Side-effects of herbicides on the soil microbial biomass

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Summary
The soil microbial biomass is highly important in regulating ecosystem-level processes. However, there are relatively few published accounts on the side-effects of herbicide applications on this component of the soil biota. A review of previously conducted studies in this area demonstrates that although the microbial biomass can be highly responsive to herbicide applications, the results may be influenced either by the herbicide concentration used (laboratory experiments) or by different weed levels between treated and untreated plots (field experiments). Herbicides may exert short-term disturbance effects on the microbial biomass but these influences are frequently minor when compared with natural spatial and temporal variation in the soil microbial biomass, especially as influenced by climate. Studies on glyphosate suggest that some herbicides may enhance growth of the microbial biomass, through the herbicide acting as a resource and thus reducing fungal interspecific competition.

Introduction
The soil microbial biomass is increasingly becoming recognised as a highly important component of most terrestrial ecosystems, since it is the component of the soil biota which is directly responsible for regulating nutrient cycling, litter decomposition and energy flow. While the effects of herbicides on some aspects of the soil biota have been extensively studied (e.g. soil processes, bacterial populations), relatively few have considered the influence of herbicides on the entire microbial biomass (8). The purpose of this paper is to review those studies which have investigated the side effects of herbicides on the soil biota, and to utilise this information to assess the potential threat to the soil ecosystem caused by herbicide usage.

Response of microbial biomass
The results of previous studies which have assessed the response of the microbial biomass to herbicides is shown in Table 1. These have all been performed in temperate locations, and with one exception have all included soils from arable systems.

Studies which have investigated microbial biomass responses in laboratory incubations have typically found the response of this component to be slight or non-detectable at concentrations below 20-30 μg a.i./g soil, suggesting that microbial responses to herbicides in steady-state conditions may be relatively small. While such studies enable detailed assessment of the mechanisms of interaction which may occur between herbicides and the microbial biomass (7), it is difficult to utilise these results to predict the likely effects of the herbicides in the field. This is because they are usually conducted in the absence of plants (thus eliminating potential interactions with microbes associated with the rhizosphere) and because concentrations of herbicides applied to incubated soil samples are frequently

Table 1. Short-term influences of herbicide applications on measurements of soil microbial biomass.

Ref.	Location and land use	Herbicide and rate	Response of microbial biomass
Laboratory experiments		*(rate in µg a.i./g soil)*	
1	N. Carolina, U.S. (forestry)	hexazinone(2)+ glyphosate(4)	apparent decline
4	Michigan, U.S. (arable)	atrazine(30)	no effect
5	Italy (arable)	atrazine(2,20,200)	no effect
7	France	2,4-D(3.2)	no effect
8	Alberta, Canada (barley)	2,4-D(2,20,200)	0-23% decline
		glyphosate(2,20,200)	0-27% enhancement
		picloram(2,20,200)	0-25% decline
Field experiments		*(rate in kg ha^{-1})*	
3	England (vegetables)	repeated MCPA(1.6)	no effect
		repeated simazine(1.6)	no effect
		repeated paraquat(4.5)	42% decline
6	Czechoslovakia (barley)	atrazine(20)	13% decline
11	Alberta, Canada (barley)	2,4-D(3)	29% enhancement
		glyphosate(4)	no effect
12	Alberta, Canada (barley)	2,4-D(4)	no effect
		glyphosate(5)	0-23% enhancement

difficult to relate to concentrations of herbicides actively present in the field following application (2, 11).

Field studies have demonstrated that herbicides may have neutral, stimulatory or inhibitory effects on the microbial biomass, and these effects may be relatively strong. It is often not possible to distinguish, however, whether such side effects affect the microbial biomass directly, or indirectly through the herbicide killing weed biomass and/or influencing crop growth, thus influencing the quality and amounts of organic matter returned to the soil system. Wardle and Parkinson (12) determined that herbicide stimulation of the microbial biomass was often detectable only in the weedy (and not in hand-weeded) plots, indicating that the microbial biomass is highly responsive to organic matter enhancement caused by weed death due to herbicide spraying.

All the detected herbicide effects in Table 1 were relatively short term, indicative of both the rapid microbial response-time and recovery-time to pesticide additions. Furthermore, the magnitude of observed responses of the microbial biomass to herbicide applications may often by relatively small when compared with the response of the microbial biomass to temporal and spatial variation in soil chemical and physical factors (2). Thus, Wardle and Parkinson (10, 11) demonstrated that short-term responses of the microbial biomass to 2,4-D, even when highly statistically significant, were frequently of relatively minor importance when the data were compared against a background of natural variability in the microbial biomass caused by soil microclimate. For example, while herbicide additions were observed to cause microbial biomass values to change by around 20%, wetting-drying cycles could induce microbial biomass shifts of ±80%.

Mechanisms of microbial biomass enhancement

The microbial biomass is frequently stimulated by herbicide addition, and in the case of glyphosate, this is probably through glyphosate acting as a resource, resulting in a stimulation of fungal growth (8). Wardle and Parkinson (9) demonstrated that slight enhancements of microbial biomass caused by glyphosate were accompanied by large shifts in fungal community structure, and biomass increases were coincident with increases in frequency of the principal species present. A subsequent study (13) indicated that glyphosate had the potential to eliminate fungal interspecific antagonism, thus promoting the abundance of many of the fungal species present, and henceforth the total microbial biomass. Further work is needed in this area to determine whether such mechanisms are widespread.

In conclusion, soil microbial biomass demonstrates a variable response to herbicide applications, and based on the limited numbers of studies conducted to date, no universal pattern emerges. Despite the problems associated with methodology, the microbial biomass remains a highly useful bioindicator of herbicide side-effects because of its sensitivity to soil disturbance, enabling it to reflect the ecosystem-level effects of herbicide application.

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