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Hot foam for weed control—Do alkyl polyglucoside surfactants used as foaming agents affect the mobility of organic contaminants in soil?

H. Cederlund*, E. Börjesson

Swedish University of Agricultural Sciences, Uppsala BioCenter, Department of Microbiology, Box 7025, Uppsala, Sweden

HIGHLIGHTS

- An APG concentration of 0.3% did not affect mobility of organic contaminants.
- An APG concentration of 1.5% increased leaching of diuron and glyphosate.
- APGs increased water solubility of diuron and PAHs but not of glyphosate.
- APGs decreased adsorption of glyphosate but increased adsorption of diuron.
- Leaching of PAHs appeared to be decreased but the effect was not significant.

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ABSTRACT

Use of alkyl polyglucosides (APGs) as a foaming agent during hot water weed control may influence the environmental fate of organic contaminants in soil. We studied the effects of the APG-based foaming agent *NCC Spuma* (C8-C10) on leaching of diuron, glyphosate, and polycyclic aromatic hydrocarbons (PAHs) in sand columns. We also examined how APG concentration affected the apparent water solubility and adsorption of the herbicides and of the PAHs acenaphthene, acenaphthylene and fluorene. Application of APGs at the recommended concentration of 0.3% did not significantly affect leaching of any of the compounds studied. However, at a concentration of 1.5%, leaching of both diuron and glyphosate was significantly increased. The increased leaching corresponded to an increase in apparent water solubility of diuron and a decrease in glyphosate adsorption to the sand. However, APG addition did not significantly affect the mobility of PAHs even though their apparent water solubility was increased. These results suggest that application of APG-based foam during hot water weed control does not significantly affect the mobility of organic contaminants in soil if used according to recommendations. Moreover, they suggest that APGs could be useful for soil bioremediation purposes if higher concentrations are used.

1. Introduction

This study was performed as part of an evaluation of a hot water weed control method, modified by the addition of a foaming agent consisting of alkyl polyglucosides (APGs), for use on rail yards and railways in Sweden. Weeds on railways are normally controlled by herbicides, some of which may cause contamination of groundwater adjacent to the railway [1,2]. However, the number of no-spray zones on railways, put in place primarily to protect groundwater, is currently increasing in Europe, creating a need to find other ways of controlling weeds. The main alternatives to using chemical pesticides on non-crop areas are mechanical or thermal weed control methods [3]. The principle of the thermal methods is transfer of heat energy to the plant in order to cause destruction of cell structures and denaturation of proteins. Hence, the energy dose, *i.e.* the amount of energy applied per unit surface area, is a critical parameter that can determine the efficacy of weed control. An appropriate dose may decrease the required treatment frequency and increase the overall energy use efficiency [4,5]. APGs are added to the hot water treatment in order to create a foam layer on the treated surface. The rationale is that the foam insulates the weeds from the surrounding air and increases the energy transfer to the plant, thus lowering the energy dose required and increasing the efficiency. Hot foam treatments have been shown to be more efficient than methods using hot air, open flame or steam [6]. However, direct comparisons between hot water with and without foam are currently not available in the scientific literature, so it is difficult to quantify the importance of this insulating effect. Notably,

* Corresponding author.
E-mail address: harald.cederlund@slu.se (H. Cederlund).

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other mechanisms explaining an increased effect are possible, *e.g.* Hansson and Mattson [7] observed a 27% increase in weed control efficacy following the addition of another (non-foaming) wetting agent, but attributed this to the herbicidal activity of the wetting agent itself.

Alkyl polyglucosides are non-ionic surfactants made up of a hydrophilic sugar moiety coupled to a hydrophobic alkyl chain. Commercial products are typically mixtures characterised by the length of their alkyl chain and by their average degree of polymerisation (*i.e.* number of glucose molecules) [8,9]. APGs are used for many different purposes including as detergents and in personal care products. Due to their manufacture from renewable precursors, such as starch and fatty alcohols, their inherent high biodegradability [10–12] and their comparatively low toxicity [12–14], APGs are generally perceived as "natural" or "green" surfactants, posing low risk to humans and to the environment. Use of APGs has extended into a range of different environmental applications, *e.g.* they have been found to stimulate the composting of agricultural wastes [15], increase the biodegradation of polycyclic aromatic hydrocarbons (PAHs) [16,17], increase the biodegradation of diesel oil [18] and enhance the washing of crude oil contaminated soils [19]. The common theme of these studies is that APGs generally appear to increase the water solubility and bioavailability of organic contaminants in soil. Railways are well known to be potential sources of both organic and inorganic contaminants [20,21]. Sources of organic contaminants include oil spills, pesticide application [22] and creosote-treated wooden railway sleepers [23,24]. Application of APGs to railways may thus increase the biodegradation but also, crucially, the mobility of such contaminants. The latter is of concern since hot water weed treatments are likely to be predominantly used in non-spray zones created to protect groundwater.

The aim of this study was to investigate whether use of a commercial alkyl polyglucoside-based foaming agent during hot water weed control has the potential to increase leaching of organic contaminants in the railway environment. The working hypothesis was that the effects of APG addition are slight or undetectable when APGs are applied at realistic field rates. We tested this hypothesis by studying the leaching behaviour of two herbicides, glyphosate and diuron, as well as that of PAHs, in a sand column system with and without the addition of APGs. In order to elucidate the mechanisms by which APGs could affect leaching, its effects on the apparent water solubility and adsorption of the model compounds to the sand used in the columns were also studied. The model compounds were all chemicals that are either currently used or could be expected to be present in the railway environment. Glyphosate is the most widely used herbicide for weed control on European railways today. It is a broad spectrum post-emergent herbicide generally considered to have low inherent leachability in non-structured soils such as railways [25,26]. Diuron is a pre-emergent herbicide which is no longer used on railways in Europe but is still used in non-crop areas elsewhere in the world. It is known to be both more persistent and more mobile than glyphosate when used on railways [22]. PAHs are present in wooden railway sleepers impregnated with creosote and may leach out into the ballast [23].

2. Experimental

2.1. Chemicals

Certified pesticides: *diuron* (3-(3,4-dichlorophenyl)-1,1-dimethylurea, CAS[330-54-1], 97.9%) and *glyphosate* (*N*-(phosphonomethyl)glycine, CAS[1071-83-6], 98%), were obtained from Dr. Ehrenstorfer, Augsburg, Germany. Radiolabelled *diuron* [ring-U-^{14}C], 96.4%, 5.71 MBq mg^{-1} was obtained from Institute of Isotopes Co., Ltd., Budapest, Hungary. [^{14}C] glyphosate, ARC 1313 glyphosate-[phosphonomethyl-^{14}C], 50 mCi mmol^{-1}, was obtained from American Radiolabeled Chemicals, Inc., St. Louis, MO. Quicksafe A (Scintvaruhuset LAB-service, Uppsala, Sweden) was used for the scintillation counting analysis. PAH-Mix 9, 100 ng/μl in acetonitrile, used for spiking the sand in the leaching test, and PAH-Mix 9, 100 μg/ml in cyclohexane used as reference standard for GC–MS evaluation, both containing 16 different PAHs, were obtained from LCG Limited, Hannover, Germany. *Acenaphthene*, CAS[000083-32-9], 99%, and *fluorene*, CAS[000086-73-7], 98.2%, were obtained from LCG Limited, Hannover, Germany and *acenaphthylene*, CAS[208-96-8], 99%, from Dr. Ehrenstorfer, Augsburg, Germany. The foaming agent used (NCC Spuma), containing APGs with an alkyl chain of 8–10 carbons (C8–C10) (main constituent identified in the MSDS as decyl glucoside, CAS[68515-73-1], purity not stated) was a gift from NCC Skumextrakt, NCC Roads A/S, Vejen, Denmark.

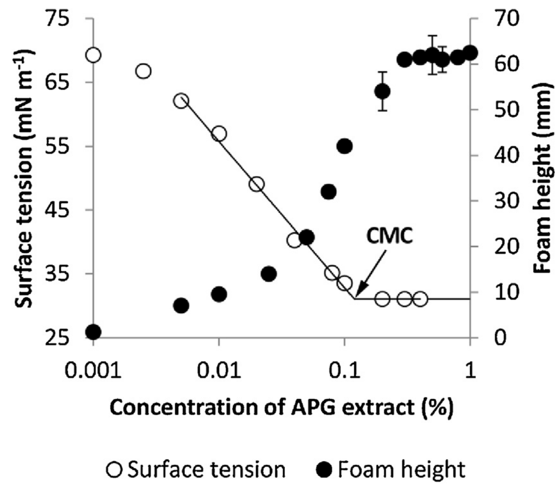

Fig. 1. Effect of alkyl polyglucoside concentration (log scale) on surface tension (N = 3) ± standard deviation and foam formation in a shaking experiment (N = 2) ± standard deviation. The arrow indicates the critical micelle concentration (CMC).

2.2. Surface tension and foam formation

Surface tension values of 0–0.4% APG solution were measured on a Krüss K6 manual tensiometer using the ring tear-off method. The measured values of interface tension were corrected according to Harkins and Jordan [27]. The critical micelle concentration (CMC) was determined as the inflection point in a plot of the surface tension against the log APG concentration, *i.e.* the point where the lowest surface tension is reached (Fig. 1). Foam formation was studied using a simple shaking test where 2.5 ml of APG solution with concentrations between 0 and 1% were added to new 12-ml glass tubes with screw caps. The tubes were vigorously shaken by hand for 10 s and then allowed to settle for 10 s before the height of the foam was measured (Fig. 1).

2.3. Column leaching experiment

The test system followed the recommendations of the OECD guidelines for the Testing of Chemicals, Test no 312 for leaching in soil columns. Glass columns (37 cm length, 4 cm inner diameter; Saveen & Werner AB, Limhamn, Sweden), with a glass sinter plate in the bottom, were packed with washed sand (Ø = 0.5 mm; Rådasand AB, Lidköping, Sweden). Sand was added to the columns in small portions and the columns were packed by gently tapping them on a soft rubber plate.