Biodegradation of Three Cellulosic Fabrics in Soil

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RESEARCH PROBLEM AND BACKGROUND INFORMATION

The cellulosic fabrics cotton, rayon, and Tencel® are commonly used in the textile industry (Kroschwitz, 1990). The chemical composition of the fabrics is similar, but they differ in the arrangement of the cellulose polymers in the fabrics (Collier and Tortora, 2001). The basic polymer for all cellulosic fibers consists of repeating glucose units. For the cotton fabric, the cellulosic polymers within the cotton fibers have a high degree of polymerization (approximately 6,000 to 10,000 units), highly reactive hydroxyl (-OH) groups, and the ability to support hydrogen bonding with the 70% crystalline area. The remaining 30% of the fiber is amorphous. Like cotton, rayon is composed of cellulose, but the cellulose chains in rayon are shorter with the degree of polymerization being between 400 to 700 units. Thus, about 30% of the cellulose is crystalline with 70% being amorphous. Tencel® lyocell (generic classification) is a highly crystalline fiber with high strength capacity.

In 2007, over 9 Tg (10 million tons) of textile waste went into landfills in the U.S. (U.S. EPA, 2008). The anaerobic conditions found in landfills result in slow biodegradation rates of cellulosic materials. To divert fabric waste from landfills, an alternative method of fabric disposal would be application of cellulosic fabric waste to surface soil where aerobic conditions could result in enhanced biodegradation rates. Information on cellulosic fabric biodegradation rates in surface soil would also be valuable in providing estimates of the length of time that fabrics have been buried in soil, contributing useful data to forensic investigations (Janaway, 2008). The objective of this field study was to determine the biodegradation rates of 100% rayon, cotton, and Tencel® woven fabrics buried in an aerobic Captina silt loam soil.

RESEARCH DESCRIPTION

For the field biodegradation study, rayon, cotton, and Tencel® fabrics were cut into 25 × 25-cm units and placed in tulle having 1 × 2-mm mesh openings. The

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tulle, which was resistant to degradation, was used to hold the fabric specimens in tact as much as possible during the degradation process. The enclosed fabric samples were buried in a Captina silt loam soil (fine-silty, siliceous, active, mesic Typic Fragiudult) that had been tilled to a depth of 15 cm. The fabric was buried at a depth of 10 cm and oriented parallel to the soil surface. Plots were maintained vegetation free by an application of the herbicide Roundup®.

At 14, 28, 42, 77, and 112 days, five replications of each experimental fabric were carefully excavated, lightly brushed to remove soil particles, dried to a constant weight at 55 ºC, and a representative subsample of the fabric ashed at 650 ºC. All fabric weights were reported on a dry, ash-free weight basis. The initial weight of the fabrics at 0 days also was determined. During the field study, mean soil temperature at a depth of 10 cm was approximately 25 ºC and ranged from 14 to 34 ºC. Optimal soil moisture of approximately -33 kPa, which corresponded to 18% gravimetric moisture, was maintained through rainfall and supplemental irrigation during the study.

The constant decomposition rate of the fabrics in soil over time suggested that degradation followed zero-order kinetics where the rate was independent of the substrate concentration (Wolf and Wagner, 2005). The zero-order kinetics model [Eq. 1] was used to describe fabric biodegradation.

$$A_t = A_o - kt \qquad \text{[Eq. 1]}$$

where

- A_t is the amount of fabric remaining at any given time (mg dry, ash-free fabric)
- A_o is the initial amount of fabric added to the soil (mg dry, ash-free fabric)
- k is the zero-order rate constant (d^{-1})
- t is the time (d)

The percentage of fabric remaining was regressed on time and yielded a straight line with a slope of -k, the zero-order rate constant. Analysis of covariance was used to determine if the zero-order rate constants differed for the experimental fabrics. The half-life ($t_{1/2}$), or time required for 50% of the initial fabric to decompose, was calculated using [Eq. 2].

$$t_{1/2} = A_o/2k \qquad \text{[Eq. 2]}$$

RESULTS AND DISCUSSION

With optimal soil moisture of -33 kPa and soil temperature of approximately 25 ºC during the field study, rapid cellulose biodegradation would be expected (Janaway, 2008; Wolf and Wagner, 2005). The amount of fabric remaining over time demonstrated rapid biodegradation of rayon, intermediate biodegradation of cotton, and slow biodegradation of Tencel®. Plots of the percentage of fabric recovered vs. time showed that fabric biodegradation could be described by zero-order kinetics (Fig. 1). The zero-order rate constants, or k values, were significantly different and followed the decreasing order of rayon > cotton > Tencel® (Table I). The calculated half-life values were 22, 40, and 94 days for rayon, cotton, and Tencel®, respectively. Rayon and cotton have been reported to be highly vulnerable to decomposition (Janaway, 2008). As the quantity of amorphous cellulose in the fabric increased and the length of the polymer chains decreased, availability of the cellulose substrate for microbial metabolism increased; thus, resulting in more rapid fabric biodegradation (Kaplan et al., 1970).

PRACTICAL APPLICATION

Aerobic, moist, warm soil conditions resulted in rapid fabric biodegradation and rates decreased in order of rayon > cotton > Tencel® with half-life values of 22, 40, and 94 days, respectively. Compared to landfilling, an alternative method of fabric disposal could be application and mixing with aerobic surface soil. By using the fabric biodegradation zero-order rate constants, it is possible to estimate the time fabrics have been buried in soil and such information would be useful for potential forensic applications. Determining cellulosic fabric biodegradation rates in soil has forensic and environmental implications.

For more details and additional information, the complete results from this study will be published in *AATCC Review*.

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Table I. Zero-order rate constants (k) and half-life ($t_{1/2}$) values for rayon, cotton, and Tencel® fabrics buried in Captina soil.

Fabric	Zero-Order Rate Constant (k)	Standard Error of Estimate	Half Life ($t_{1/2}$)	Standard Error of Estimate
	-----------------/day-----------------		----------------days---------------	
Rayon	2.624 a[1]	0.252	21.6	0.9
Cotton	1.238 b	0.107	40.2	2.0
Tencel®	0.528 c	0.063	93.6	8.1

[1]Rate constants followed by the same letter are not significantly different (P = 0.05).

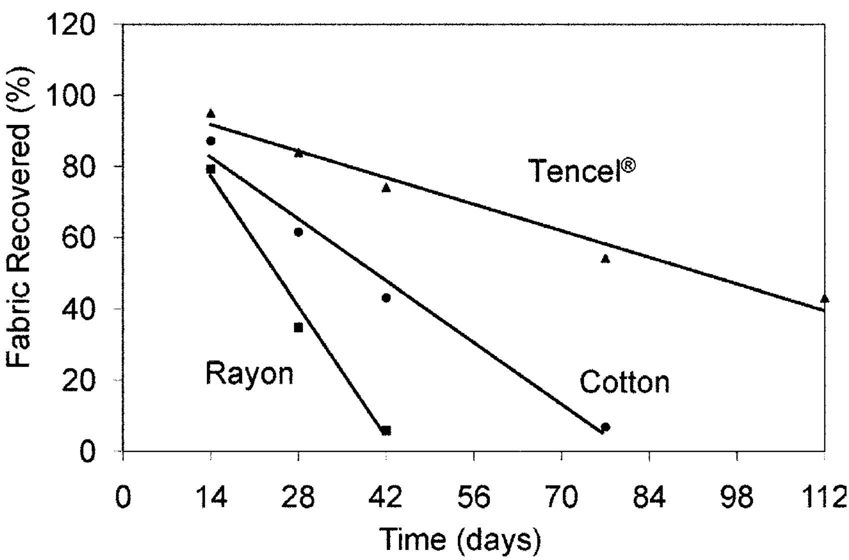

Fig. 1. Zero-order biodegradation of the rayon, cotton, and Tencel® fabrics in the field study.