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The effects of temperature on decomposition and allelopathic phytotoxicity of boneseed litter

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ABSTRACT

Decomposition of plant litter is a fundamental process in ecosystem function, carbon and nutrient cycling and, by extension, climate change. This study aimed to investigate the role of temperature on the decomposition of water soluble phenolics (WSP), carbon and soil nutrients in conjunction with the phytotoxicity dynamics of *Chrysanthemoides monilifera* subsp. *monilifera* (boneseed) litter. Treatments consisted of three factors including decomposition materials (litter alone, litter with soil and soil alone), decomposition periods and temperatures (5–15, 15–25 and 25–35°C (night/day)). Leachates were collected on 0, 5, 10, 20, 40 and 60th days to analyse physico-chemical parameters and phytotoxicity. Water soluble phenolics and dissolved organic carbon (DOC) increased with increasing temperature while nutrients like SO_4^{-2} and NO_3^{-1} decreased. Speed of germination, hypocotyl and radical length and weight of *Lactuca sativa* exposed to leachates were decreased with increasing decomposition temperature. All treatment components had significant effects on these parameters. There had a strong correlation between DOC and WSP, and WSP content of the leachates with radical length of test species. This study identified complex interactivity among temperature, WSP, DOC and soil nutrient dynamics of litter occupied soil and that these factors work together to influence phytotoxicity.

Introduction

Decomposition of plant litter, a fundamental process of an ecosystem's function, is essential to carbon and nutrient cycling, and consequently, may influence climate. Research has suggested both positive (Northup et al., 1998) and negative (Xiong and Nilsson, 2001) impacts of litter decomposition on the environment. The impact of some environmental parameters such as soil quality and microorganisms on litter decomposition has been well established (Kobayashi, 2004). The mechanisms underpinning the positive impacts of litter decomposition are widely recognised and include: controlling soil erosion, preserving moisture, providing soil nutrients, reducing weed infestations, and providing habitat for soil fauna (Davies, 1988; Facelli and Pickett, 1991; Holland and Coleman, 1987; McGinnies, 1987). However, there are negative impacts related to: the release of greenhouse gases (Schlesinger and Andrews, 2000), leaching of allelochemicals (Unger et al., 2010), physical impediment (Jones et al., 1997), reduced light penetration (Foster and Gross, 1998), and detrimental effects on beneficial soil microorganisms (Rice, 1965). Litter carbon, mineral and toxin decomposition and their potential possible positive or negative feedback on soil processes and the local plant community are controlled by the types and quantity of the litter, soil characteristics, soil microorganisms and climate, in particular temperature and rainfall (Beare et al., 1992; Hobbie, 1992, 1996; Salamanca et al., 2003; Saura-Mas et al., 2012).

In the last few decades, studies on litter decomposition have focused on carbon balance and climate change (Cramer et al., 2001; Davidson and Janssens, 2006), nutrient cycling (Flanagan

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and Cleve, 1983), and, more recently, effects of litter on biodiversity (Harun et al., 2014; Kumar et al., 2009). Comparatively few of these recent investigations have probed the mechanisms underpinning the effects of litter on biodiversity. Litter allelopathy, although considered an important mechanism influencing plant community structure (Lodhi, 1978), has been little studied in dynamic relation to other parameters including temperature, soil carbon and nutrient content, and phytotoxicity. An et al. (2002) suggested that it is important to include both intrinsic and extrinsic factors in the study of residue allelopathy as they function interactively. There have been studies on the impacts of aerobic and anaerobic conditions on litter decomposition and phytotoxicity (Uddin et al., 2014b), however, the influence of temperature on these processes has not been investigated. Kinetic theory postulates that the constraints to decomposition that are caused by biological and chemical processes must themselves be affected by temperature (Thornley and Cannell, 2001) and other climate-related drivers. May and Ash (1990a, 1990b) suggested that allelochemicals decay over time, but only tested this under constant temperature. Likewise, temperatures that simulate those in nature have received no attention in relation to decomposition times and decomposition materials. The impact of temperature on the fate of allelochemicals remains largely unanswered even though the role of temperature and seasonal variation is critical to understanding the decomposition of allelopathic components in litter and their relative phytotoxicity (Steinsiek et al., 1982).

There has been an increasing focus on temperature in relation to soil organic matter decomposition in recognition of its importance to the global carbon cycle and the contribution of decomposition to climate change. Litter decomposition and its impact on nutrient availability and net primary production have been identified as a major driver of species diversity and richness (Shaver and Chapin, 1986). Mitchell et al. (2011) in a study on invasive species, suggested season-varied, and thus temperature related impacts on nitrogen mineralization and immobilization, soil carbon decomposition and microbial activities. Allelochemicals produced by plants may exhibit a phytotoxic effect, including effects on decomposition rates of soil organic matter, and may, in some cases impact directly on available nitrogen and phosphate content of soil organic matter (Inderjit and Mallik, 1997). Polyphenolics are the main components of plant allelochemicals that are associated with litter decomposition and nitrogen cycling mechanisms and are primarily responsible for the observed phytotoxic effects (Baldwin et al., 1983; Gosz, 1981; Inderjit, 1996; Rice, 1984).

Previous studies have suggested that allelopathy may play as important a role as competition for soil moisture, nutrients, sunlight, and space in determining plant community structure (Inderjit and Dakshini, 1994). Plant-plant negative interactions through the release of allelochemicals in the mode of volatilization (Halligan, 1975), root exudation (Liu et al., 2013; Uddin et al., 2014a), decomposition of residues in soil (Bonanomi et al., 2005), and leaching (Ens et al., 2009; Uddin et al., 2012) are well established. More specifically, plant litter may affect seed germination and seedling growth of neighbouring species (Rice, 1984). The dynamics of phytotoxicity may be either increased or decreased by the change in the composition and quantity of allelochemicals in association with litter decomposition time (An et al., 2001). Additionally, allelochemical concentrations have been found to seasonally vary in their specific content and related phytotoxicity (Yamamoto, 1995). Allelopathins of plant litter may have direct impacts, through leaching, on plant growth (Bonanomi et al., 2005), or indirect effects by reducing soil nutrients and affecting the soil microbial community (Teuben, 1991).

Weeds under nutrient stress may produce large quantity of allelochemicals, and similarly, crops under conditions of nutrient scarcity accumulate higher amount of allelochemicals. Residues of such crops may exhibit phytotoxicity (Inderjit and del Moral, 1997). Nutrient immobilization, depletion of O_2 in the soil, toxicity of CO_2 produced in soil, and allelochemicals may, together, determine the phytotoxicity of litter on neighbouring species (de Jong and Klinkhamer, 1985; Rice, 1979). Although the allelopathic effects of plant residues have been extensively studied (Horner et al., 1988; May and Ash, 1990a, 1990b), the impact of temperature on the fate of these toxins and their phytotoxicity remain unknown. There is a need to investigate the impact that temperature has on litter decomposition and subsequent phenolic concentration, soil nutrient availability and phytotoxicity dynamics.

Boneseed (*Chrysanthemoides monilifera* subsp. *monilifera*), a Weed of National Significance in Australia and listed on the National Pest Plant Accord in New Zealand, has been identified as a major source of phytotoxic allelochemicals and a plant of serious ecological impacts on native species (Groves, 2008; Harun et al., 2014; Weiss et al., 2008). Boneseed infestations have also occurred in South Africa, USA and France (Weiss et al., 1998). Boneseed develops monocultures in areas of undisturbed native vegetation because of its prodigious potential for spread and regeneration, absence of natural enemies, competitive capacity and is seen as a major threat due to its fire hazard, economic and environmental impacts and its threat to native species (Parsons, 1973; Rudman, 2001; Thomas et al., 2005; Thorp and Lynch, 2000; Vranjic et al., 2000; Weiss et al., 1998). Collectively the two sub-species of *C. monilifera* (subsp. *monilifera and* subsp. *rotundata*) threaten about 200 indigenous species in Australia (Department of Environment Conservation, 2006), including significant rare species such as *Pterostylis truncata* in Victoria. This highly invasive woody shrub drops allelochemical laden litter throughout the year although the quantity varies with season and geographical location (Lindsay and French, 2005; Melland, 2009). Litter and soil properties in boneseed infested areas inhibit germination and growth of native species (McAlpine et al., 2009). We have recently described the significant allelopathic impacts of boneseed on model species and associated native species (Harun et al., 2014).

The current study aimed to investigate the role of temperature in the decomposition of water soluble phenolics (WSP), carbon and nutrients in boneseed litter-mediated soil in relation to phytotoxicity dynamics.

1. Materials and methods

1.1. Sample collection and processing, and seed collection

The You Yangs Regional Park, Victoria (37° 59′ 44″ S, 144° 24′ 39″ E) was selected as the study area as it is representative of