PLANT NUTRITION TODAY

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IMPROVING FERTILIZER NITROGEN PERFORMANCE –

Recent Global Nitrogen Conference and North America Science Examples

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Fertilizer industry leaders, professional crop advisers, and their farmer customers are working more intentionally to improve fertilizer nitrogen (N) use efficiency and effectiveness. Their goal is to use site-specific 4R *(right source, rate, time, and place)* N management practices, in concert with proven soil and water conservation practices, to get as much of the applied N into the crop as economically possible. Such complementary management actions increase the opportunities to raise crop yields and decrease crop yield gaps; while also helping to reduce the risks of residual nitrate-N buildup in the soil profile and helping to minimize losses of N to the environment via other major N loss pathways.

Many different factors affect fertilizer (and manure) N performance in various cropping systems, but as the Table below illustrates, it is quite important to recognize that many are under farmer management control; while many are not.

Below, we call attention to a dozen (12) examples of relatively recent (late 2016 to early 2017) science reports that are identifying and validating more of the options available to professional practitioners and farmers to improve fertilizer N performance; for increased crop yields while also protecting soil, water, and air resources.

Papers presented at 7th International N Initiative Conference (INI 2016) on *Solutions to Improve Nitrogen Use Efficiency for the World*.

Papers by International Plant Nutrition Institute (IPNI) scientists:

- Evaluation of a new fertilizer recommendation approach to improve nitrogen use efficiency across small-holder farms in China, by Dr. He Ping (IPNI China)
- Addressing heterogeneity of maize yield and nitrogen use efficiency in India: Farm-specific fertilizer recommendation from the Nutrient Expert® Tool, by Dr. Kaushik Majumdar (IPNI Asia-Africa)
- Nitrogen performance indicators on southern Australian grain farms, by Dr. Rob Norton (IPNI Australia-New Zealand)
- Enhanced nitrogen fertilizer technologies support the ‘4R’concept to optimize crop production and

MANAGEMENT FACTORS	ENVIRONMENTAL FACTORS
Fertilizer type (SOURCE)	Temperature
Application rate (RATE)	Precipitation
Application technique (PLACE)	Soil moisture content
Timing of application (TIME)	Organic carbon content
Tillage practices	Oxygen availability
Use of other chemicals	Porosity
Crop type	pH
Irrigation	Freeze and thaw cycle
Residual N and carbon from crops and fertilizer	Microorganisms

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> “These newer scientific reports are illustrating that sizable (> 20 to 50%) reductions in the loss of N from farm fields may be achieved with improved 4R N management practice implementation.”

minimize environmental losses, Dr. Cliff Snyder (IPNI Nitrogen)

- Influence of soil fertility variability and nutrient source on maize productivity and nitrogen use efficiency on smallholder farms in Zimbabwe, by Dr. Shamie Zingore (IPNI Sub-Saharan Africa)
- Full INI 2016 Conference program and other papers on improved N use efficiency

Recently published soil and agronomic science articles from North America:

- Nitrogen Extenders and Additives for Field Crops, by Dr. Dave Franzen (North Dakota State University, USA)
- Effect of enhanced efficiency fertilizers on nitrous oxide emissions and crop yields: a meta-analysis by Mr. Resham Thapa and Dr. Amitiva Chaterjee and others (North Dakota State University, USA)
- Ten Ways to Reduce Nitrogen Loads from Drained Cropland in the Midwest by Dr. Laura Christianson and others (University of Illinois, USA)
- Improving fertilizer management in the U.S. and Canada for N_2O mitigation: understanding potential positive and negative side-effects on corn yields by Dr. Diego Abalos, Dr. Claudia Wagner-Riddle, and others (University of Guelph, Canada)
- Lower nitrous oxide emissions from anhydrous ammonia application prior to soil freezing in late fall than spring pre-plant application by Dr. Mario Tenuta and others (University of Manitoba, Canada)
- Assessment of drainage nitrogen losses on a yield-scaled basis, by Mr. Xu Zhao, Dr. Laura Christianson, and others (University of Illinois, USA)
- Corn nitrogen management influences nitrous oxide emissions in drained and undrained soils by Dr. Fabian Fernandez and others (University of Minnesota, USA)

These newer scientific reports, along with other published research results, are illustrating that sizeable (often > 20 to 50%) reductions in the loss of N from farm fields (via drainage of nitrate-N and/or emissions of ammonia or nitrous oxide) may be achieved with improved 4R N management practice implementation. We are also learning that although the reductions in N losses from farm fields may be proportionately large with some of the improved N technologies, tools, and practices—depending on the soil, cropping system, and climatic conditions—some of the crop yield benefits may be relatively modest to small. That makes it difficult for farmers to economically implement some environmentally important N management and conservation practices, without some incentives or supporting policy.

As you consider the many options available to improve the performance of applied N in your cropping system, try to base your management decisions primarily on sound regional or local science. Where such science is not available for your area, consult your crop adviser or trusted agronomic professional for assistance in choosing economically rewarding and environmentally protective nutrient management practices. Make sure that the right soil and water conservation practices are also in place to protect soil health, water quality, and sustainable production.

PLANT NUTRITION TODAY
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POP-UP FERTILIZER... BENEFITS, RISKS, AND OTHER CONSIDERATIONS

Placing fertilizer in-furrow with the seed is a common practice in small grain and row crop production. Often called "pop-up", fertilizer placed with the seed can under certain conditions have several benefits including promotion of early root growth and plant vigor, which in turn can result in a crop with greater resistance to pests, improved ability to compete with weeds, hastened maturity (associated with P fertilizer), and increased yield.

But, caution is warranted with pop-up fertilizer use since over application can result in seedling damage, and ultimately stand and yield loss. The type of crop, fertilizer source, row spacing, and soil environment all affect how much fertilizer can be safely applied with seed.

Type of crop: Some crops are more susceptible to injury from pop-up fertilizer than others. Oil seed crops are particularly sensitive. The general order of sensitively (most to least) among major crops is soybeans > sorghum > corn > small grains.

Type of fertilizer: Fertilizers are salts… too much fertilizer (salt) in seed contact and desiccation or "burn" can occur. Some fertilizer materials have higher salt index or burn potential than others. As a general rule, most N and K fertilizers have higher salt index than P fertilizers; therefore, a common predictor for the potential for salt damage is the sum of $N+K_2O$ per acre applied with the seed. For example, most guidelines for corn in 30-inch rows will allow for no more than 10 lb/A of $N+K_2O$ in medium to fine textured soils (no urea-containing products).

Potential for ammonia formation: Fertilizers that have the potential to release free ammonia can cause ammonia toxicity to seed. Thus, in-furrow placement of urea-containing fertilizers is usually ill-advised. In some cases, UAN is applied successfully in-furrow in small grain production, but there is risk in this practice because of the potential for ammonia damage. As a general rule, the use of urea or UAN in-furrow in row crop production should be avoided.

Example of the impact of in-furrow (pop-up) phosphorus application on early corn growth and development. Corn rows on the right received pop-up P while rows on the left did not.

Row spacing: For a specific set of circumstances (crop, soil conditions, etc.) safe rate of in-furrow fertilizer increases as row space narrows. This is because the narrowing of row space has the effect of diluting fertilizer over more linear feet of row (per acre).

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“The type of crop, fertilizer source, row spacing, and soil environment all affect how much fertilizer can be safely applied with seed.”

Soil environment: Soil conditions that tend to concentrate salts or stress the germinating seed increase damage potential. So, the safe limit for in-furrow fertilization is reduced in sandier soils and in drier soil conditions. Also, environmental conditions that induce stress and/or slow germination (e.g., cold temperature) can prolong fertilizer-seed contact and thus increase the likelihood of damage.

Seed bed utilization: The type of planting equipment and seed opener used influences the intimacy of seed-fertilizer contact. The more scatter there is between seed and fertilizer in the seed row the more fertilizer can be safely applied. The concept of “seed bed utilization” has been used to address this factor. SBU is simply the seed row width divided by the row width, or the proportion of row width occupied by the seed row. The wider the seed row for a specific row width the greater the SBU. As SBU increases so does the safe rate of in-furrow fertilization.

A detailed rendering of the topic is beyond the scope of this newsletter, so the information here is mostly general and conceptual. For more specific information regarding in-furrow fertilization refer to university extension resources, and/or consult a knowledgeable and experienced crop adviser or industry professional. Also, IPNI has some helpful electronic tools available online.

Seed-Placed Fertilizer Decision Aid: http://www.ipni.net/article/IPNI-3268 (Excel format)

Seed Damage Calculator: http://seed-damage-calculator.herokuapp.com (Web-based)

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PLANT NUTRITION TODAY
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FAVORABLE SOIL pH: DOES IT REALLY INCREASE NUTRIENT USE EFFICIENCY?

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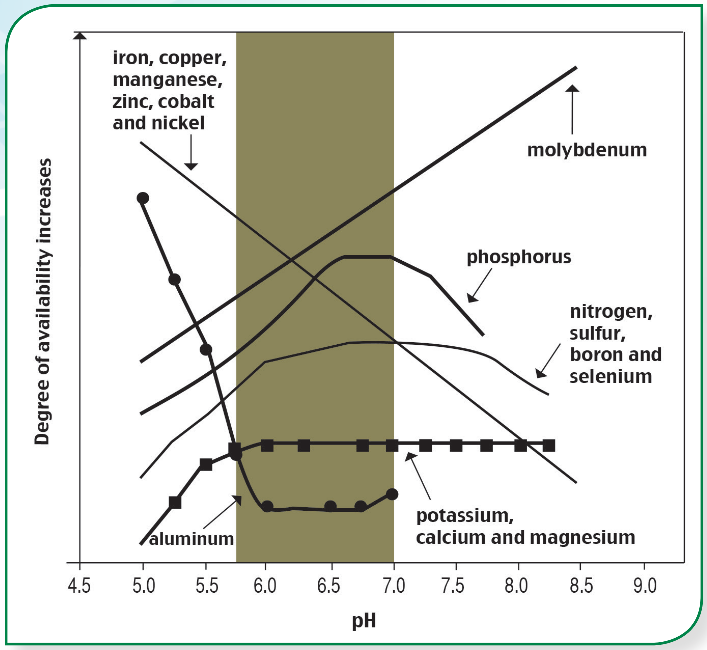
More than ever agriculture needs to follow principles of sustainability that ensure build up and maintenance of long-term soil productivity. The benefits of high soil productivity include efficient use of crop inputs, environmental protection, social benefits to stakeholders, and greater farmer profits.

Many soils around the world have a natural tendency to become acidic with time. Many factors, natural and managed, contribute to this increase in soil acidity. Soil acidity is especially widespread in tropical regions due to climates that cause intense weathering of soils. It is estimated that about 30% of soils in the world are acidic, but these regions still represent some of our most important food-producing centers.



Typical effect of soil pH on plant nutrient availability. Actual effects may vary with other soil chemical and mineralogical properties.

On soils where acidity limits crop yields, soil acidity amelioration constitutes an important best management practice to achieve sustainability. Soil acidity can slow crop development and reduce yield. Contributing factors to acidity damage include its negative impacts on soil physical and biological properties, high toxicities of elements like aluminum, iron, and manganese, and reduced effectiveness of certain herbicides and availability of plant nutrients.

The efficient use of nutrients is part of sustainable agriculture around the world. There are many practices that should be taken into account to assure high nutrient use efficiency (NUE). The 4R Nutrient Stewardship approach of using the right source, rate, time, and place summarizes the site-specific principles for using nutrients correctly. It should be emphasized that each combination of 4R practices interact with many factors in the field, including soil pH, to optimize the use of nutrients.

Research has proven that each crop develops better in a specific range of soil pH and that range should also optimize nutrient availability. The chemical availability of several nutrients is improved by liming acid soils. For example, insoluble forms of phosphorus and sulfur are changed to more plant-available forms by correcting the soil pH. In general, the availability of most nutrients is greatest in the soil pH range of 5.8 to 7.0. In some cases, nutrient absorption can be doubled simply by correcting the soil pH.

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> *“It is estimated that about 30% of soils in the world are acidic, but these regions still represent some of our most important food-producing centers.”*

Around the world there are numerous agronomic experiments showing the paybacks of correcting soil pH in the form of better crop development, NUE, and final yield. Yield increases of up to 500% have been reported in different regions.

The most common practice to correct soil pH is liming. This practice neutralizes excess soil acidity and improves the growing environment of root systems, leading to more absorption of nutrients.

Research on the correction of soil pH is region specific so one should look for local recommendations to guide farm practice.

In the end, the ultimate benefits of correcting soil pH to the grower are higher and more profitable crop yields. A broader benefit goes to the surrounding environment due to the increased resource efficiency of producing more crops on less land.

A.Tasistro and L.Prochnow/IPNI

Examples of phosphorus deficiency in corn (left) and magnesium deficiency in soybean (right) which are two common issues on acidic soils.

Centre for Rhizobium Studies, Murdoch University.

Poor nodulation and lower biomass production in sub clover due to aluminum toxicity/soil acidity.

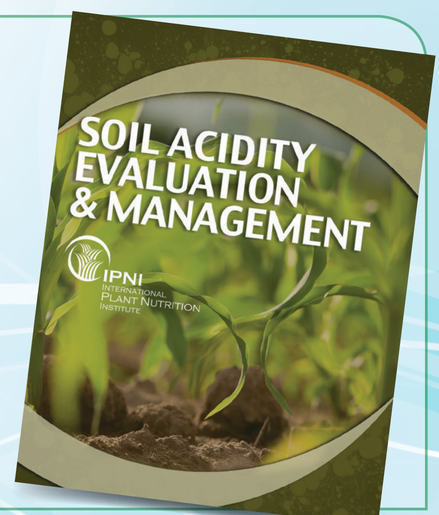
Soil Acidity Evaluation & Management

IPNI has developed a Booklet with accompanying PowerPoint slide set that is designed to provide a concise review of key concepts related to soil acidity, its evaluation and control through various management practices.

Booklet (30 pages, 8.5 x 11 in., wire bound)
Cost: US $12.00

PowerPoint Slide Set (30 slides with speaker's notes)
Cost: US $10.00

Order online at **http://store.ipni.net**



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PLANT NUTRITION TODAY

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GOOD NUTRITION: KEY TO PLANT HEALTH

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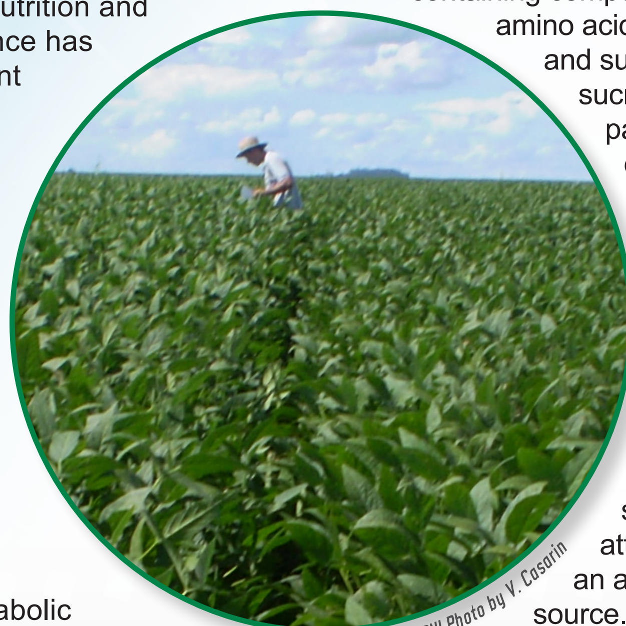
Getting crops off to a good start is critical for achieving high yields. During this early stage of growth, seedlings are especially vulnerable to many environmental and biological stresses. Protecting plants from stress and disease begins with providing balanced nutrition from planting through harvest. The critical link between plant nutrition and disease resistance has become apparent as the frontiers of plant health are better understood. A few of these examples are explained here:

Potassium

Potassium plays an essential role in many well-recognized metabolic processes for plants. Potassium's contribution to sustaining high yielding crops with top quality is well understood. However, the role of potassium in plant stress resistance is less known and appreciated. Potassium is unique among the essential mineral nutrients in its role for plant survival against environmental stress, pests, and diseases.

Supplying adequate potassium to crops through proper fertilization is a simple way to lower the requirement for pest-control treatments that may be costly, time-consuming, and troublesome. The frequently observed benefits of potassium on plant health were reviewed by Wang et al. (2013), which summarizes many recent scientific studies.

When there is a lack of sufficient potassium in plants, low molecular weight compounds begin to accumulate. This build-up of soluble nitrogen-containing compounds (such as amino acids and asparagine) and sugars (such as sucrose) makes a particularly favorable environment for numerous pathogens and insects. For example, aphids are severely nitrogen limited, making potassium-stressed plants an attractive host as an abundant nitrogen source. The presence of sufficient potassium also promotes the production of defensive compounds (such as phenols) which are an important component in plant pest resistance.



Potassium fertilization boosts soybean growth (right), enhances pest resistance, and promotes plant health.

An adequate potassium concentration within the plant decreases the internal competition with various pests and pathogens for resources. This results in more resources available for hardening cell walls and tissues to better resist penetration of pathogens and insect

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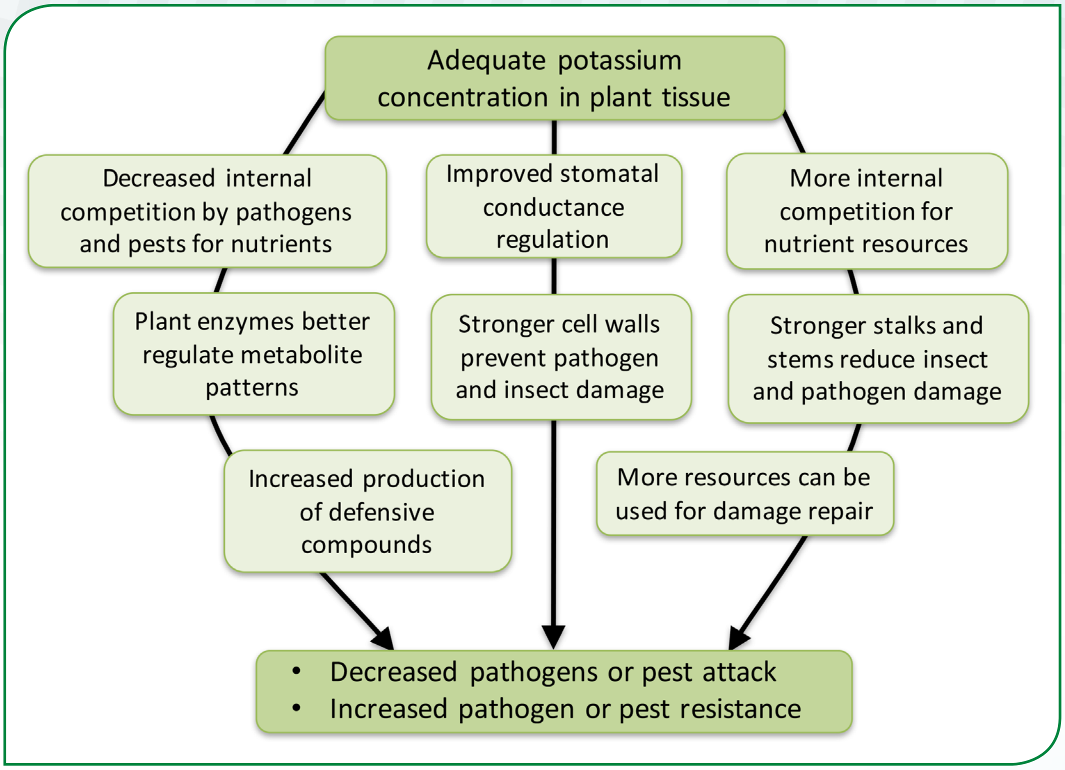
> *"Healthy plants with sufficient phosphorus have vigorous root growth which allows them to outgrow and escape disease"*



***Proper potassium nutrition** improves plant resistance to pathogens and insects through many mechanisms (Figure adapted from Wang et al., 2013).*

pests, and to repair any damaged tissue. Air-borne pathogens are more rapidly shut out from stomatal invasion when adequate potassium is present.

Phosphate

The link between adequate phosphate and plant health is also well known, but perhaps less understood than the association with potassium. Phosphorus is involved in the synthesis of many organic molecules and complex metabolic functions within plants. Crop growth and yields will be significantly reduced when phosphorus is deficient in soil or when plant roots cannot access it.

A shortage of phosphorus frequently leads to more disease for many crops. Some of the protective response occurs because healthy plants with sufficient phosphorus have vigorous root growth which allows them to outgrow and escape disease. More specifically, an adequate phosphorus supply has been linked with decreased incidence of Pythium root rot for wheat, leaf blight for rice, numerous tobacco diseases, blight in soybean, and many other diseases.

Foliar application of phosphorus-containing sprays is reported to induce protection against powdery mildew.

Chloride

The important role of chloride as a nutrient is often overlooked, especially in regions where soil salinity is a concern. However in many areas, the addition of chloride results in increased plant vigor and disease resistance. The occurrence and severity of a number of plant diseases have been documented to be reduced following the application of chloride. This includes take-all, stripe rust, and Septoria in wheat, and stalk rot in corn.

Promoting plant health clearly includes a solid foundation in proper nutrition. Strong and vigorous crops are able to produce abundant yields of high quality, while better resisting diseases and pests.

References

Wang, M. et al. 2013. Internat. J. Molec. Sci. 14:7370-7390. Available at: http://www.mdpi.com/1422-0067/14/4/7370

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PLANT NUTRITION TODAY
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CITIZEN SCIENCE FOR PRODUCTION AGRICULTURE

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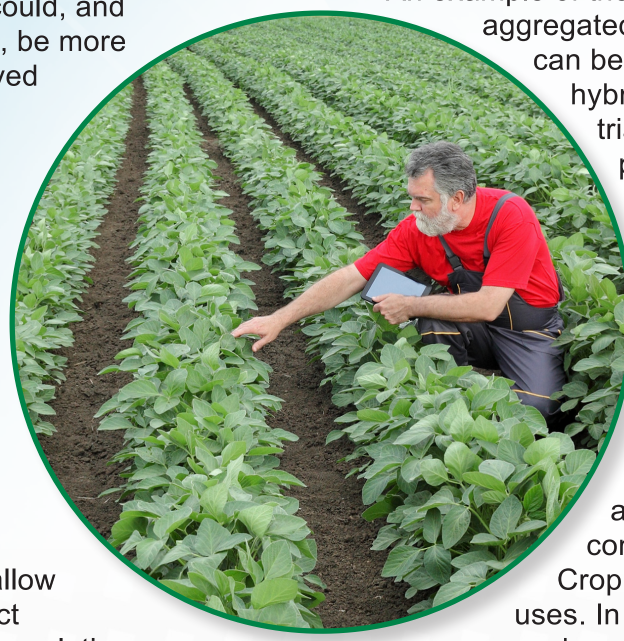
Citizen science can be defined as "the participation of non-scientists in the process of gathering, using, and interpreting data." The approach has been around for decades, but it's a little surprising that it has not been employed to much extent in production agriculture research. Considering farmers' vested interests in agricultural research, they could, and probably should, be more frequently involved in the scientific process.

Precision agriculture (PA) technologies such as auto-guidance and section control, planting and harvest monitors, and variable-rate input mapping allow farmers to collect abundant, high-resolution data. These data combined with other site information such as measured or remotely sensed soil characteristics and crop imagery collected via satellites, UAV's, or canopy sensors result in multiple layers of on-farm data that can be explored and modeled as part of a scientific process.



Farmer collecting data from field.

The greatest value in data is realized when the data are aggregated within communities or networks. Aggregating data into a database structure allows end-users of the information to see previously hidden relationships among the layers of data. Data aggregation either among farmers using a common service provider, or among farmer clients of multiple dealerships, is a service currently offered by over 30% of PA providers according to a recent survey. Over 80% offer some level of data support, so an increase in data aggregation services is a reasonable expectation for the future.

An example of the power of aggregated farmer data can be seen in a simple hybrid performance trial. In his presentation at InfoAg, Dan Frieberg showed an example of how a traditional research approach differs from the aggregated data approach that his company, Premier Crop Services (PCS), uses. In the traditional approach, each hybrid yield was measured from research plots replicated across 59 locations for a total of 177 total observations for each hybrid in the trial. PCS collected much higher resolution data (observation recorded every 400 m^2) and aggregated the results across all their customers resulting in over 300,000 observations for a single hybrid. The multiple layers of meta-data available in the aggregated approach allowed the results to be parsed out by soil type and crop rotation and still

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"To fully engage farmers in citizen science, research must be designed in a manner that satisfies their "non-scientist" views as well as academic rigor."

included over 18,000 yield observations for a single hybrid in a common region.

PCS also places replicated, randomized plots in specific zones within fields to generate numerous controlled comparisons. These so-called "Learning Blocks" allow what were once observational data to be evaluated in a more rigorous traditional statistical fashion. This style of merging the traditional scientific process with the aggregated, citizen science-based approach bridges "big data" with "small data" and may well become a significant part of agronomy's future.

To fully engage farmers in citizen science, research must be designed in a manner that satisfies their "non-scientist" views as well as academic rigor. Studies must work for the benefit of the end users (multiple stakeholders) and the participants (farmers and scientists). Academic research tends to be hypothesis driven and focused on one or two isolated variables to provide insight for many individuals. Conversely, a farmer's view of research would include multiple factors for maximum realism, be outcome driven, and be relevant for specific individuals. Thus, successful citizen science projects must have evaluation built into the design to ensure the quality of the scientific data generated is measureable, but be adaptable as necessary. Citizen science in production agriculture must be collaborative, credible, and most importantly, a continuous learning process.

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PLANT NUTRITION TODAY
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EL NIÑO, FERTILIZER APPLICATION, AND COCOA YIELD IN SULAWESI, INDONESIA

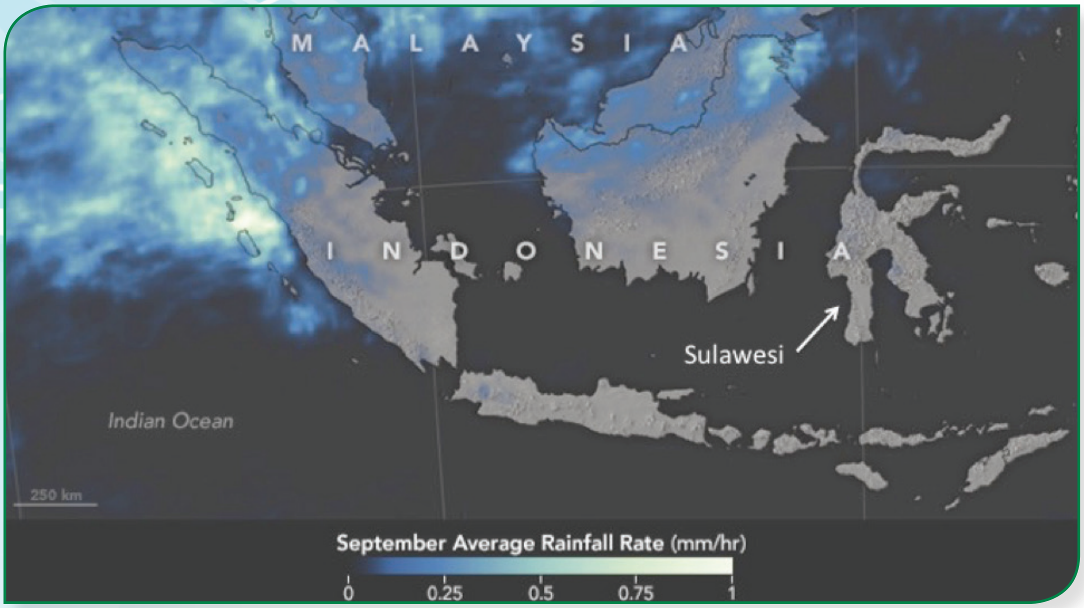

Figure 1. Satellite observations of rainfall over Indonesia, captured by the Global Precipitation Measurement (GPM) mission for September 2015. (Source: Joshua Stevens, Jesse Allen, NASA Earth Observatory, Precipitation Processing System of GPM's Science Team, accessed in September 2016 at http://power.larc.nasa.gov/cgi-bin/cgiwrap/solar/agro.cgi.

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In 2015, an unusually strong El Niño had been brewing in the Pacific Ocean. Fishermen of Northern Peru used the term to describe a warm southward coastal current that occasionally develops around December. Now meteorologists use the term to describe large increases in sea surface temperatures in the eastern and central equatorial Pacific that occur at irregular intervals.

In El Niño years, parts of Indonesia experience drought, just like in 2015. The map (**Figure 1**) indicates the areas that received the most rainfall in September 2015 with white colors, low rainfall is indicated by blue areas, while no rain is shown in gray. Sulawesi is almost entirely gray. Similarly, the Prediction of Worldwide Energy Resource website indicated a much lower cumulative rainfall in 2015 (1,350 mm) than in 2014 (1,656 mm) (NASA, 2016) for the Soppeng area of Sulawesi.

Since 2012, IPNI and Cocoa Care engaged with Indonesian smallholder farmers to understand the impact of good agricultural practices and complementary 4R nutrition on cocoa bean yields. One group of 16 farmers collaborated with IPNI and Cocoa Care during 2014 and 2015.

Farms were divided in two equal sized parts. In one half, good agricultural practices without additional fertilizer nutrients (GAP) were implemented, while GAP with 4R-consistent nutrient management (GAPN) was imposed in the other half. GAP involved regular pruning, weeding, and phyto-sanitation. In 4R Nutrient Stewardship, the right source of fertilizer is used, at the right rate, time, and place.

Our fertilizer recommendation was developed based on the replacement of nutrients exported by a target yield of 2 t/ha. Inorganic fertilizer nutrients were selected compost sources are limited. The fertilizers were applied twice a year with the onset of the rainy season (December/January and July/August). Nutrients were buried in four 20 cm deep holes with 10 cm diameter, equally spaced around the tree and along the edge of the canopy to match root growth.

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> *"The fields that were only managed with good agricultural practices (GAP) had a 23% yield reduction in [drought conditions], while yields in farms receiving GAP and complementary nutrition only dropped by 12%."*

Table 1 shows the average dry cocoa bean yields for the two groups. As expected, GAPN performed better than GAP in both years. In 2014, the complementary fertilizer application translated into 230 kg of extra beans per ha, about 25% higher than GAP only. In 2015, this difference was more than 280 kg/ha, or 34% more yield in GAPN.

The comparison across the two years indicated the influence that El Niño had on the yield. The fields that were only managed with good agricultural practices had a 23% yield reduction in 2015, while yields in those farms that received GAP and complementary nutrition only dropped by 12%. These results underscore the role adequate and balanced nutrition plays in water stressed conditions.

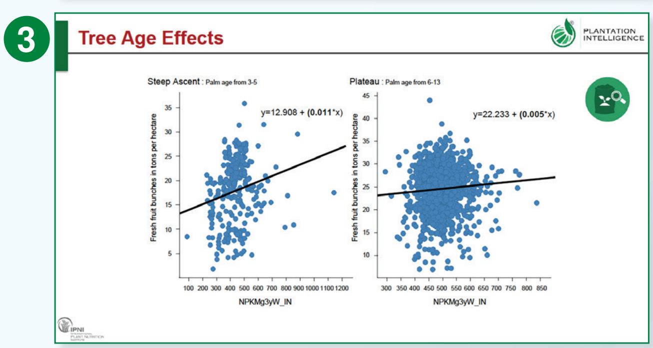
TABLE 1: Group average dry cocoa bean yields for a group of 16 farmers who worked with the IPNI Cocoa Care project in 2014 and 2015 in the Soppeng area of Sulawesi, Indonesia.

	GAP	GAPN	Difference, kg/ha	Difference, %
2014	696 kg/ha	928 kg/ha	232	25
2015	533 kg/ha	817 kg/ha	284	35
Difference, kg/ha	-163	-111		
Difference, %	23	12		

Yields are given for good agricultural practices without additional fertilizer nutrients (GAP), and GAP with 4R-consistent nutrient management (GAPN).

IPNI Southeast Asia Program - Information Services

Access useful information from our Southeast Asia Program (SEAP) online at **http://seap.ipni.net/library/resources**



1. Library – contains lists of new entries to the IPNI SEAP library; updated every quarter.

2. Videos – review all our webinars online, or catchup on others that you may have missed. Crops range from oil palm, cassava, cocoa, to maize.

3. Presentations – showcases key talks on topics presented at various conferences and seminars by the IPNI SEAP team.

PLANT NUTRITION TODAY

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HEALTHY SOIL NEEDS BURIED PHOSPHATE

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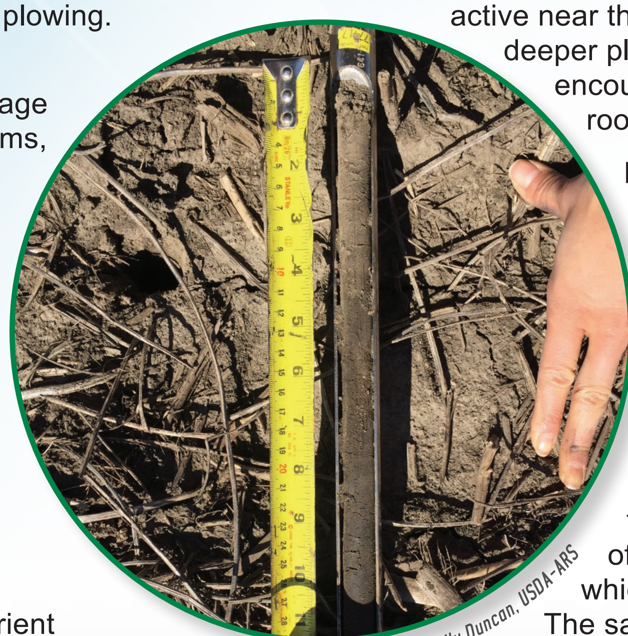
Today's conservation tillage systems do a lot less mixing. When soils were moldboard plowed, the top six to ten inches of soil were inverted, aggressively blending in concentrated layers, bands or pockets of nutrients. In a regularly plowed field, a sample taken to two inches depth gave more or less the same result as one taken to the full depth of plowing.

With advent of conservation tillage and no-till systems, however, that changed. Applied nutrients are no longer mixed as thoroughly into the soil. Crop residues stay on the soil surface, and release their nutrients there. For a nutrient like phosphorus (P) that moves slowly through soil, this means that the top two inches of soil now holds more available P than the layers below. In recent studies of farm fields across Ohio and in the western Lake Erie watershed—conducted by Heidelberg University, USDA-ARS and Ohio State University—soil test P in the top two inches is now on average 43 to 48 percent higher than in the top 8 inches, and in some farm fields it is as much as three times as high.



Emily Duncan, USDA-ARS

The top two inches of a soil core can be tested separately to assess stratification.

Why might stratification matter?

Two possible reasons: for the crop and for the environment.

For the crop, concentrating the nutrients might mean lower availability, particularly if the top layer dries out and the roots can't be active there. However, that's rarely been found to be an issue for no-till production. It's quite possible that the thicker crop residue layer improves water retention enough to allow roots to be more active near the surface. But deeper placement can encourage deeper roots.

For the environment, however, when water leaves the field by surface runoff, its concentration of dissolved P is influenced by the availability of P in the soil to which it is exposed. The same is true for water that reaches the tile drains by preferential flow through macropores (cracks in clay soils, or earthworm channels) or surface inlets. Most crop fields discharge water, either directly off the soil surface, or through tile drains. Ultimately this water ends up in ponds, reservoirs and lakes. Many of these receiving waters are sensitive to increases in P concentrations and loadings, and algal blooms may result.

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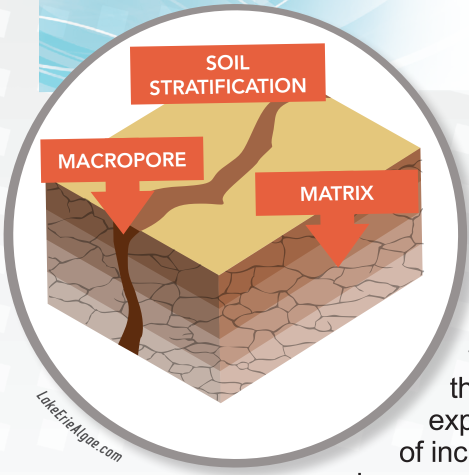
"Soil test stratification matters, and managing it is a key part of 'right place' in 4R Nutrient Stewardship."



Soil test P at the surface affects both runoff and macropore losses.

So how does stratification affect P loss? For any given soil, the concentration of P in the runoff water increases with soil test P in the soil to which it is exposed. The amount of increase in loss per unit increase in soil test, however, varies considerably from soil to soil. A review of 17 runoff studies, published in 2005, found that the increase in concentration of dissolved P in runoff for each part per million increase in either the Bray P1 or Mehlich-3 P soil test ranged from 0.4 to 13 parts per billion (ppb). The most typical value, however, was around 2 ppb. It may not seem like a large increase in P loss. However, because dissolved P in drainage water from soils testing in the agronomic optimum range is often already close to a level that can support an algal bloom, small increases can matter. The effect is chronic, not acute. The increase in dissolved P in the water leaving the field is not drastic. But the effect continues with every rainfall event. So for water quality, soil test stratification matters, and managing it is a key part of "right place" in 4R Nutrient Stewardship.

What can be done?

1. If you currently broadcast P fertilizer or manure in no-till or conservation tillage fields, consider ways to inject or apply in subsurface bands instead.
2. Sample fields to two depths separately, 0 to 2 inches and to your typical sampling depth. Consider analyzing the shallow sample for an environmental test like P sorption, or water extractable P.
3. If the degree of stratification is substantial, and the soil test P level in the shallow sample markedly exceeds the optimum range, consider a tillage operation to mix all or part of the topsoil. Such a tillage operation should be done at a time of year when potential erosion or runoff events are least likely (often, late summer or early fall). Protect against soil erosion by leaving adequate crop residue cover, or plant cover crops.

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IMPROVING PRODUCTIVITY OF PERENNIAL MIXED FORAGE STANDS

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Evidence-based stewardship applies proven science-based principles to management decisions with full consideration of the characteristics of the specific site and the needs of the specific production system. Key soil properties are an essential subset of site characteristics. The many tame pastures of central British Columbia, Canada offer an excellent example. These pastures are the result of former forested land being logged for lumber, then cleared and converted to grazing land. After tree stumps and roots are piled and burned, the land is smoothed out and large rocks removed before broadcast seeding, and harrowing to mixed forage stands. The mixed forage stands will often consist of a mixture of cool grass species such as brome and timothy grasses, and legumes species such as clovers and spreading alfalfa. Many ranchers and mixed farm operators graze beef cattle on these pastures and don't see the need of applying supplemental nutrients as fertilizers, or use soil amendments. However, some significant improvements in productivity of these pastures can be realized with modest applications of fertilizers, as well as lime ($CaCO_3$) and gypsum ($CaSO_4$). Improvement is noticed by increased carrying capacity of pastures, and greater weight gain by livestock.

These formerly mixed wood forest soils are commonly called call Gray Wooded [Gray Luvisolic, (Canada), Boralf (U.S. Soil Taxonomy), and Albic Luvisol (FAO Soil Classification)]. The soils tend to be neutral to moderately acidic in pH (pH 5.5 to 6.5), they are organic matter (<2%), and comparatively low in plant available N, P, and S.

Miles Dyck/Univ. Alberta

Gray Wooded soil profile (left) with decomposed leaf litter on surface over a leached mineral surface layer. A grassland soil profile contrasts on the right.

By applying fertilizer nutrients and soil amendments forage quantity and quality can be enhanced. Each forage species has its own need for soil conditions. In the mixed forage stands mentioned above alfalfa is less tolerant of soil acidity, and will do less well, compared to the grass species or clovers when soil pH is between 5.0 to 6.0. This is primarily due to the adverse effect acidity has on the *Rhizobia* bacteria that inhabit root nodules of the alfalfa. Acidic conditions result in poor nodulation of the alfalfa and N fixation is low, making alfalfa less competitive with the other forage species in the seeded mixtures. A benefit of applying granulated lime to raise pH slightly, and granulated gypsum to supply sulfur is the improved growth of alfalfa in the pasture stand that increases forage yield and especially an improved protein source for the grazing cattle.

Thirty-five years of research from the University of Alberta Breton

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"Thirty-five years of (Breton Plot) research clearly shows the benefit of balanced nutrition along with lime applications every few years to maintain soil pH above 6.0."

Tom Jensen/IPNI

Lime, gypsum, and P fertilizer (right) resulting in increased clover and alfalfa in stand, compared to nothing applied on the left resulting in mostly grass and bushy species present.

Plots, near Breton, AB, clearly shows the benefit of balanced nutrition (N, P, K, and S), along with lime applications every few years to maintain soil pH above 6.0. When the soil is not limed the alfalfa in the stand is significantly less and volunteer white clover and grass species dominate. An alfalfa grass mixture is preferred for hay production compared to a combination of white clover and grasses.

In most situations, an application of fertilizer nutrients, along with lime applications can improve grazing forage production or hay production, on the formerly forested soils. It also allows forage species to better outcompete weeds. A modest investment in plant nutrients, and applying lime to amending the soil pH, can be a positive return on investment.

Table 1. Effect of liming along with N, P, K, and S fertilizer, on species composition of first cut hay in a mixed forage stand. U of A Breton plots. Adapted from Puurveen and Olson, 2006.

Forage yield, t/A	Soil pH	Nutrients applied	Lime applied every 5 years as needed	Percent of forage species in hay cut			
				Bromegrass	Alfalfa	White clover	Weeds
1.3	5.3	N, P, K, and S	No	34	1	64	1
1.5	5.9	N, P, K, and S	Yes	17	43	34	6
0.8	5.9	None	No	44	30	19	7

Dick Puurveen/Univ. Alberta

No lime (far middle left) versus lime applied on right, U of A Breton Plots.

References

Puurveen, D. and C. Olson. 2006. Effect of Volunteer Clover on Forage Yield at Breton Plots. Poster in Proceedings of 2006 Alberta Soil Science Workshop.

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