AGRICEN

Growing for the FUTURE

Supporting Sustainable Agriculture with a New Generation of Biologically Sourced Tools for Plant Nutrition

As food demand has grown, so has the call for using sustainable practices to feed a growing world. New innovations in plant nutrition will play a key role in ensuring that growers can sustainably meet future food demands while also remaining economically productive. These innovations include advancements in biologically sourced inputs such as agricultural biologicals and biostimulants that can make existing practices more efficient by improving plant and soil health.

How Will We Feed the World?

The world population is growing. By today's best estimates, the population will exceed 9.7 billion by 2050[1], requiring a projected 70% increase in crop production to meet expected food needs[2] **(Fig. 1)**. How will we meet these increased demands?

The Food and Agriculture Organization (FAO) projects that, globally, 90% of the required growth in food production will need to be achieved by increasing crop yields and cropping intensity[2]. Accounting for much of this percentage, crop yields will need to rise substantially to meet growing global needs. Policymakers, growers, non-profits and industry today devote an enormous amount of time planning and innovating new ways to improve crop yields so that we will be able to meet our future food needs.

An Increasing Population Means an Increasing Need for Food and Resources

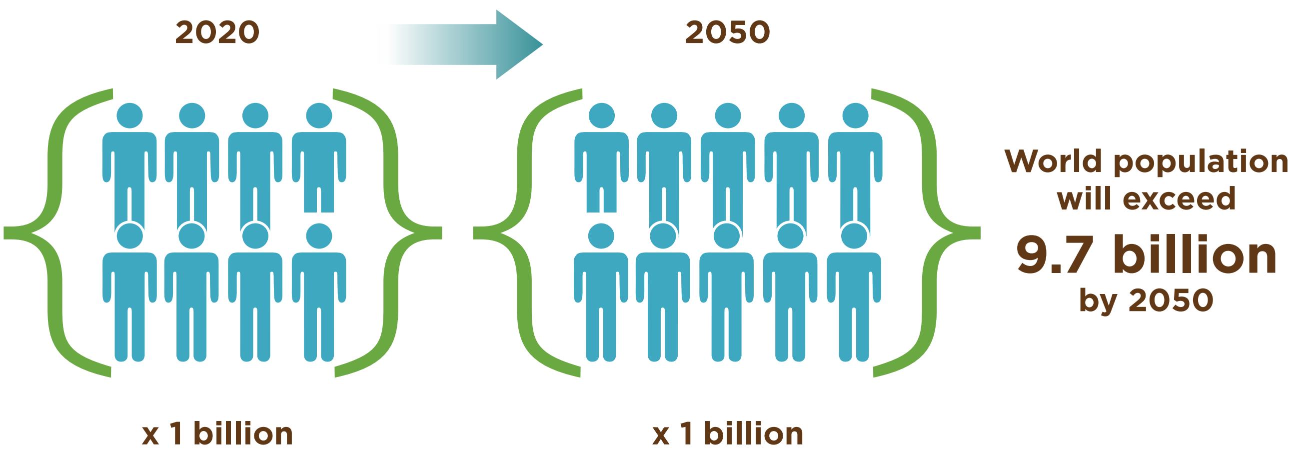


Figure 1. Crop production will need to significantly increase to meet the future food demands of a growing world population.

Making Progress, Yet Needing More

Growers are facing increasing demands to adopt more sustainable practices. These demands are coming from wide-ranging interests—from consumers and advocacy groups to regulators and large companies that are increasingly evaluating sustainability practices among their produce suppliers. Within the field of agriculture, too, growers are becoming increasingly more likely to incorporate sustainability practices into their current operations, motivated by data from agronomic studies showing that ideas like efficient nitrogen use initiatives[3] can pay off environmentally and financially. Industry is also calling for efficient nutrient use, in the form of enhanced efficiency fertilizers that allow growers to increase yields while reducing inputs.

We are already making progress. A recent report from Field to Market shows that production agriculture has become increasingly efficient, with many crops producing more yield on less land with improved environmental outcomes[4]. Per bushel of corn, for instance, productivity (crop yield per acre) increased by 61% from 1980 to 2015 **(Fig. 2)**, while land use per bushel, soil loss, water use, energy use, and greenhouse gas emissions all decreased by 30% or more. However, some of these improvements are already plateauing or even receding. Although impressive, today's gains will not meet the escalating demand for global human nutrition. We must do more. Not only do we need to increase yields without dramatically increasing the number of arable acres in use, we must also manage those finite acres more sustainably to assure that any yield gains achieved can be maintained. Thus, the challenge for growers is two-fold. They must increase productivity while becoming more sustainable.

Impressive Improvements, But More Gains Are Needed

Figure 2. Over the past four decades, corn yields have increased, while agricultural energy use, land use per bushel and soil loss have decreased. However, more production and efficiency gains are still needed to meet future food needs.

Growers are facing increasing demands to adopt more sustainable practices.

Sustainable Growing Practices That Make Economic & Environmental Sense

Simply intensifying current agricultural practices—whether by farming more land, using more irrigation or using more fertilizer—won't be enough to sufficiently augment crop yields. We can't simply do more of the same and expect to meet greater demands for food.

Instead, the next wave of agricultural productivity will have to incorporate new technologies. It will also have to do so in a sustainable way; that is, by using practices that meet human needs while reducing environmental impacts.

Moreover, as consumer and industry pressures for sustainable food production increase, broad behavioral change—including rapid adoption of new, more efficient practices—will be driven by grower economics. In a sense, the starting point is economic sustainability—where growers will find ways to reduce input costs, sustain or increase output value and simultaneously improve the environmental sustainability of what they do. **Agricultural sustainability does not need to come at the cost of economic sustainability.**

As part of the equation that aligns good economics with good environmental practices, Agricen is deepening the science behind biologically sourced tools that enhance nutrient use efficiency and increase yields more sustainably. Our goal is to help growers use practices that make both environmental and economic sense.

Agricultural and economic sustainability are possible, and even go hand in hand.

Agricultural Biologicals and Biostimulants: Time for a New Appraisal?

For thousands of years, the world regarded the act of growing a plant in the soil as a biological process. But—as in all systems—the need for scalability to meet growing demands called for new, more efficient technologies to improve food production.

The agricultural advancements of the post–World War II era were nothing short of transformational in the scheme of human affairs. Worldwide, food production skyrocketed, owing to improved seed varieties, modernized irrigation, better control of plant diseases and pests, increased use of chemical fertilizers, and evangelists like Dr. Norman Borlaug, who brought these practices to the world to help it feed itself. **From 1966 to 1999, total rice production increased by 132% and wheat production increased by 91%[5].** The efficiencies created by the broad availability and use of chemical fertilizers were a driving force behind this transformation. However, as the agricultural practices of the Green Revolution swept the world, the contribution of biological elements to crop production received significantly less and less attention.

In more recent years, we have realized that the gains achieved through the tools of the Green Revolution are not limitless. We have also realized that the intensity of agricultural production has some significant, long-term impacts on soil, air and water resources. These realizations have prompted a renewed interest in the biological elements of crop production, including the use of soil management practices meant to improve the conditions of the soil and the organisms that it harbors. They have also led to the development of new biological and biochemical technologies that are rooted in science and can be incorporated into current production practices to enhance agricultural sustainability and increase yields.

However, until recently, agronomists and other researchers have largely dismissed the possibility that biologically sourced tools—things like agricultural biologicals and biostimulants—could contribute significantly to feeding a growing population. Why is that? What have been some of the challenges to the development of this field?

> **"Without increased investments in agricultural research and technology development, it is unlikely that we will achieve adequate growth in agricultural production, and certainly not in environmentally sustainable ways."**
>
> *– Norman Borlaug, "Investing in Agricultural Research"*

One of the challenges has been the profusion of companies over the years selling "miracle" microbial solutions of indeterminate quality or origin. By making claims that were often overstated and not backed by any rigorous science, these companies contributed to the perception that biologically sourced tools for plant nutrition were little more than "snake oil."

Another major challenge has been the complexity of the soil-plant system (also called the "phytobiome"), coupled with the limitations of the technology to meaningfully analyze this system. In fact, developing a full understanding of the complex microbial communities in the soil is a challenge of staggering magnitude. Today, even with sophisticated genetic analysis tools, we can identify only about 10%[6] of the microorganisms found in any soil sample at the species level **(Fig. 3)**. Thus we know very little about how the remaining 90% of the microbial community, which is still unidentified, functions in the soil-plant system.

Even more challenging—and perhaps more important—may be trying to understand how these microbial communities biochemically impact plant nutrition. Each of these organisms may be the source of unique biochemical compounds that affect a variety of soil, plant and microbial community functions through interactions triggered at the molecular level. Indeed, with the evolution of next generation tools for molecular analysis, there are now numerous examples in the scientific literature of signaling compounds and other molecules that are capable of "turning on" various plant genes that affect plant functioning – improving things like nutrient acquisition, rooting responses and the production of secondary metabolites within the plant itself.

Researchers today are working to deepen their understanding of how these complex microbial communities and their metabolites affect plant nutrition, and they are applying this knowledge to improve crop production. Fueled by the development of improved methods for molecular and genetic analysis, their efforts are reflected in a growing body of literature that supports the use of biological tools in agriculture **(Fig. 4)**. These efforts are also reflected in the increasing recognition by growers, policymakers and international organizations such as the FAO of the importance of integrated nutrient management, which involves incorporating both organic and inorganic elements into growing practices.

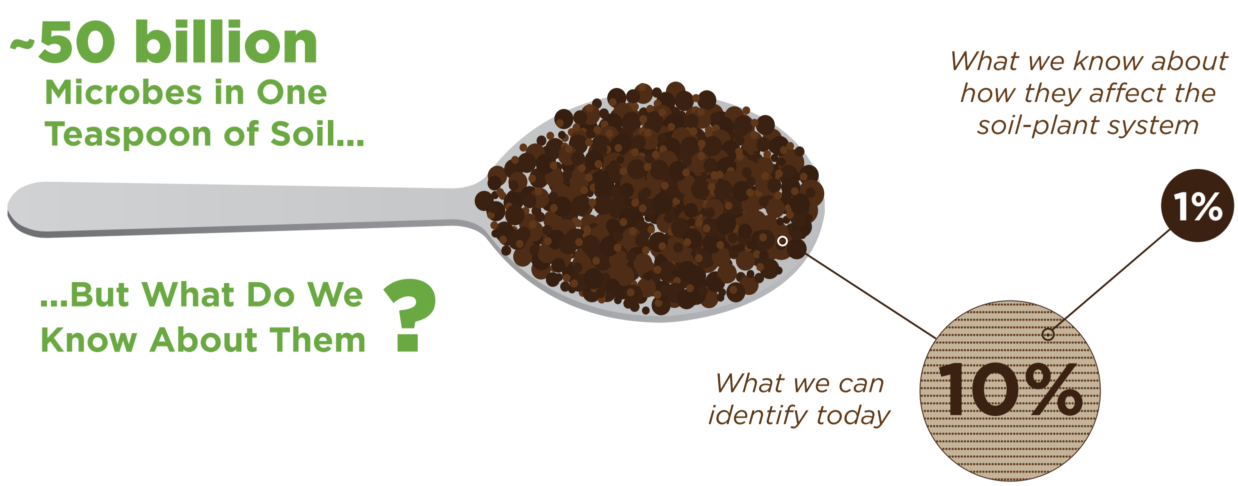
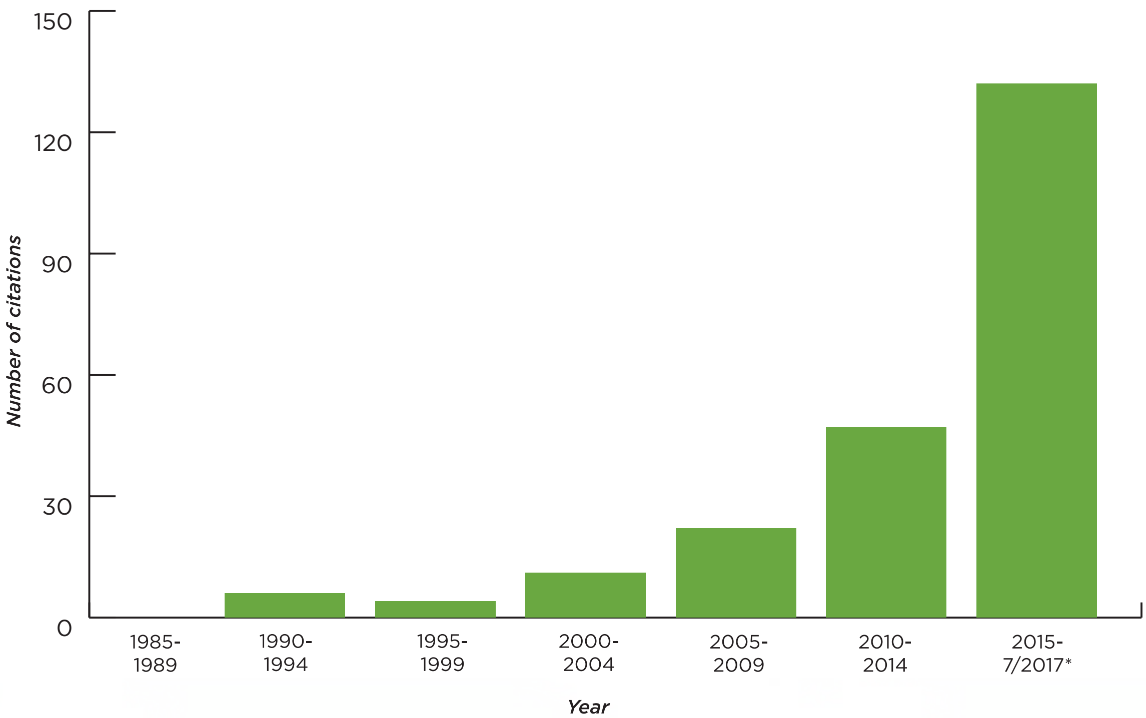


Figure 3. Even with today's sophisticated tools for genetic and molecular analysis, we know little about microbial communities in the soil and how they directly and indirectly affect plant nutrition.

It's time for another look at using the tools of biology to enhance an inherently biological system. This doesn't require an anti-chemical approach. Rather, we can make our agricultural practices both more productive and more sustainable by incorporating the next generation of biologically sourced tools into existing growing practices—in a sense, an "integrated nutrient management" approach similar to the integrative frameworks used in crop protection practices.

It will take time for this science to evolve and mature. Years—perhaps even decades—of work lie ahead in deciphering the biologically induced changes within the soil-plant system. However, we don't have to wait until all of the mysteries are solved to start putting the knowledge we do have to work for us—and solving some of the great challenges of the day.

A Growing Body of Scientific Literature on Microorganisms and Fertilizer Use Efficiency Has Emerged in Recent Years



**Note: This period is ~31 months, while others are periods of 60 months.*

***Figure 4.** Search performed August 1, 2015 and July 17, 2017 by J. Kloepper and C. Jenda at Auburn University using Web of Science-Thomson Reuters database. Searchers selected "only science citations" and searched for the terms "microorganism" and "fertilizer use efficiency" [personal correspondence].*

Agricen Is Advancing the Next Generation of Biologically Sourced Tools for Plant Nutrition

Agricen is a plant health technology company delivering innovative products and solutions for efficient and sustainable plant nutrition. Our products, which are derived from complex microbial communities and their metabolites, work with both conventional and organic fertilizer programs to increase nutrient availability, improve nutrient use efficiency and help growers increase their yields more sustainably. This means more bushels per acre and more income for the grower.

For more than a decade, Agricen has invested in rigorous scientific research focused on developing practical applications rooted in biology and biochemistry to improve the quality and performance of plant nutrition programs. Today, Agricen is leading the innovation and delivery of biochemical technologies that provide growers with the tools they need to increase productivity and sustainability.

Over 1,000 field and greenhouse trials have been conducted by Agricen, universities, government and other third-party evaluators to test our plant health solutions, both in the U.S. and internationally. These trials have shown that Agricen's technology can consistently, effectively and sustainably improve plant health. In addition, new and ongoing studies with our many research partners **(Fig. 5)** continue to enhance our understanding of how biologically sourced tools can contribute to the economic and environmental sustainability of production agriculture.

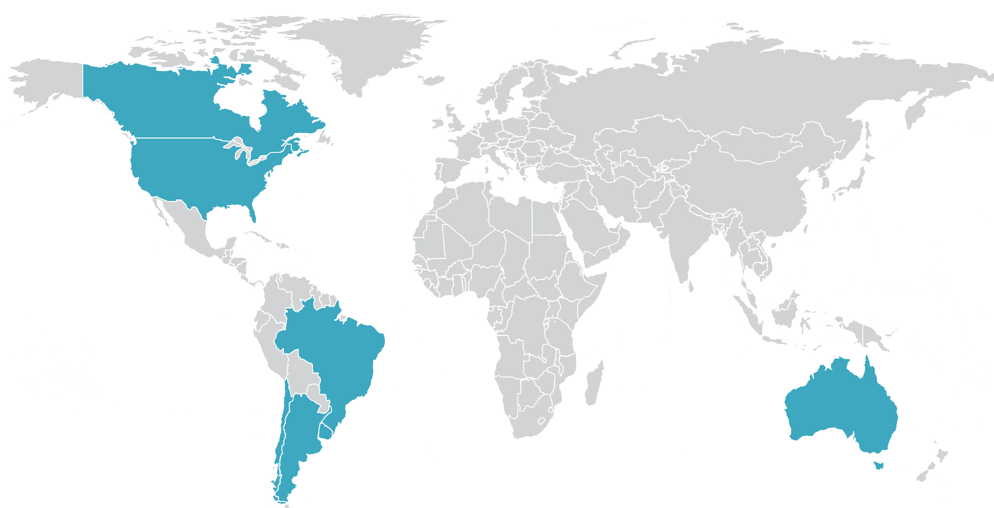
An active laboratory research program complements these efforts. Our scientists, who are specialists in plant pathology, soil microbiology and molecular microbiology, are helping to unravel the complexity of microbial communities and their interactions within the plant-soil system.

1,000+ Studies to Date Demonstrate Agricen's Product Efficacy

Third party, private studies and university trials document benefits, including:

- Better Root Growth
- Increased Yields
- Improved Soil Health
- Nitrogen Use Efficiency
- Higher Nutrient Uptake

Rigorous Trials Across the U.S. and Abroad



EFFICACY and EFFICIENCY tested on variety of crops and plants

Corn | Soybeans | Ornamentals | Wheat | Turf | Fruits & Nuts | Vegetables

Case Study: Agricen's Nutrient-Release Technology Reduces Nitrate Leaching, Increases Corn Yields

A three-year field study was conducted to evaluate the ability of Agricen's biochemical nutrient-release technology to reduce nitrate leaching from nitrogen (N) fertilizer and improve yields in corn.

The study was conducted using lysimeters at the field research facilities of Arise Research & Discovery, Inc., in Illinois. Fertilizer treated with Agricen's nutrient-release technology was compared to untreated fertilizer (control) over three growing seasons. The four treatments for each of the three years consisted of a standard N (163 lbs. N/acre) and reduced N (145, 154 or 130 lbs. N/acre) application rate, with or without the nutrient-release technology applied at 1 gallon/acre with UAN-28 at planting. An additional UAN-28 sidedress was applied without nutrient-release technology, two to four weeks after planting.

Each lysimeter plot (10' x 30') was seeded with field corn (Tristler T7N88CB) at a rate equivalent to 30,000 seeds/acre with four rows spaced at 30 inches. Water leaching through the soil profile of each lysimeter was captured by a drain tile at a depth of 42" and deposited into a lysimeter well at the end of each plot. Prior to pumping the lysimeter wells, four water samples were collected at various depths and analyzed for nitrate concentration. The volume of leachable water and nitrate:nitrogen (NO_3:N) concentrations in the water were determined six times during each season. Corn yield was evaluated at the end of each season.

In each of the three seasons, adding Agricen's nutrient-release technology to fertilizer increased yields over the control **(Fig. 6)**. It was also associated with a significant reduction in nitrate leaching compared to the control **(Fig. 7)**.

The average rate of nitrate leaching during the first growing season is shown in **Fig. 8**.

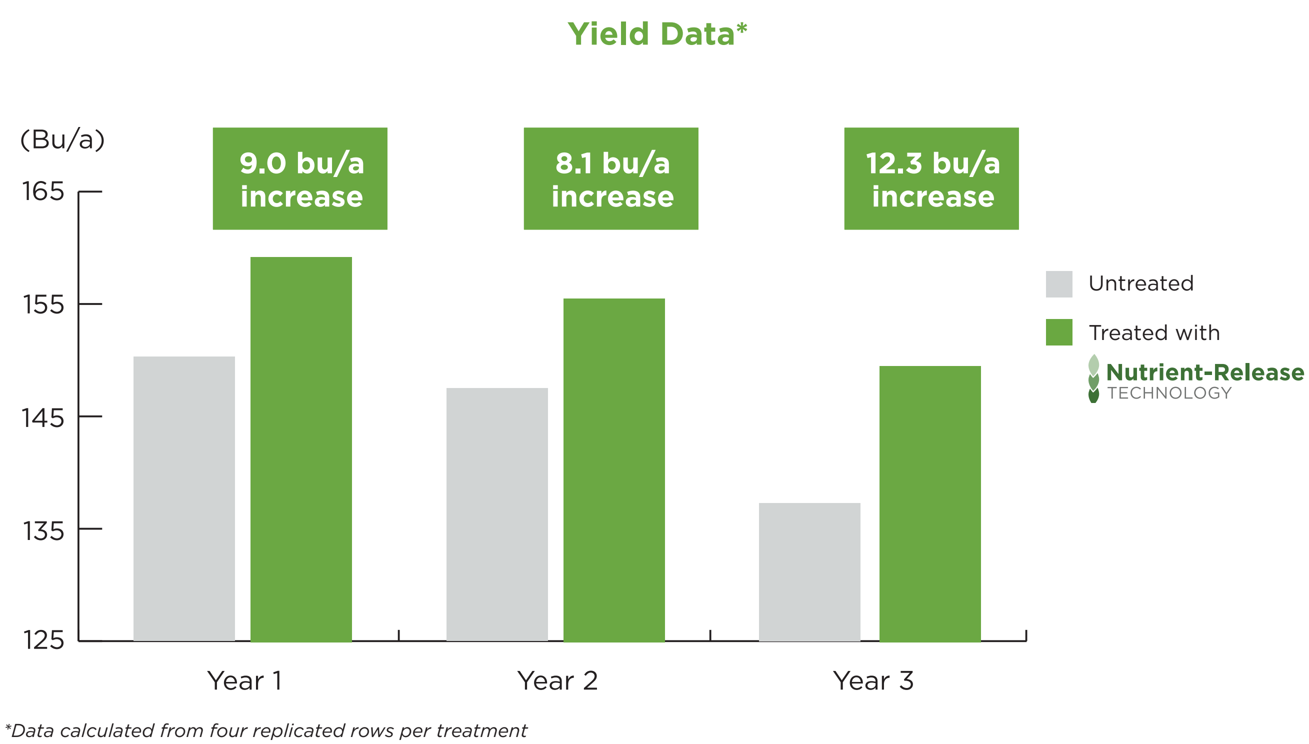
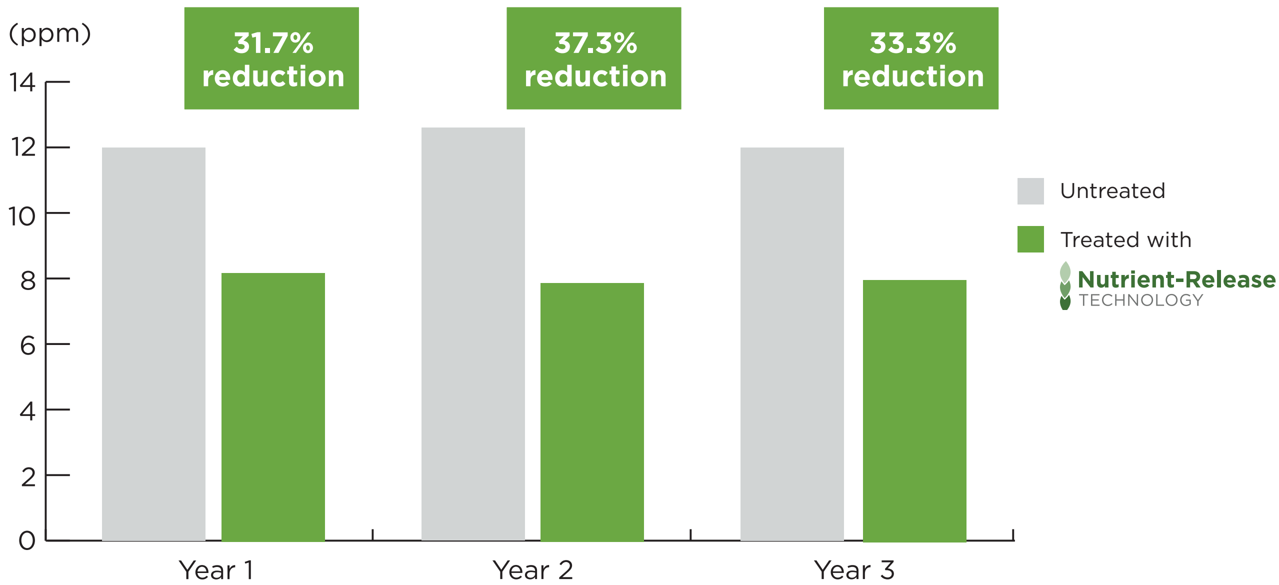


Figure 6. Treating fertilizer with Agricen's nutrient-release technology consistently improved yields. Differences between treatments within each year were statistically significant at P<0.05.

Average Nitrates Leached*



Average of six lysimeter pumping dates.

Figure 7. Adding Agricen's nutrient-release technology to fertilizer significantly reduced nitrate leaching.

Average Rate of Nitrate Leaching, Year 1

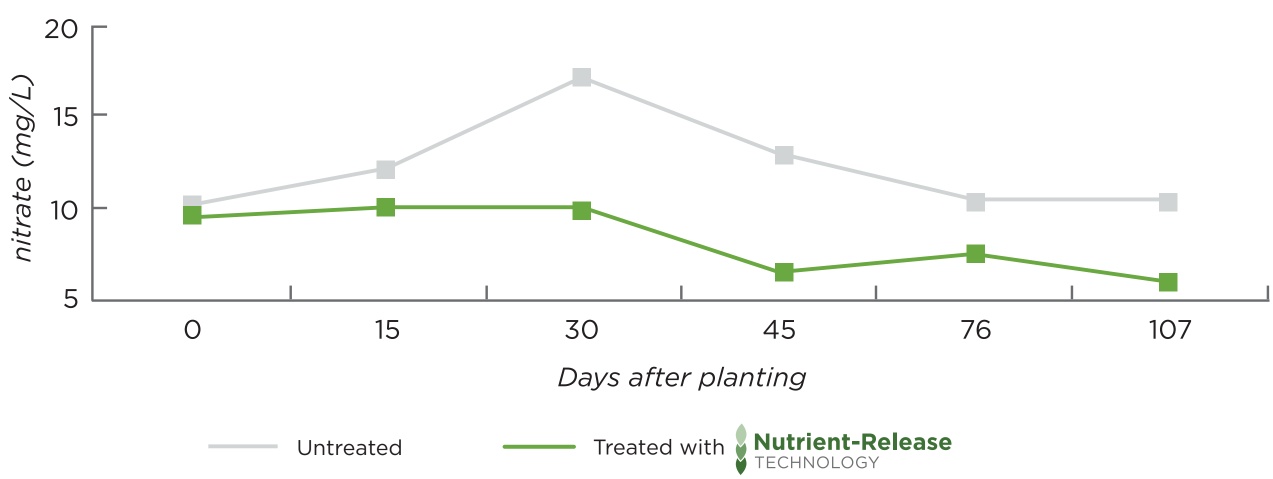


Figure 8. Agricen's (NRT) was applied at 1 gallon/acre with 14 gallons of UAN-28 banded at planting. At day 18, another 40 gallons of UAN-28 was side-dressed without NRT, followed by 3 inches of rain over the next 5 days. An analysis of nitrates in lysimeter well leachate at 6 pump dates showed reduced nitrate leaching from NRT-treated plots.

Overall, this field trial shows the ability of Agricen's nutrient-release technology to reduce nitrate leaching and increase nitrogen uptake by the crop. This translates into increased yields and more income for the grower.

This study is just one of the many field studies we have conducted to demonstrate that our biologically sourced tools can effectively and sustainably increase crop yields.

Case Study: Accomplish® LM Increases Crop N Uptake without Additional N Application, Also Improves P Availability

Over two years, independent agronomy researchers conducted field studies on corn at five locations in Iowa to investigate whether adding an additional 40 lbs N/acre above the grower's standard NPK fertility rate would reduce microbial competition for N, improve cornstalk nitrate N levels, and increase yield. The grower's standard N rate was 200 lbs N/acre. Additional N, above the standard rate, was supplied using four different N-containing fertilizers. Accomplish LM (Loveland Products, Inc.), a biochemical fertilizer catalyst manufactured by Agricen, was also included in this study at the standard fertility rate but with no additional N to determine if it would impact N availability to the crop. The six treatments in the studies were:

- Grower's standard N (200 lbs N/acre) (control)
- Grower's standard N + Accomplish LM at 1.5 quarts/acre (no additional N)
- Grower's standard N + 39 lbs N/acre using urea ammonium nitrate (UAN), 28-0-0
- Grower's standard N + 41 lbs N using ammonium sulfate (AMS), 21-0-0-24S
- Grower's standard N + 41 lbs N using MicroEssentials® SZ (MESZ; Mosaic Company), 12-40-0-10(S)-1(Zn)
- Grower's standard N + 39 lbs N using urea, 46-0-0

Treatments were applied in late March of both years. In Year 1, soil nitrate testing was performed in late spring and stalk nitrate evaluations were made from each treatment strip in late fall. In Year 2, soil phosphate (P) availability was determined, rather than nitrate.

When soil nitrate levels were averaged across the five Iowa locations in Year 1, Accomplish LM treatment was associated with the highest soil nitrate levels, indicating that more of the applied N from the grower's standard treatment remained in the soil compared to the other treatments where additional N was applied on top of the standard fertility rate **(Table 1)**.

Table 1. Soil and Stalk Nitrate Tests, Year 1

	28% UAN	AMS	MESZ	Urea	Accomplish LM*	Check
Additional Nitrogen Added	40 lbs.	40 lbs.	40 lbs.	40 lbs.	0 lbs.	0 lbs.
Avg. Late Spring Nitrate Test – ppm NO_3	10.2	8.8	18.8	8	20.6	7
Avg. End of Season Stalk Nitrate Test – ppm NO_3	5716	6435	8938	7319	5519	5990

**Accomplish LM applied at 1.5 quarts per acre*

By late spring, Accomplish LM increased soil N availability without additional N application.

At the end of the first season, stalk nitrate was lowest in Accomplish LM-treated plants **(Table 1)**, but the average yield was highest with this treatment **(Fig. 9)**, results that were repeated in the second growing season **(Fig. 10)**. These results indicate that more of the applied N was taken up by the crop and utilized for grain production with Accomplish LM, rather than remaining in the stalks.

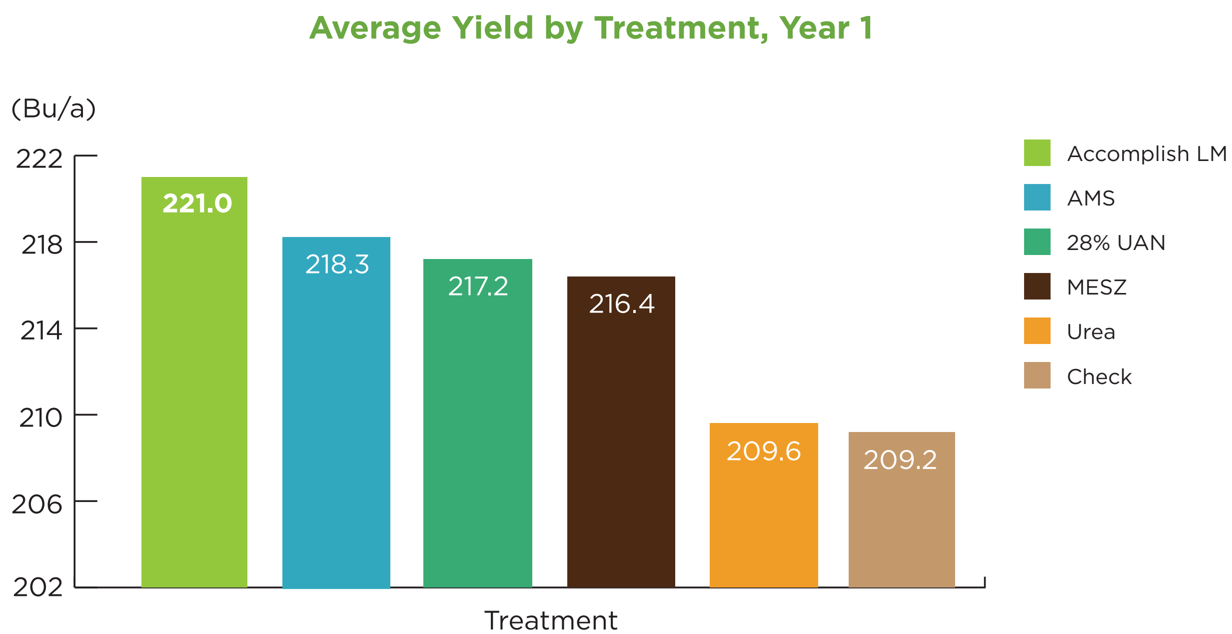


Figure 9. The average corn yield in Year 1 was highest with Accomplish LM.

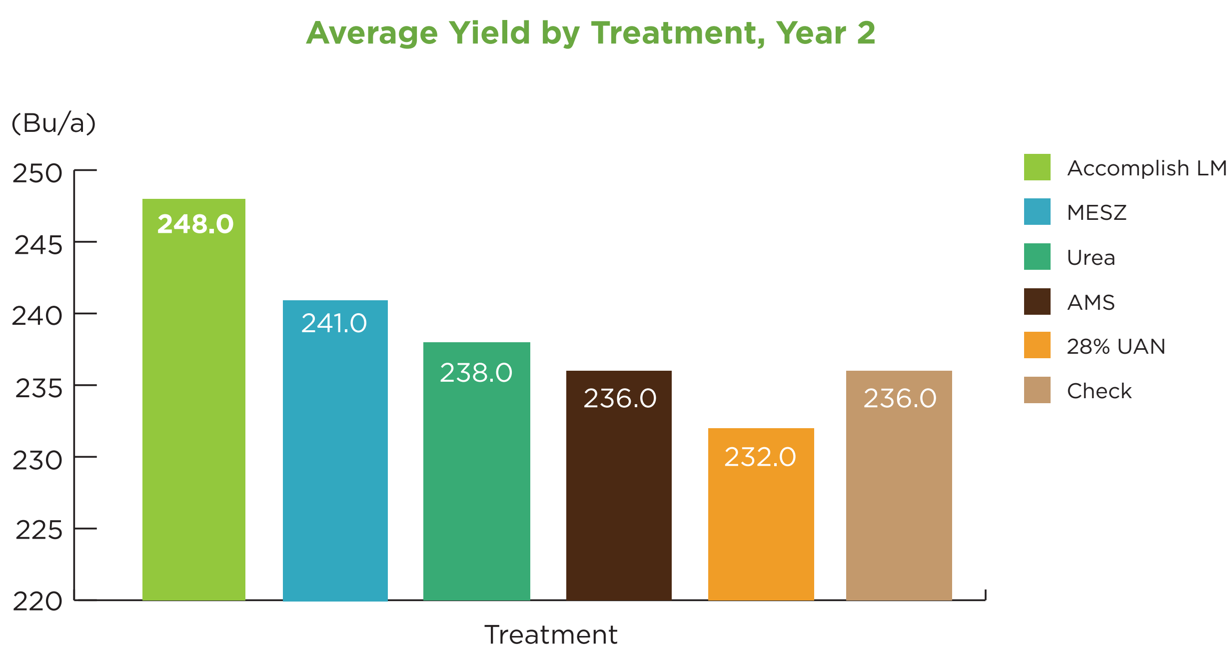


Figure 10. As in 2010, the average corn yield in Year 2 was highest with Accomplish LM.

Phosphorus analysis of the soil at five locations in Year 2 indicated that, on average, more P was available to plants in the Accomplish LM-treated plots compared to the plants grown in plots with the other treatments, including those with additional N applications **(Table 2)**. This P increase was observed with two extraction methods: Bray P1 (analyzes for readily available P) and Bray P2 (analyzes for P that is in a plant-available form, but more difficult for the plant to take up from the soil). Thus, Accomplish LM was shown to be more efficient in keeping P available to the crop.

Table 2. **Soil P (ppm), Year 2**

Location	Check P2	Check P1	Accomplish LM P2	Accomplish LM P1
Garnavillo, IA	51	37	76	47
Lamont, IA	172	108	195	124
Nora Springs, IA	82	54	89	64
Ossian, IA	40	31	48	35
Waverly, IA	214	124	325	150
Average	**112**	**71**	**147**	**84**

P availability improved when Accomplish LM was combined with a standard NPK fertility program.

In summary, two years of field studies conducted at several locations in Iowa demonstrated that Accomplish LM, when combined with a grower's standard fertility program, can increase both soil N and P availability for corn and increase corn yields.

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