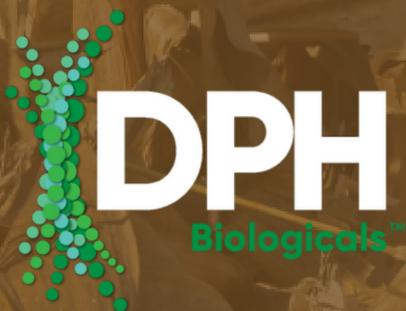


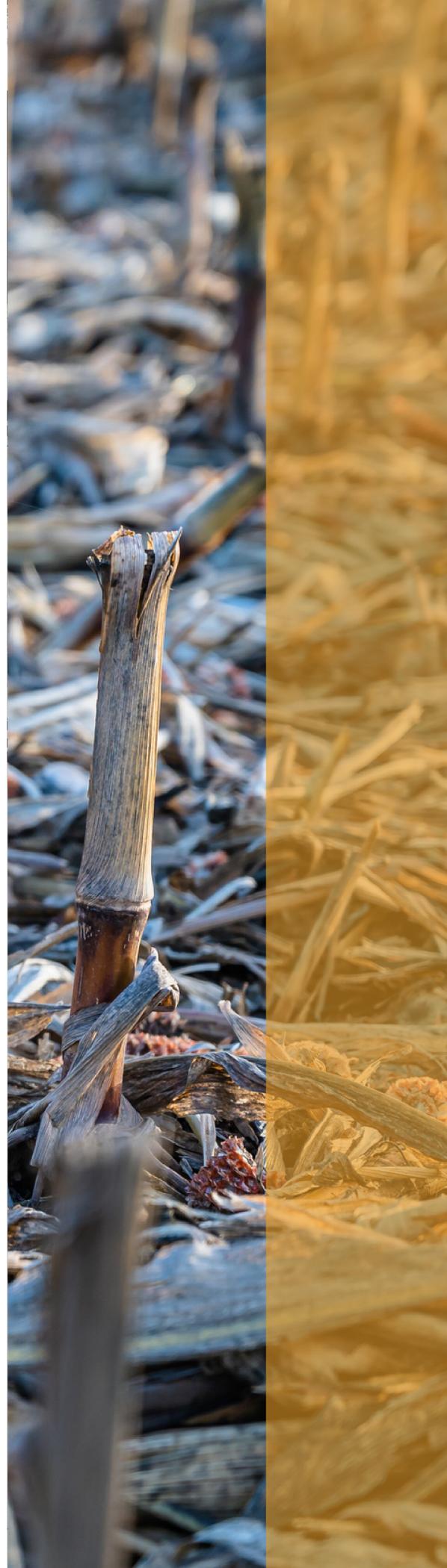
Rethinking Crop Residue Management with Biodigesters



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Residue is nature's biological. It's just so good for the soil and the plant, and there's a lot of nutrition there. But it can be your best friend or your worst nightmare. The quicker you can degrade residue, the easier you can plant, the more uniform your crop is going to emerge and the more likely you're going to get the benefits of that residue.

**- Fred Below, Professor of Plant Physiology
University of Illinois**



Crop residue management is nothing new for growers, but it has become an increasing headache under modern-day production practices. However, there is a new solution for the problem of crop residue – biodigesters.

Biodigesters are a natural product formulated specifically for their ability to break down plant material. Biodigesters jumpstart and accelerate natural crop residue decomposition, solving the operational challenges of residue management while unlocking new pathways to better soil health and nutrient management strategies including reduced fertilizer use, reduced presence of disease inoculants, and more cropping choices.

This white paper presented by DPH Biologicals, a leading independent manufacturer of data-tested and field-verified biological solutions for commercial growers, explores the potential use of biodigesters in crop residue management, including the latest third-party science and commercial field trial results.

What is a Biodigester?

For the purposes of this paper, a biodigester is any naturally-derived product that works to accelerate the natural decomposition of plant residue. The most effective biodigesters include a mix of living (microbes) and nonliving biostimulants designed to work together in the decomposition and nutrient-cycling process.

BIODIGESTER? BIODEGRADER? BIOREDUCER? BIODECOMPOSER? BIOCATALYST? WHAT'S THE DIFFERENCE?

Like many products in the biological sector, the language is still evolving to what the agricultural industry defines as a biological product specifically formulated for plant residue decomposition.

As this technology becomes more widely adopted, growers and channel partners may be confused by different names for products with the same primary function. DPH Biologicals has chosen to use the name “Biodigester” as we believe it best describes the process and benefits of biologicals formulated for residue breakdown. The most economically beneficial technologies accelerate the natural ‘digestion’ process of turning carbon into plant-available nutrients, providing additional agronomic benefits.

For an overview of the different types of biologicals and their benefits in agriculture, including biocontrols and biofertilizers, see our [Biologicals 101 White Paper](#).

LIVING MICROBES IN BIODIGESTERS

Saprotrophic organisms are a primary component of biodigester technology.

Saprotrophs feed specifically on dead or decaying plant matter and are found naturally in great abundance in perennial ecosystems such as forests or permanent grasslands, but their populations are generally reduced in intensively managed soils due to tillage and exposed soil.

While grower practices that increase organic matter, such as no-till, can help to improve naturally-occurring saprotrophic communities, it can take years to build up and maintain populations, especially within a tightly-managed cropping system.

Fungi, Bacteria and Other Components in Biodigesters

Two types of saprotrophic organisms are important in agricultural residue management - fungi and bacteria.

Fungal saprotrophs break down more complicated compounds such as woody fibers with a high percentage of lignin, the natural polymer forming the key structural materials supporting plant tissue. Bacterial saprotrophs, on the other hand, break down 'easier' plant residues, like leaf matter and typical crop stubble, by producing cellulase, an enzyme that converts the cellulose found in plant cell walls into simple sugars.

Non-Living Components of Biodigesters

Other, non-living biostimulants, such as fulvic or humic acid, may be used as stand-alone products to help residue management or can be effectively combined with residue-degrading microbes for a more effective formulation. Non-living biostimulants in biodigester technologies stimulate microbial activity and facilitate the transfer of micronutrients released by saprotrophic organisms into the soil.

Additionally, microbial food sources included in a biodigester formulation initiate early establishment and rapid colonization of the applied microbials. Not all biodigester products include a food source, however.

Terra Trove™ Residue®

A Biodigester Platform

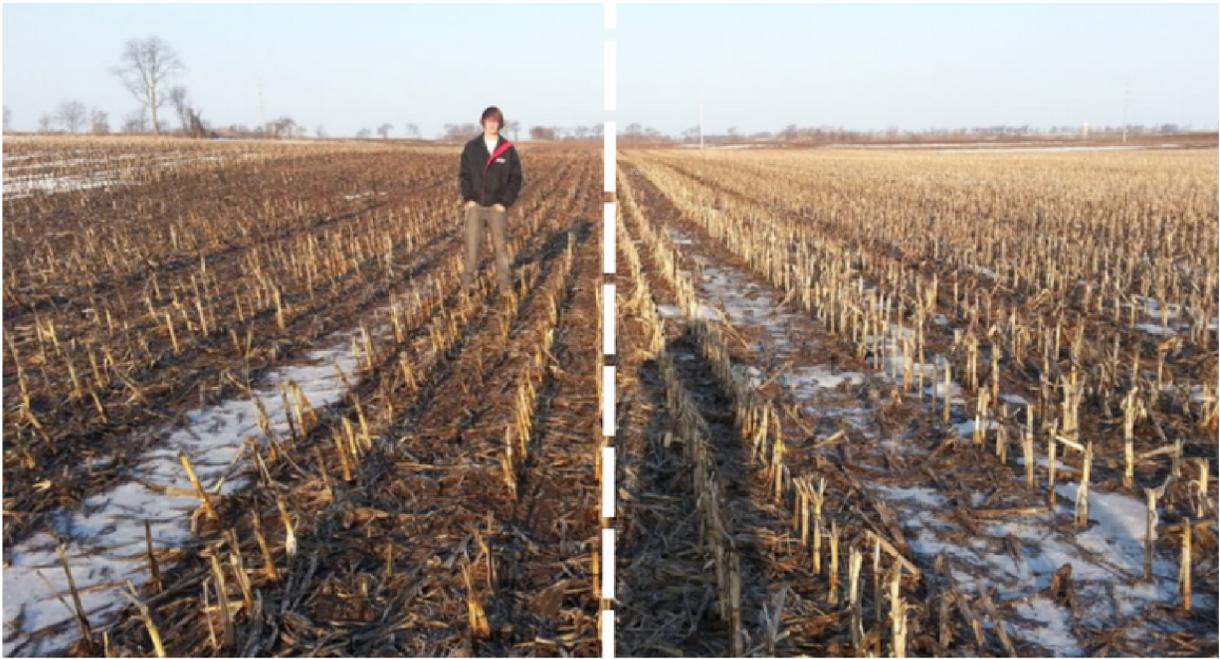
Terra Trove™ Residue® is a proprietary biodigester platform formulated and produced by DPH Biologicals for commercial-scale crop residue management. Residue technology induces rapid plant residue break-down while optimizing the nutrients and organic matter potentially available in recalcitrant organic materials, such as corn stalks, sugar cane leaves, wheat straw and soybean stubble.

The Power of Residue Technology

The Residue product line combines a community of powerful nutrient-cycling microorganisms formulated to be highly resistant to break-down when in storage but activating quickly as soon as they are placed in the field and on plant residue.

The microbes used in Residue technology may include:

- **Bacillus Consortium:** Isolated strains of bacteria species known for the ability to accelerate cellulose breakdown through the production of the enzyme cellulase.
 - ***Bacillus amyloliquefaciens*:** Scientifically proven to accelerate the degradation of lignin found in high-carbon plant residue. [A 2020 study](#) found 22% increased degradation in wheat straw compared to control.
 - ***Bacillus licheniformis*:** Well-known across sectors for releasing a powerful starch-processing enzyme. [A 2016 study](#) resulted in 15-30% accelerated decomposition in sunflower and 40-60% in corn stubble when combined with another Bacillus strain.
 - ***Bacillus megaterium*:** [Known since 1935](#) for its ability to decompose organophosphorus compounds such as pesticides, also linked to rapid breakdown of inorganic phosphorus in soils.
 - ***Bacillus pumilus*:** Useful for multiple soil, nutrient availability and plant health applications, important for [enhancing bacterial biodiversity](#).
- ***Trichoderma harzianum*:** A filamentous fungi well known for its biostimulant and biofungicide properties but is also a major producer of cellulase.
- ***Phanaerochaete chrysosporium*:** Commonly known as “white-rot fungus,” this fungi has powerful lignin degradation abilities and sustains activity at moderate to high temperatures.



Corn Stover Breakdown After Residue Application

Residue WS is a dry formulation of the DPH Biologicals' Residue technology platform including all the above bacterial and fungal microorganisms. It can be applied as a granular product but is also easily mixed for liquid application. Residue WS is OMRI-listed for organic production systems.

The Residue WS bacillus consortium is also available as Residue Complete, a liquid formulation with added fulvic acid to stimulate and support microbial activity and a food source to ensure successful colonization.

Untreated



Treated



The Problem & Potential of Crop Residue



Residue is on the rise. There's the push for no till, more residue. Strip till, more residue. Cover cropping, more residue. Double cropping, more residue. And then every bushel you get increased in yield also comes with more residue, even in your conventional systems.

-Connor Sible, Postdoctoral Research Associate studying biostimulants and biologicals, University of Illinois Urbana Champaign

Crop residue has long played a contradictory role as a farmer's foe, and friend.

Conservation best practices of the past several decades have encouraged keeping and even encouraging residue for multiple sustainability benefits, including better soil health and less soil erosion. However, the last few decades of changing agronomic practices and high-input, high-yield cropping has turned crop residue from a manageable problem to a major roadblock, forcing growers to choose between sustainability and farm economics.

High-yielding corn and grain hybrids bred for a shorter, stouter structure combined with increased plant population seeding practices, a rising use of in-season fungicides that slows the natural decomposition process and the adoption of reduced tillage techniques and soil-health building practices like cover cropping, have left today's growers dealing with much higher volume of crop residue and more degradation-resistant crop stubble.

At the same time, growers are being pressured to switch away from traditional quick-fix residue management practices such as burning wheat fields after harvest and intensive tillage because of negative environmental and sustainability outcomes.

WHY SO MUCH CORN STOVER?

A 60% increase in Michigan corn yields over the last 30 years has corresponded to approximately the same increase in corn stover production. Nationally, corn yields have risen by approximately 40% since 2015.

A Minnesota-based 2015 study estimated approximately 4.85 tons of stover produced per acre in average yielding maize production. Corn yields of 200-bushel per acre common in high-input corn production generally yield stover in the range of six to eight tons per acre.

RESIDUE REMOVAL TRADE-OFFS

Nutrient Removal Rates of Three Michigan Grain Crops (Pounds Per Bushel)			
Crop	N Removal Pounds Per Bushel	P205 Removal Pounds Per Bushel	K20 Removal Pounds Per Bushel
Corn	0.9	0.37	0.27
Soybean	3.8	0.80	1.40
Wheat	1.2	0.63	0.37

With an expanding demand for biomass for biofuel production many growers have seized upon the opportunity as a solution to their residue management, removing the residue while also capturing a new revenue stream. However, stover removal comes with trade-offs.

The Michigan Corn Stover Project found removing stover in an average 150-bushel per acre corn scenario would result in a potential nutritional loss of 135 lbs of N, 56 lbs of phosphorus (P) and 41 lbs of potassium (K).

Excessive and ongoing removal of post-harvest residue can have a negative impact on soil health, fertility and water infiltration. Stover harvest also comes with operational challenges. Farmers find they don't have time to fit one more operation into a busy harvest season, run up against bad weather and muddy fields before they have a chance to bale their stover or don't have the heavy-duty bailers and windrowers needed to bale tough, fibrous residue like corn stover. While stover harvest has been the strategy some growers have taken to manage their residue, the increased workload, wear and tear on machinery and soil health penalties continue to pose a significant barrier to any benefits.

CROP RESIDUE HEADACHES

- **Increased tillage = wear and tear on equipment + soil compaction.**
- **Thick residue layer = cool soils that impede & delay germination.**
- **Large residue chunks = impede proper seed placement, uneven stands.**
- **Slow residue breakdown = N immobilization & yield penalties.**
- **Corn residue buried in soil = toxic to new seedlings, delayed growth and lower yields.**
- **Heavy winter residue = a home for pests and diseases to overwinter.**

Biodigesters as a Solution for Crop Residue

Biodigesters are a new solution to crop residue, optimizing all the benefits that come with residue – and even working in conjunction with other management practices, while solving the modern-day headaches of residue management.

Growers don't have to buy crop residue. It is a free and abundant solution to improved nutrient cycling and soil organic matter (carbon sequestration), wind erosion, soil structure and water conservation, both preventing run-off and improving water infiltration and holding capabilities. And residue is already field-applied right where growers need it as part of the harvest process, unlike other soil-building strategies, such as spreading compost or manure.

By harnessing and controlling the natural decomposition process, biodigesters turn crop residue from trash into treasure, putting post-harvest stubble and cover crop biomass to work on a grower's time schedule, benefiting their cropping rotations and management practices.

THE DATA: BENEFITS OF BIODIGESTERS

Compared to the understanding and research into using biologicals for their positive impact on soil fertility, plant growth and disease resiliency, biodigesters are a relatively new area of agronomic research. However, that is changing rapidly with growing recognition of the benefit of biodigesters, especially for high-input, high-yield cropping systems.

The following section of this paper summarizes the benefits revealed via academic data and research into biodigesters, including a series of field trials conducted by DPH Biologicals using the Residue technology platform.

See DPH Bio’s White Paper [“Improving Farm Profitability with Biofertilizers”](#) for a detailed understanding of the science and methodology in using biofertilizers for increased farm profitability, including a biofertility calculator to estimate the potential increased revenue on a farm-by-farm and year-by-year basis.

ACCELERATED RATE OF DECOMPOSITION

The first and foremost benefit of biodigesters is an accelerated rate of decomposition. While different crops, management practices, climates and weather will invariably impact the rate of post-harvest stubble decomposition, field trials have reliably shown that using biodigesters can significantly accelerate the break-down of stubborn crop residue, like corn stover.

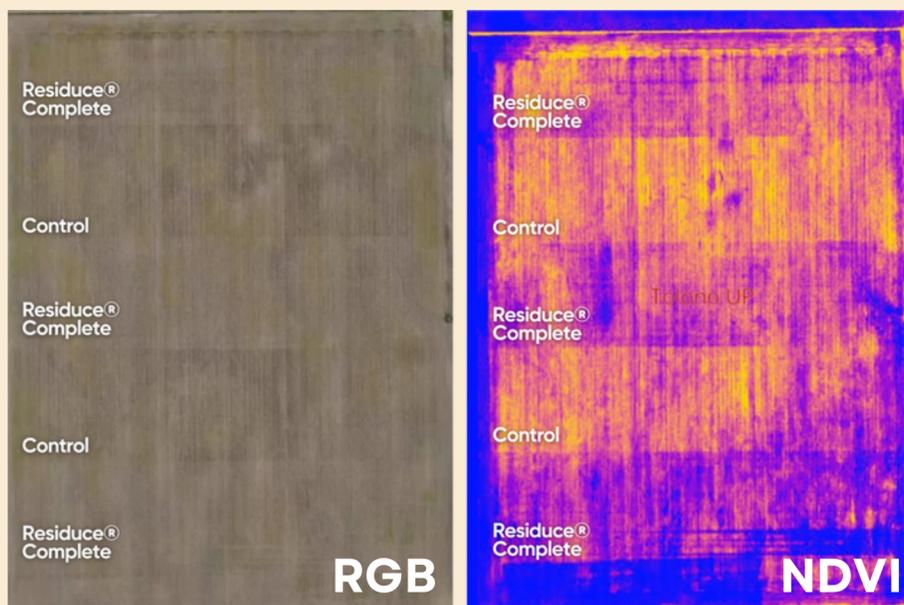
Fall-Treated Nebraska Corn Stover Study

A 2020-21 central Nebraska study corn stover study conducted in collaboration with AgriThORITY using Residue resulted in increased residue degradation by 11% over the untreated control.

Residue was applied on October 14, 2021 with significant acceleration over the control field beginning at 150 days past application (March 18) and a continued accelerated decomposition rate recorded an additional 30 days later (170 days past application).

Fall-Treated Illinois Corn Stover Study

A DPH Biologicals 2022-23 trial in Tolono, Illinois using a fall application of Residue across 113 acres of high biomass corn (>200 bu/A) stubble increased residue decomposition by nearly 20%, despite a dry winter season. Residue was applied on November 23 (spray application) and aerial images used to calculate decomposition rates were taken on April 13.



RGB : Darker areas equal more corn stalks left out in field

NDVI: Darker images represent more bare soil as bare soil has an NDVI around 0-0.1 while dried corn stalks have an NDVI of 0.4ish (lower value = closer to being bare soil).

In addition to reduced field coverage, splitting stalks showed more evidence of saprotrophic fungal decomposition (black) as compared to the untreated control.

Accelerated Wheat Residue Management

While most of the current research into residue management using biologicals has been focused on corn stover, a [2018 Russian study](#) revealed positive impacts on winter wheat stubble management.

The Russian study trialed three-different biological treatments (a humic acid treatment, a bacterial-based treatment and a fungal-based treatment) on winter wheat with a 15.47% average increased rate of decomposition across all biological treatments.

INCREASED & STEADY NUTRIENT RELEASE SAVES FERTILIZER COSTS

By adding biodigesters to accelerate the rate of decomposition, growers can capture nutrient availability, especially core macronutrients of N, P, K and sulfur (S) and facilitate a steady release of nutrients over time, saving growers on fertilizer costs.

Using Michigan State University's NPK calculator to estimate potential nutrient availability in crop residue, we can calculate the nutrients released just during the accelerated decomposition period as measured in DPH Biological's field trials.

For instance, when fully decomposed, the residue in a 200-bushel per acre corn crop equals 100 lbs of N, 50 lbs of P₂O₅ and 210 lbs of K₂O. In DPH Biologicals' Tolono, Illinois overwintered corn residue trial, a 19.7% accelerated degradation rate released an additional 19.7 units of N, 9.85 units of P and 41.37 units of K by mid-April, when the grower was preparing to put in their spring planting, equaling a \$45.87 per acre fertilizer savings. Additionally, accelerated decomposition will extend throughout the spring and summer, with an estimated fertility value of \$91.92 per acre for the full season, a six-to-one total return on investment over the per-acre application cost of NPK.

19.7% Accelerated Stover Degradation Equals		
NPK Released	Market Price	Value Delivered /Acre
19.7 units of N	\$0.80 (32% UAN)	\$15.76
9.85 units of P	\$0.87 (MAP)	\$8.60
41.37 units of K	\$0.52 (Potash)	\$21.51
Total Value of \$45.87 / Acre		

OFFSETTING THE CONTINUOUS CORN YIELD PENALTY

Biological residue management in combination with other management techniques reduced the continuous corn yield penalty (CCYP), according to a two-year research study conducted by the University of Illinois Urbana-Champaign (UIUC). Trials were conducted between 2017 and 2018 in a field that had been in no-till continuous maize (corn) production for 17 years.

While there are multiple factors contributing to CCYP, research has conclusively linked residue accumulation as a key contributor. Multi-year residue accumulation in continuous corn production reduces N mineralization, lowers seedling germination and emergence rates and promotes the negative effects of autotoxicity from decomposing corn stover in contact with new seedling roots.

Residue accumulation also increases disease and pest populations, with suspected links to yield penalties. Even when no-till practices and continuous corn practices were observed to naturally increase fungal populations known to mediate biomass degradation, some of those species (*Aspergillus* spp) also increase the risk of mycotoxins in grain harvests, posing additional complications for growers.

The UIUC study found that a fall-applied fertilizer - Ammonium Sulfate (AMS), combined with mechanically reducing the size and breaking up corn stover at harvest

plus the application of biological products developed for residue management generated the most significant CCYP reduction.

Out of the three different biodigester products used – a non-living microbial fermentation extract, a humic acid and a live microbial blend – the microbial blend combined with the fall fertility application and mechanically sizing rollers resulted in a 25-bushel reduction of the CCYP penalty.

INCREASED SOIL ORGANIC MATTER

With biodigesters, growers have an opportunity to improve the SOM potential of their crop residue. Crop residue, especially high C:N ratio residue like corn and wheat straw, are excellent sources of carbon once they have been broken down, increasing SOM levels and improving the physical, chemical and biological functions of the soil for better soil structure, water-holding capacities, nutrient availability and biological activity.

A DPH Biologicals' cross-trial summary of three Illinois-based corn fields treated with a spring pre-plant application of Residue recorded increased SOM levels just a few months after application, averaging a .2% increase in organic matter across all three fields.

REDUCED DISEASE, LESS STALK LODGING

Using biodigesters can reduce the ability of pathogens to persist between crop plantings by overwintering in residue, especially those known to contribute to stalk lodging.

Multiple economically-significant diseases have been linked to residue accumulation in corn, soybean and wheat production, especially in no-till systems with heavy residue accumulation.

2022 DPH Biologicals' testing across four Illinois locations in different management practices averaged a 22% reduction in corn stalk lodging caused by pathogens that overwinter in field debris and infect corn seeds at planting, leading to weak plants with compromised root systems susceptible to lodging. On average, yields increased by 25-bushels.

SEASON-LONG, PLANT GROWTH IMPACTS

Aerial imaging recording field NVDI (the amount of vegetative growth) shows season-long plant growth benefits with biodigesters.

DPH Biologicals trials in Walnut, Illinois of Residue Complete and Residue WS (plus AMS) in a continuous corn rotation showed significantly increased plant vigor and vegetation in corn growth after Residue was applied. Increased leaf chlorophyll, leaf nitrogen as well as less runts, skips and more uniform crop growth were also recorded.

NEW CROPPING & FIELD MANAGEMENT OPPORTUNITIES

Using biodigesters to improve residue management unlocks new cropping opportunities and makes sustainability practices more accessible to growers.

Spring Pre-Plant Applications

Biodigesters that perform quickly, like the Residue technology platform, can be used in spring applications.

In northern locations, the fast arrival of winter weather means growers don't have enough time after harvest to take any residue management actions, whether that's post-harvest tillage, harvesting of excess residue or applying a biodigester. Additionally, cold climates can deter the establishment of a residue-decomposing microbial population.

A 2023 DPH Biologicals' Residue spring pre-plant trial looking at three Illinois corn fields averaged a 12.9 bushel per acre yield bump over control plots. In all three of the tests, Residue was applied in April and no additional fertility was added. Soil tests conducted at the V5 leaf stage found increased potassium, phosphorus and organic matter. Two of the fields were in back-to-back corn rotations, one was previously planted into soybeans.

Summer Double Cropping

Biodigesters are a useful agronomic tool to unlock new opportunities in summer planted double crop rotations.

Changing climate conditions are extending the growing season. That weather change, combined with earlier-maturing wheat and soybean cultivars, has promoted many growers to pursue new double-crop rotational plantings, especially soybeans planted into winter wheat. However, high grain yields plus the short planting time between crops has resulted in wheat straw stubble stymying soybean stand establishment and growth.

A summer application of a biodigester will accelerate rapid wheat stubble breakdown in a wheat-soybean rotation. DPH Biologicals is currently working with the UIUC lab on a study capturing the impacts of different summer-applied biodigesters, including Residue, in a winter wheat followed by soybeans rotation.

Increased Ability to Use Cover Crops

The multiple management headaches that come with cover crop residue, even yield penalties, have slowed the adoption of cover crops, despite the many proven soil health benefits of cover crops. Biodigesters, however, can help solve all these problems, simply by accelerating the time it takes for cover crop biomass to decompose.

Short planting windows between cover crop termination and new seedings can negatively impact crop yields, especially in non-legume cover crops planted into corn rotations. Some growers end up terminating their cover crops early as a strategy. However, by terminating early, growers sacrifice the optimal cover crop biomass potential that comes with rapid spring growth, limiting the potential economic payback of their cover crop investment. Additionally, especially in no-till systems, heavy crop residue from the previously harvested crop can impede the germination and emergence of a new cover crop planting.

In spring 2023 DPH Biologicals began working with the UIUC lab on a four-year trial to quantify the benefits of using a spring-applied biodigester to accelerate the decomposition of recently terminated spring cover crop biomass in a no-till corn and soybean production system including a fall-planted cover crop.

Untreated (left) vs. Treated (right) ***Note Evidence of Fungal Break Down***



Tips for Choosing a Biodigester

- **Select a biodigester with a consortium of microbes targeting crop residue degradation**
- **Look for a biodigester that includes a food source for the microbial population to support quick and early colonization and includes non-living biostimulants known to enhance microbial activity and nutrient cycling, such as fulvic or humic acid.**
- **Make sure the bacterial spores in the formulation are gram positive, ensuring they are highly resistant to breakdown as formulated in the product, but will activate when placed in the field and on plant residue. Shelf-life should be at least one year, if not longer.**
- **Choose a biodigester that matches the application needed for your residue management goals, for instance, a liquid formula for spraying on cover crop residue or a dry application for broadcast in wheat stubble.**
- **Make sure the biodigester includes an adjuvant to ensure the product sticks to its target (in this case, crop residue).**
- **Look for products with multiple years of field-trial validation, tested in many locations, on different crops and different management practices**

READY TO ADD A BIODIGESTER?

Biodigesters are a win-win-win for growers.

They optimize the high-input, high-yield cropping systems that have come with better breeding and agronomic solutions while solving the operational headaches of residue management. They satisfy the sustainability demands of consumers and buyers, while unlocking new revenue-producing cropping opportunities and allowing growers to adopt better soil-health practices without adding work or jeopardizing their yields.

For more information on DPH Biologicals' Residue technology platform, including how to successfully incorporate a biodigester into your growing practices, contact DPH Biologicals at www.dphbio.com, call 1(800) 648-7626 or email info@dphbio.com.

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