accelerate earthworm growth and reproduction (Reinecke and Kriel, 1981; Presley et al., 1996; Butt, 1997; Fayolle et al., 1997), affect development and reproduction of soil organisms, such as collembolan (Choi et al., 2002). Moreover, it may lead to enhanced metabolic activity of the organisms as well as the uptake rates of toxicants (Smit and Van Gestel, 1997; Martikainen and Krogh, 1999).

On the other hand, low temperatures are potentially lethal for many soil organisms and plants (Holmstrup et al., 2008), causing a decrease in burrowing activity in earthworms (Perreault and Whalen, 2006), changes in membrane physical properties of plants (Crockett et al., 2001), inducing a relatively inactive state in many invertebrates (Cáceres, 1997), decreasing rates of oxygen consumption (Tripathi et al., 2011) and metabolism (Penick et al., 1998) or dessication.

The aim of this study was to predict the toxicity of carbaryl at low and high temperature, using four standard organisms that are representative of different taxonomic levels, ecological functions, trophic level, life history and route of exposure to chemicals.

Carbaryl (1-naphthyl-N-methylcarbamate) is a carbamate insecticide commonly used in agricultural activities worldwide, known for its action on insects by inhibiting the acetylcholinesterase (AChE), an essential enzyme in the nervous system of invertebrates. Carbaryl is not considered persistent in soil, and the adsorption coefficient values (from 100 to 600) indicate that it moderately binds to soil particles (IPCS, 1994; Jana and Das, 1997). Its half-life ranges from 4 to 27 days in aerobic soils and from 72 to 78 days in anaerobic soils (Miller, 1993; IPCS, 1994), but the half-life of carbaryl in soil can be significantly reduced by increasing the temperature (Uyanik and Özdemir, 1999).

Studies on the effects of temperature on carbaryl toxicity are limited to aquatic toxicology. Sanders et al. (1983) reported that at temperatures of 7, 12 and 22 °C, there were no differences within carbaryl toxicity to rainbow trout (*Oncorhynchus mykiss*), but for other fish species (*Lepomis macrochirus*) an increase in temperature of 12 °C from 22 °C increase its toxicity twice, causing mortality. Increase of temperature also affected the survival of *Rana clamitans* tadpoles (Boone and Bridges 1999), of the midge, *Chironomus riparius* (Lohner and Fisher, 1990) and the molluscs *Melanopsis dufouri* (Almar et al., 1988) exposed to carbaryl.

But studies regarding the effect of temperature on the toxicity of carbaryl to soil organisms are scarce. The toxicity of carbofuran, another carbamate pesticide, did not differ much on its acute toxicity to earthworm when exposed to tropical (26 °C) and temperate (20 °C) conditions (De Silva et al., 2009).

To predict joint effects of the carbaryl and temperature on the chosen test-species, the Independent Action (IA) conceptual model for mixture toxicity prediction was adopted in this study. This model has been used to evaluate mixtures of chemicals that have different modes of action and their effects are statistically independent of each other (Bliss, 1939).

2. Materials and methods

2.1. Test species

Due to their sensitivity to chemicals, important role in the soil ecosystem, rapid life cycle and ease to maintain in the laboratory, these species are widely used in ecotoxicological tests (Crouau and Cazes, 2003; Fountain and Hopkin, 2005) and so were chosen for this study.

Folsomia candida and *Eisenia andrei* were obtained from laboratory cultures. The earthworm cultures were maintained at a constant photoperiod (16:8/Light: dark) and temperature (20 ± 2 °C), in plastic boxes with artificial soil prepared according to OECD (1984) and fed weekly with horse manure. The springtails were kept in laboratory cultures on a moist substrate of plaster of Paris and activated charcoal, at 18 °C in the dark, and fed weekly with dried Baker's yeast. Seeds of *Brassica rapa* were purchased from Carolina Biological Supply Company (US) and caryopsis of *Triticum aestivum* from a local supplier (Aveiro, Portugal).

Collembolans are abundant and distributed worldwide (Hopkin, 1997) whose role is to contribute to the decomposition of leaf litter (Klironomos et al., 1999), representing also a key position in the soil food web as a prey and consumer (Fountain and Hopkin, 2004). In addition, they have shown to be vulnerable to the effects of soil contamination (Fountain and Hopkin, 2005). Earthworms are ubiquitously distributed (Diao et al., 2007) and their feeding and burrowing activity facilitates the nutrient cycling, increases soil organic matter, changes the activity of microorganisms and consequently soil fertility and nutrient availability to plants (Coleman and Ingham, 1988; Haynes et al., 2003). They are generally good indicators of the relative health of soil ecosystems (Kuhle, 1983; Spurgeon and Hopkin, 1996). Also, terrestrial plants play a very important role in ecosystems, as they are an important source of organic matter, act in nutrient cycling and soil