

BIODEGRADABLE AGRICULTURAL MULCH FILMS WITH CONTROLLED NUTRIENT RELEASE

BACKGROUND

Agricultural mulch films are integral to enhancing crop yields and promoting long-term resilience across global farming communities. Also, controlled fertilization is vital to replenish soil nutrients (nitrogen, calcium, etc.) and supporting overall plant health. However, up to 40% of fertilizer nitrogen is lost to the environment. When poorly-utilized by industry, atmospheric emissions and leaching to water sources contributes to greenhouse gas release and eutrophication of waterways.

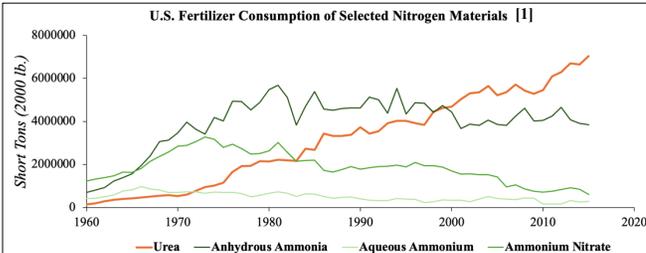
This research aims to produce biodegradable mulch films filled with urea-cocrystals (URCASU) capable of controlled nutrient release.

Benefits of Mulch Films:

- Soil moisture protection
- Soil temperature regulation
- Soil fertility
- Fertilizes soil
- Degrades on time-scale
- Eliminates film waste



Research Development



METHOD

Co-Crystal Mfg.	Horizontal mill: $\text{CaSO}_4 + 4\text{CO}(\text{NH}_2)_2 + \text{H}_2\text{O} \rightarrow [\text{CaSO}_4 \cdot 4\text{CO}(\text{NH}_2)_2]$ 4 hrs. for full conversion of cocrystal
Small Batch Mixing	Effect of co-crystal loading on material properties and processibility 170°C, 50 RPM, 10 minutes Brabender Intelli-Torque Plasti-Corder
Compound Material (7.5% URCASU)	Prepare feedstock for film manufacturing with minimal shear 160-165°C, 300 RPM mixer, 40 RPM extruder Farrel Pomini CPeX™
Cast Film Extrusion	Collin Teach-Line • Leaching Quantification – Urea Spectrophotometry • Mech. Properties - Tear testing (ASTM D1922) • Thermal Testing – TGA, DSC
Blown Film Extrusion	• Morphology – SEM • Biodegradation Testing – (ASTM D5338-15 Compost)

Halka Inagaki

Margaret Sobkowicz

Plastics Engineering Department, University of Massachusetts, Lowell

ABSTRACT

This research explores the potential of alternative polymer materials designed with sustainability in mind for the mulch film industry. Such alternatives aim to support agricultural productivity while reducing environmental impact and promoting long-term economic resilience across global farming communities. The single-use nature of conventional plastic mulch films contributes millions of tons of waste to landfills annually. Additionally, uncontrolled fertilizer applications have led to excessive runoff, causing harm to the surrounding environment by eutrophication waterways. Poly(butylene adipate-co-terephthalate) (PBAT) is a commercially available polymer that combines soil biodegradability from aliphatic polyesters with favorable physical properties from aromatic rings. It is blended with polylactic acid (PLA) to produce a material with exceptional melt strength suitable for blown film processing. This research investigates the incorporation of a urea-containing cocrystal into biodegradable PBAT/PLA matrices. The objectives are to produce high-quality blown films with these blend composites and to characterize the compatibility, degradation, and nutrient-release behaviors of the resulting films. Controlled-release composting is conducted to understand the influence of the urea-based additive on degradation profiles. A controlled release study elucidates nutrient release kinetics, and tensile testing reveals the mechanical properties of the films. Processing challenges associated with additive dispersion and film uniformity are also assessed. These findings provide insight to structure-property relationships governing the performance of nutrient-loaded biodegradable films and demonstrate the potential of PBAT-urea cocrystal composites as sustainable alternatives to conventional mulch films.

RESULTS

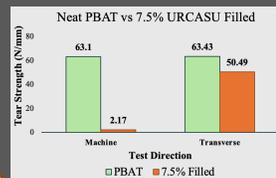
Thermal Analysis – Effect of Co-Crystal on Degradation and Crystallinity

URCASU Fill	0% (PBAT)	10%	20%	30%
Primary T _g Onset (°C)	367	367	362	356
Relative Crystallinity (%)	100	111.86	132.47	145.71

↑ URCASU Fill = ↓ Degradation Onset Temperature = ↓ Thermal Stability
• No effects on T_g observed until above 10% fill

↑ URCASU fill = ↑ Nucleation = ↑ Crystallinity
• Increase in crystallinity with co-crystal loading, nucleation

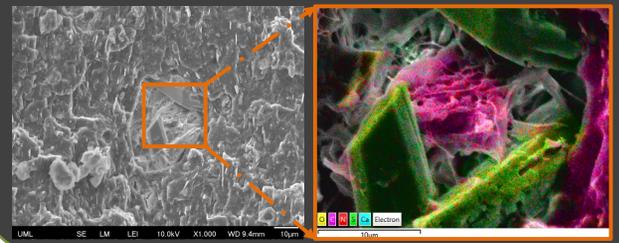
Mechanical Testing – Effect of Co-Crystals on Propagated Tear Strength



Addition of Co-Crystal to Film

Machine: ~97% strength loss
Transverse: ~20% strength loss

Composite Morphology – Distribution and Dispersion of Filler Within Matrix



End-of-Life – 113 Day Incubated Biodegradation

Film Material	PBAT	7.5% URCASU
Biodegradation (%)	67 ± 2	46 ± 4

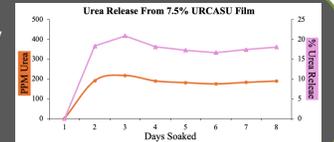
→ Addition of co-crystal filler hinders rate of biodegradation
Mulch film application timeline: 6-9 months

Nutrient Release – Urea quantification

~20% Urea releases from films rapidly

Future work studying:

- Longer timeline
- Nutrient entrapment by polymer
- Correlation with degradation timeline



DISCUSSION, STEERING FUTURE WORK

Processing Challenges

- Loss of nutrition in ammoniacal form (>170°C)
- Filler addition = ↓ Melt viscosity = ↓ Melt strength

Filler Dispersion

- Nitrogen shows slight enrichment on film surface
- Expecting a trend of nutrition migration

Effect on Material Properties

- No significant reduction in film degradation temperature at low co-crystal fill levels
- Slight loss in degree of crystallinity
- Anisotropic effects amplified – mechanical strength
- Biodegradation timeline longer with calcium sulphate urea co-crystal addition
- Burst urea release from film surface
- Impact on filler loading on melt viscosity



REFERENCES

[1] U.S. Department of Agriculture, Economic Research Service, "Fertilizer use and price," USDA ERS.

ACKNOWLEDGEMENTS

I would like to thank The U.S. Department of Agriculture (USDA) for supporting this research project. I would also like to thank Jonas Baltrusaitis and Ammar Mohamed at Lehigh University for their collaboration and innovation of urea co-crystals, which has allowed the novelty of this research. I would also like to thank my lab mate, Hrushikesh Pujari, for being my right-hand man when processing. Finally, thank you to my advisor, Meg, for her guidance and inspiration through the progression of this project.