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Comparison of cellulose vs. plastic cigarette filter decomposition under distinct disposal environments

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ABSTRACT

It is estimated that 4.5 trillion cigarette butts are discarded annually, making them numerically the most common type of litter on Earth. To accelerate their disappearance after disposal, a new type of cigarette filters made of cellulose, a readily biodegradable compound, has been introduced in the market. Yet, the advantage of these cellulose filters over the conventional plastic ones (cellulose acetate) for decomposition, remains unknown. Here, we compared the decomposition of cellulose and plastic cigarettes filters, either intact or smoked, on the soil surface or within a composting bin over a six-month field decomposition experiment. Within the compost, cellulose filters decomposed faster than plastic filters, but this advantage was strongly reduced when filters had been used for smoking. This indicates that the accumulation of tars and other chemicals during filter use can strongly affect its subsequent decomposition. Strikingly, on the soil surface, we observed no difference in mass loss between cellulose and plastic filters throughout the incubation. Using a first order kinetic model for mass loss of for used filters over the short period of our experiment, we estimated that conventional plastic filters take 7.5–14 years to disappear, in the compost and on the soil surface, respectively. In contrast, we estimated that cellulose filters take 2.3–13 years to disappear, in the compost and on the soil surface, respectively. Our data clearly showed that disposal environments and the use of cellulose filters must be considered when assessing their advantage over plastic filters. In light of our results, we advocate that the shift to cellulose filters should not exempt users from disposing their waste in appropriate collection systems.

1. Introduction

With an estimated 4.5 trillion cigarettes discarded every year in the environment, cigarette butts are the most common type of litter on earth (Novotny et al., 2009) and are typically found in many ecosystems from urban and peri-urban areas to beaches and oceans (Ariza et al., 2008). Aside from being unsightly, they represent a serious threat to organisms and ecosystems as they are toxic to microbes, insects, fish and mammals (Novotny et al., 2011). Since these filters are made of plasticized cellulose-acetate inaccessible to microbes for biological decomposition (Zugenmaier, 2004), they likely accumulate and the environmental issue they cause keeps rising. Consequently, the tobacco-industry has developed in the last decade an environmentally-friendly alternative to conventional plastic filters, consisting of filters made of pure cellulose, i.e. a molecule that is entirely biodegradable by soil and aquatic microbial communities (Berg and McClaugherty, 2008). However, the relative advantage of these filters for decomposition remains unknown.

In the only peer-reviewed publication that assessed the decomposition of conventional cigarettes filters, Bonanomi et al. (2015) reported that while the paper wrapped around the filter was readily decomposed, the plastic part was mostly unaffected after two years of decomposition. In turn, the OCB® brand for instance, that sells filters for hand-rolling cigarettes, advertises an almost complete decomposition of cellulose filters in 28 days. However, these results, coming from a test made by an independent laboratory following the 301B biodegradability protocol of the Organization for Economic Cooperation and Development (OECD), have not been published, and do not compare with the decomposition of conventional plastic filters, making it impossible to evaluate the advantage of cellulose filters over the plastic ones. Particularly, given the predominant control of environmental conditions on biotic litter decomposition (Berg and McClaugherty, 2008), the decomposi-

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tion of the cellulose filters is likely to vary widely depending on their disposal environment. In contrast, environmental conditions were shown to have no effect on decomposition of plastic cigarette filters (Bonanomi et al., 2015). Consequently, in composts, where environmental conditions are prone to microbial activity, the relative advantage of cellulose filters over the plastic ones may be reinforced. Moreover, the goal of the OECD protocol is to evaluate the biodegradability of the substance out of which the product is made without necessarily taking into account its previous use. Such potential decoupling of the test from realistic conditions could importantly limit the validity of the results. Indeed, once the cigarette is smoked, the filter gets charged with a large variety of compounds including tars, carcinogenic compounds and numerous metals (Hoffmann, 1997; Moerman and Potts, 2011), which leads to an increased toxicity of filters for wildlife (Dieng et al., 2013; Slaughter et al., 2011; Suárez-Rodríguez et al., 2013) as well as microorganisms (Micevska et al., 2006). Consequently, the microbial decomposition of cellulose filters is likely to be substantially decreased for smoked filters, decreasing the relative advantage of cellulose filters over plastic ones.

In this study, we aimed at providing some very first robust scientific data assessing how much faster cellulose filters decompose compared to their plastic equivalents. During a six-month incubation under field conditions (Mediterranean old-field), we compared the decomposition of cigarettes filters made out of cellulose (and so-called hereafter) and cellulose acetate (called 'plastic' hereafter). To determine the advantage of composting over simple discarding, we compared decomposition on the soil surface to that within a composting bin (referred to as 'compost' hereafter). Finally, to evaluate the importance of filter use on their decomposition, we compared the decomposition of smoked and new filters. We hypothesized that (i) cellulose filters would decompose considerably faster than plastic filters, that (ii) smoked filters would decompose more slowly compared to new filters, and that (iii) these effects would be more pronounced in a compost where decomposition would be hastened.

2. Methods

2.1. Filters

Cigarette filters of the OCB® brand, made for hand-rolling cigarettes, were purchased in 2013. We selected slim filters (length × diameter: 15 × 6 mm) of two different qualities, one made of cellulose acetate (plastic), and one made of cellulose (cellulose). To study the effect of smoking on the subsequent decomposition of filters, cigarette butts were collected from voluntary smokers that collected their own cigarette butts in portable ashtray, and used filters of both plastic and cellulose filter from the same aforementioned brand. Filters were then retrieved from the cigarette butts. All types of filters were then dried at 60 °C for 48 h, weighed and placed in a 25 × 25 mm litterbags made of polyethylene (mesh size: 0.6 × 0.5 mm).

2.2. Experimental design

Litterbags containing all types of filters were placed to decompose in the experimental field of the Center of Evolutionary and Functional Ecology, on February 21, 2014, under two conditions, either directly on the soil surface of a Mediterranean old-field, or buried in a plastic container containing compost. The compost consisted in a mixture of green manure made of ramial chipped wood and mature compost to ensure microbial inoculation. The first condition corresponds to the scenario where butts are thrown on the soil and remain there to decompose, while the second condition corresponds to the scenario where butts would be collected and composted with other organic waste. The climatic conditions at the study site are typically Mediterranean, with a mean annual temperature of 15 °C and a mean annual precipitation of 570 mm (average of the 1981–2010 period). Over the 5.4 months of the experiment, cumulated precipitation was 124 mm, with an average temperature of 17.4 °C. The experimental design included four factors: filter type (plastic vs cellulose), use (smoked vs unsmoked), soil conditions (soil vs compost) and length of incubation (five harvests). As all factors were crossed, we obtained 40 treatment combinations. For each combination, six replicates were placed in six separate blocks and litterbags were randomized within each block. The six replicates of the smoked filters consisted of three filters from each smoker to allow testing for the smoker effect. To ensure the start of microbial decomposition both on the soil surface and in the compost, all blocks were watered at the beginning of the experiment, with additions of 20 mm precipitation pulses. Additionally, to ensure optimal conditions for microbial decomposition in the compost, the plastic containers were rewetted every month with additions of 10 mm precipitation pulses. Litterbags were harvested at five different times (2, 4, 8, 16, 32 weeks) after the start of the experiment. At each harvest, filters were cleaned to remove soil particles, dried at 60 °C for 48 h and weighed to determine the mass loss. In order to assess the amount of mass loss due to leaching for all filter treatments (plastic and cellulose filters, both smoked and unsmoked), we ran an additional leaching experiment. To do so, 10 filters of each filter treatments were dried at 60 °C for 48 h, weighed and placed separately in a Falcon® tube with 15 ml of deionized water placed on a rotator spinning at 8 rpm for 24 h (Joly et al., 2016). Filters were then dried at 60 °C for 48 h and weighed to determine mass loss. For both experiments, mass loss was expressed in percentage of initial litter oven-dry weight.

2.3. Data analysis

First, to ensure that the decomposition process was not affected by the identity of the smoker, the smoker effect (n = 3 per smoker) was evaluated separately using a one-way ANOVA and then with the others factor using a complete ANOVA model. As it was not significant in any case ($p > .05$), this factor was finally not taken into account for the final analysis. Then, at each harvest time, mass loss was compared across treatments using ANOVA model for split-plot design (Logan, 2011). Soil conditions (soil vs compost) was the main between-block factor whereas type of filter (plastic vs cellulose) and use (smoked vs unsmoked) were the within-block factors, and block was included as a random factor. For the additional leaching experiment, mass loss by leaching was compared across treatments (filter types and use) using a two-way ANOVA model. All data was checked for normal distribution and homoscedasticity of residuals. As both assumptions were met, analyses were made on non-transformed data. Finally, a first order kinetic decay model ($R_t = R_0 \times e^{-kt}$), in which R_t is the remaining mass at time t and k (d^{-1}) the decomposition constant, was fitted to the experimental data. The estimation of equation parameters was used to estimate the half-life of filters ($T_{50\%}$) and their total decomposition time ($T_{99\%}$). All statistical analyses were performed using the R software, version 2.14.1 (R Core Team, 2014).

3. Results

3.1. Effect of soil conditions

The decomposition of cigarette filters was strongly affected by soil conditions. At the end of the experiment, 92% of initial mass