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Decomposition of Artificial Litter Made of Polypropylene

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1. Introduction

Environmental pollution with plastic, especially polyolefins increased during the last decades. Due to recalcitrance of these substrates the studies on procedures speeding up the degradation and biological decomposition of polyolefins are carried intensively. The data concerning polypropylene (PP) disappearance rate are scarce comparing to the decomposition of polyethylene (PE) products (Ammala et al., 2011, Arutchelvi et al., 2008, Eubeler et al., 2010). It has been shown that pretreated PP disappear more quickly than poly(propylene-co-ethylene) (CPP) and PE polymers (Arutchelvi et al., 2008, Meligi et al., 1995, Sivan, 2011). However slower degradability of PP comparing to other plastics has been reported (Yang et al., 2005). It is known that UV radiation and weathering processes can speed up biodegradation processes of plastics in later stages of disappearance. Some studies of the PP and PE biodegradation showed that microorganisms, both bacteria and fungi, colonised the pre-treated or composted plastic substrata to greater extent comparing to control treatments (Ammala et al., 2011, Arutchelvi et al., 2008, Eubeler et al., 2010, Grunz et al., 1999, Meligi et al., 1995). There is a little information about the biodegradability of PP in the natural environment and impact of fresh organic matter input on PP decomposition. It seems that the natural input of nitrogen-rich organic matter both of plant and invertebrate origin might accelerate microbial activity and in consequence speed up the decomposition processes of recalcitrant materials (Crow et al., 2009, Dekker et al., 2005, Griffiths, 1994 Prévost-Bouré et al., 2010, Szanser, 2000).

The aim of the study was to compare the decomposition rate of the PP and natural plant litter (NPL). The hypothesis was that the decomposition of artificial litter made of PP will proceed effectively as in the case of natural litters due to additive effects of the input of plant and invertebrate remains into the litter.

2. Materials and methods

2.1 Study site and experimental design

The study was carried out in a permanent meadow of the type Arrhenatheretalia situated in the buffer zone of Kampinos National Park (52°15'30" N and 20°17' E, east-central Poland).

An experiment was conducted to compare the decomposition pattern of natural plant litters (NPL) and of artificial litter composed of natural not dyed PP agricultural string. The experimental meadow of an area of 190 x 10 m had 182 microplots (0.5 x 0.5m area and 0.15 m depth). Five natural and one artificial litter treatments in 32 and 22 plot replicates respectively according to RCB design were applied (Pearce, 1983). Eight litter containers per plot were placed. Natural litter was obtained from meadow plants, both grasses and weeds cut in August 2001 which had to simulate the input of decaying plants to soil. The same amount of PP and NPL (9 g dry wt.) irrespective of the number of plant species was exposed in modified litter containers. Experimental plots were filled with sand mixed with loam to the depth of 15 cm. Such type of simplified and uniform substrate, among them, enabled assessing the input of organic matter morphous particles in exposed litter and in underlying substrate.

Litter samples were mounted under stainless steel wires stuck into the substrate. In that way a more compact structure of exposed material which adhered to the substratum was obtained, providing fauna with better access to the litter without covering containers by a net on the top. NPL were either monospecific (I: *Dactylis glomerata*; II: *Festuca rubra* and III: *Trifolium pratense*) or were species mixtures (IV: mixture of three species I, II and III; V: mixture of twelve species, IV and nine other meadow plants). In the latter case, the following species were used: grasses: brome grass (*Bromus inermis*), meadow foxtail (*Alopecurus pratensis*), perennial ryegrass (*Lolium perenne*), oat grass (*Arrhenatherum elatius*), cocksfoot (*Dactylis glomerata*), and red fescue (*Festuca rubra*); and herbs: small plantain (*Plantago lanceolata*), common chicory (*Cichorium intybus*), red clover (*Trifolium pratense*), milfoil (*Achillea millefolium*), carrot (*Daucus carota*), and common silverweed (*Potentilla anserina*).

2.2 Sample collecting and processing

The experiment started on 24-25 March 2002. Samples were taken on 27 September 2002, 11 May 2004, 9 September 2004, i.e., 6, 26, and 30 months after litter exposure.

Litter and soil samples were taken per 5-11 in every sampling occasion. Soil samples for assessments of plant and invertebrate organic matter input were taken to the depth of 1 cm with a soil corer 100 cm^2 in area.

2.3 Plant and invertebrate materials

2.3.1 Litter mass loss

Litter mass loss was determined using the gravimetric method by drying at 65^{o}C.

2.3.2 Input of wind-borne plant matter and invertebrate remnants into litter and underlying substrate

The input of the remnants of invertebrate origin (exuviae, cocoons, other remants) was assessed in the litter and soil layer 0-1 cm underneath the litter by hand-sorting and using the stereoscope microscopy.

2.4 Statistical analysis

Statistical analyses of results (one-way *ANOVA* and regression) were performed using Statistica 8.0. software (StatSoft, Inc. (2007). Natural litter and remnants' data had no normal distribution. Only total data for PP litter and remnants had normal distribution. Differences in mass of litter and remnants between treatments were assessed using non-parametric Wilcoxon Sum-of-Ranks (Mann-Whitney) test for comparing two unmatched samples. The regression between masses of remaining litter and remnants were assessed using the Kendall tau Rank Correlation test and linear regression analysis for natural and polypropylene treatments, respectively.

3. Results

3.1 Litter decomposition

The highest values of the NPL mass loss were recorded in the initial period, while the loss of PP litter was the slowest (Table 1). In the first 6 months following exposure, the loss of dry weight mass of litter reached 59.8 and 28.1% respectively for NPL and PP treatments (Table 1). Later, further losses of litter, during over two years period, were observed being 70.53 and 72.45% for NPL and PP treatments respectively. In the final period, i.e., between the 26th and 30th months of the experiment, the increases of both types litter mass were larger than its losses. This could be explained by the organic matter (of plant and animal origin) input and colonisation of the litter by invertebrates and microorganisms during long period of the exposure (2.5 years).

Months since beginning of the experiment		Litter type NPL	PP	Significance of differences between treatments
6	g dry weight m^{-2}	362.28 (7.22)	646.78 (24.69)	n = 55, W = 502.5, p<=0.00000
	%	40.25	71.86	
26	g dry weight m^{-2}	265.26 (9.98)	337.98 (28.61)	n = 35, W = 106.5, p<=0.4229
	%	29.47	37.55	
30	g dry weight m^{-2}	293.78 (14.23)	360.88 (58.91)	n = 35, W = 111.5, p<=0.1573
	%	32.64	40.1	

Table 1. Mass (g dry weight m^{-2}) of remaining and percent (%) of initial mass of exposed natural plant (NPL) and polypropylene (PP) litter during the course of the experiment. Significance of differences between treatments are assessed by non-parametric Wilcoxon Sum-of-Ranks (Mann-Whitney) test. All data from five natural litter treatments (I: *Dactylis glomerata*; II: *Festuca rubra* and III: *Trifolium pratense*), IV: mixture of three species I, II and III; V: mixture of twelve species, IV and nine other meadow plants) were analyzed with the exception of 26th month where only data of treatments I and III were used. Standard errors in parentheses.

Differences between NPL(data taken together) and PP treatments in the litter decomposition rate resulted from litter origin. Remaining mass of artificial litter (PP) was higher in every sampling time by 43.9%, 27.4% and 22.8% comparing to natural (NPL) ones respectively after 6, 26 and 30 months of the experiment but the differences were significant only for the first sampling occasion (Table 1). Interestingly slight increase of litter mass occurred in PP treatment similarly as in natural litter at the end of the experiment.

3.2 Input of plant and invertebrate remnants

There was considerably large input of wind-borne plant material into exposed litter. It was still low after 6 months of the experiment and was particularly high by the 26th month. There was further slight increase of plant remnants input between 26th and 30th month of the experiment. PP litter had significantly higher input of wind-borne plant matter comparing to NPL only after 6 months of the experiment (Table 2). Later the differences between treatments were not significant. The values of wind-borne plant materials were 43.4 and 39.6 g dry wt. m^{-2} for NPL and PP treatments respectively at the end of the experiment. This input constituted 4.82 and 4.4 % of the initial mass of natural and artificial litter, respectively. Much smaller was the mass of invertebrate origin (exuviae, cocoons, other remnants) found in both treatments but the differences between treatments were not significant (Table 3). The mass of invertebrate remnants amounted to 2.0 and 1.2 g dry wt. m^{-2} for NPL and PP treatments respectively at the end of the experiment.

Months since beginning of the experiment	Litter type NPL	PP	Significance of differences between treatments
6	3.71 (0.37)	9.31 (1.99)	n = 60, W = 305, p <= 0.9921
26	36.77 (9.26)	14.14 (2.67)	n = 24, W = 69, p <=0.7139
30	43.40 (5.72)	39.60 (15.52)	n = 51, W = 138, p <= 0.6089

Table 2. Mass of wind-borne plant remnants (g dry weight m^{-2}) in natural plant (NPL) and polypropylene (PP) litter during the course of the experiment. Differences between treatments are assessed by non-parametric Wilcoxon Sum-of-Ranks (Mann-Whitney) test. All data from five natural litter treatments (I: *Dactylis glomerata*; II: *Festuca rubra* and III: *Trifolium pratense*), IV: mixture of three species I, II and III; V: mixture of twelve species, IV and nine other meadow plants) were analyzed with the exception of 26th month where only data of treatments I and III were used. Standard errors in parentheses.

Months since beginning of the experiment	Litter type NPL	PP	Significance of differences between treatments
6	1.48 (0.23)	2.49 (0.50)	n = 60, W = 305, p <= 0.9921
26	0.85 (0.33)	0.58 (0.33)	n = 24, W = 75, p <= 0.9734
30	2.00 (0.36)	1.17 (0.33)	n = 51, , W = 156, p <= 0.9883

Table 3. Mass of invertebrate remnants (g dry weight m^{-2}) in NPL and PP litter during the course of the experiment. Differences between treatments are assessed by non-parametric Wilcoxon Sum-of-Ranks (Mann-Whitney) test. All data from five natural litter treatments (I: *Dactylis glomerata*; II: *Festuca rubra* and III: *Trifolium pratense*), IV: mixture of three species I, II and III; V: mixture of twelve species, IV and nine other meadow plants) were analyzed with the exception of 26th month where only data of treatments I and III were used. Standard errors in parentheses.

Summarized data of both plant and invertebrate material revealed that significantly higher was the mass of new organic material in PP comparing to natural treatments after 6 months of the experiment (Table 4). Later the differences between treatments were not significant. The values of total organic matter input were 45.4 and 40.8 g dry wt. m^{-2} for natural and PP treatments respectively at the end of the experiment.

The negative correlations between mass of remaining litter and input of both types of remnants were found for NPL (r = -0.456, Z = -7.230, P <0.00000, n = 115) and PP (r = -0.415, r^2 = 0.172, F = 3.743, P <0.0689, n = 20) treatments taking the entire study period data.

Months since beginning of the experiment	Litter type NPL	PP	Significance of differences between treatments
6	5.19 (0.42)	11.8 (2.08)	n = 60, W = 305, p <= 0.9921
26	37.62 (9.32)	14.73 (2.66)	n = 24, W = 69, p <=0.7139
30	45.40 (5.73)	40.78 (15.66)	n = 51, W = 138, p <= 0.6089

Table 4. Sum of plant and invertebrate remnants (g dry weight m^{-2}) in NPL and PP litter during the course of the experiment. Differences between treatments are assessed by non-parametric Wilcoxon Sum-of-Ranks (Mann-Whitney) test. All data from five natural litter treatments (I: *Dactylis glomerata*; II: *Festuca rubra* and III: *Trifolium pratense*), IV: mixture of three species I, II and III; V: mixture of twelve species, IV and nine other meadow plants) were analyzed with the exception of 26th month where only data of treatments I and III were used. Standard errors in parentheses.

4. Discussion

The meteorological data indicated that climatic conditions in the study period were unfavourable for soil organisms (Szanser et al., 2011). Artificial litter (PP) was drier comparing to natural litters (NPL) and retained a maximum of 5% moisture even during rainfall, while its underlying substrate was similarly wet as that under natural litters (Szanser et al., 2011). Lower mass loss of PP comparing to NPL was coincided with significantly lower numbers of fungi and bacteria in the PP litter and its respiration by 3.4, 44.8 and 61.4 times respectively comparing to natural treatments (Górska unpubl., Szanser et al., 2011). Interestingly number of fungi was the parameter the least differentiating between PP and other treatments. It may signify that the decomposition of PP was of fungal nature. Nevertheless it was found that almost 60 and 70% of the exposed PP and natural litters degraded by 26th month of the experiment. It seems that degradation of PP was quite effective as far as there were no significant differences between applied treatments at the end of the experiment. Thirty months after litter exposure, the input of wind-borne plant material was similar in both treatments. Considerably smaller was the mass of invertebrate origin (exuviae, cocoons, other remnants in both treatments. Similar input of invertebrate organic matter found in later stages of the experiment is corroborated by the lack of significant differences between PP and natural litters in invertebrate macrofauna penetration (Kajak, Szanser, unpubl.). Similar values of the input of plant and invertebrate remnants into natural litter and underlying substrate were found in other agricultural and meadow environments (Szanser, 2003, Szanser, unpubl.). It seems that input of organic matter into PP had some effect on its biodegradation. It should be pointed out that the absorption of different ions (Na^+, N-NH_4^+, K^+, Mg^{2+}, Cl^-, N-NO_3^-, S-SO_4^{2-}) by exposed PP from aerosol-gaseous input, although not measured in this study, can have additional impact on speeding up PP biodegradation. It was found that absorption of elements by polymers used as "artificial leaves" can be quite high and increase with surface area of the exposed plastic (Kram, 2005, Stachurski & Zimka 2000). It seems that the aerosol-gaseous input of elements together with input of new organic matter and further development of microorganisms in fibrous PP resulted in efficient decomposition of the PP. Observed slight increase of polymer mass towards the end of the experiment simultaneously as in natural litter can be explained by the organic matter input and development of microbial communities. The mechanisms involved in PP biodegradation are corroborated by data obtained from experimental underlying substrates. There were no significant differences in microbial activity (soil respiration, microbial biomass and numbers of bacteria and fungi) between PP and NPL treatments in underlying substrate during the third year of the experiment (Górska, Szanser, unpubl.). On the opposite algal biomass and production were by 36% and 39.7% respectively higher under PP comparing to NPL treatments for entire study time (Sieminiak, unpubl.). The increase of carbon content under the PP was higher by 47% than in natural treatments at the end of the experiment (Kusińska & Szanser unpubl.). It should be pointed out that the paper presents results obtained from long-time field experiment while most of the research on degrading the polymers are short time studies.

5. Conclusions

In general, the results suggest that (1) the long term decomposition of artificial litter (PP) proceeded efficiently but was still quite low comparing to natural treatments; (2) the input of plant and invertebrate remains into the PP can be considerably large and may have an additive effect on its decomposition; (3) it seems that longtime decomposition of natural PP may be quite effective comparing to plant litters and (4) the presence of PP did not inhibit severely soil biota activity and organic matter accumulation in soil during the experiment.

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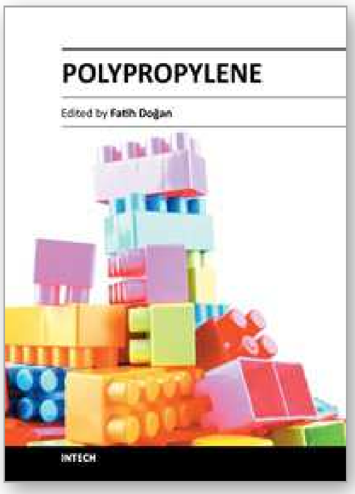

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This book aims to bring together researchers and their papers on polypropylene, and to describe and illustrate the developmental stages polypropylene has gone through over the last 70 years. Besides, one can find papers not only on every application and practice of polypropylene but also on the latest polypropylene technologies. It is also intended in this compilation to present information on polypropylene in a medium readily accessible for any reader.

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