CROPHEALTH
LABS

Nic Ellis, MS, PhD
Norden Agricultural LLC
Program Consultant
Crop Health Labs

March 1, 2015

For: Maryland Upland Rice Producers

Heinz and Nazirahk,

Thanks for your patience. I needed a few months to learn more about your crop. While I know I will not fully understand its production until I actually see it in the field, at least I have some insight. The following breakdown is very preliminary, but I hope it will give us all a starting point for discussing upland rice nutrition and how we might use sap-testing to manage it. Much of this content is a summary of the book *Mineral Nutrition of Rice* by Nand Kumar Fageria. It is an excellent resource, and my summaries only begin to scratch its surface. I have also included some content from an email I received from Carl Dischler, at Louisiana State University.

For this initial document, I focused on the major nutrients that will presumably have the greatest impacts on rice vigor and yield. As we go, we can investigate other nutrients I have not covered here. We will start with some observations from Louisiana and my summary of some reference relevant to general rice nutrition:

Carl Dischler sent me this information about his experience with rice fertilization:

4 major nutrients and 1 micronutrient are critical for high-yielding rice in Louisiana. Nitrogen (N) is the single most important nutrient necessary for maximizing yields. Most soils also need phosphorus (P) and potassium (K). Sulfur (S) may also be needed. The micro-nutrient that is deficient on some Louisiana soils is zinc (Zn).

NITROGEN. Nitrogen should be applied by the end of the spikelet stage, before flowering begins (Fageria 2014).

Significant increases were seen at application rates of 400 mg N / kg, (or 800 lb/A)[Fageria *et al.* 2010] One app of 200 mg/kg at planting and 200 mg/kg 43 days later at tillering. At planting the rice also received 200 mg/kg 0-46-0 and 200 mg/kg 0-0-60.

In the Koshihikari total N levels varied from about 1500 to 1900 ppm. Calcium levels were extremely low (perhaps as a result of competition with K). Nitrate levels were low; ammonium fluctuated, which probably contributed to the low Ca levels to some extent. K levels were extremely high, compared to other cations. Rice allocates up to 30% of its nitrogen intake to Rubisco, the most important enzyme fixing CO_2 in plants, whereas wheat allocates up to 25% (Makino 2011). Wheat and rice fix the highest amounts of carbon, relative to other crops and therefore require higher amounts of Rubisco. However, while Japanese rice (presumably lowland varieties) can efficiently make grain with their nitrogen, they exhibit source-limitation inhibiting biomass accumulation as nitrogen levels increase (Makino 2011). Source limitation implies that the most mature leaves, contributing the most to the grain-fill, reach a maximum nitrogen capacity at which they can photosynthesize efficiently. Despite this limitation, up to 60% of total rice biomass is found in high-yielding Japanese rice grains. We don't yet know how nitrogen use will manifest itself in rice sap analysis for a full season. But we can observe the sap tests with this in mind looking for indications that it may be occurring. Such indications may be changes in the proportion of nitrogen levels in young versus old sap; or increases in old sap nitrogen. I might expect changes in old sap because mature leaves are significant sources for highly mobile nutrients and solutes in plants.

PHOSPHORUS. I compared Heinz's soil phosphorus to some of the other phosphorus tests I've seen in the last couple of years. Our soils in Pennsylvania tend to be low in phosphorus, but most soils everywhere are. Heinz's are no exception. But the pH is 6.4, which means it will not be as limited as it would be at an extremely acid or basic pH. Results from a study of phosphorus input to upland rice in tropical oxisol soils (which are only found in Hawaii in the U.S.) showed that at rates of 0 to 200 ppm 21-25 panicles formed per four plants. At 400 ppm, panicle number per four plants jumped to 34 (Fageria 2014). This increase is probably related to an increase in the tillers; and because leaf areas increase under adequate phosphorus, photosynthetic capacity could also be expected to increase (Fageria 2014). A key timing for phosphorus appears to be after flowering, as the plant mobilizes phosphorus to the developing grain (Fageria 2014).

In general, rock phosphates are poor sources of phosphorus in limed soils, or soils with pH's above 6.0. They require acidic conditions to make the phosphorus in them available to plants. So, for phosphorus amendment in our eastern soils, they are most likely not the best option. From what I've read, banding phosphorus into the furrow at planting is the best way to provide rice with its phosphorus. Broadcasting is not, however. If it's possible to band phosphorus when planting transplants from trays, I would recommend that at a rate of 30 lbs/A. As the grains develop, the plants will remobilize phosphorus from the straw to the grains. I suspect that the old sap will start to show lower phosphorus than the young sap as the grains fill. "Brackets" of sap analysis taken pre-panicle initiation, shortly after flowering, and then during milk stage will show any patterns of phosphorus removal that could result in deficiencies. We will have to establish a phosphorus level well before panicle formation that we might see "shifting" in subsequent tests.

POTASSIUM. Apparently rice is a heavy potassium consumer. Eighty-five percent of potassium taken up by rice ends up in the vegetation; the remaining 15% is found in grain (Fageria 2014). In one study, 84 ppm applied resulted in 53 ppm (approx. 63%) extractable K in 0 – 20 cm of soil. Side-dressing rice late in the season has been shown to reduce leaf senescence. Optimal potassium optimizes panicle formation, but the potassium is best applied in the vegetative stages (Fageria 2014) and in split applications (261). An approximate 3-2-2 ratio of N-P-K has also been shown to promote rice root mass significantly. In the example cited on pg. 247 of *Mineral Nutrition of Rice* the rates were 600 lbs N, and 400 lbs each of P and K. In the U.S., potassium deficiency is most commonly seen during the reproductive phases, implying that sap analysis prior to these stages will definitely be beneficial to identifying its potential onset. However, potassium deficiency can be masked by sodium availability because sodium can take the place of potassium physiologically, when potassium is low (Fageria 2014). There is evidence that rice shoots accumulate more potassium than grains do (Fageria 2014) so rice must be provided with sufficient amounts of potassium.

When a Mehlich 1 extraction indicates < 50 ppm K, about 90-100 lbs K2O/A is recommended. If K > 80 ppm, 60-70 lbs K2O/A is recommended (Fageria 2014). The Mehlich 1 extraction is commonly used on acidic soils, typically having low CEC's. Potassium estimates from Mehlich 1 extractions are highly comparable to those from Mehlich 3 extractions (which are used in higher-CEC and pH soils). Ward Labs uses the ammonium acetate extraction, which is comparable to the Mehlich 3. Therefore, Fageria's estimate of potassium needs given above is relevant to Heinz's soil test. Because of potassium's uptake by diffusion, banding is the best way to apply it, if possible.

In Heinz's initial sap tests, potassium levels appear to be sufficient in the sap. It's my experience (so far) that potassium is a dominant ion in the plant sap system. If it is more abundant in the old sap, or the two values are approximately the same, the sap is "loaded" with the amount of potassium it needs. That is, the sap is moving to from sources, or the roots, to sinks where it is needed, and being replaced without inducing deficiency. In the second test, potassium was lower in both old and young sap, suggesting to me that there may have been aggressive growth of the plants occurring when the samples were collected.

CALCIUM and MAGNESIUM. Are not as critical early in the rice growing cycle as nitrogen. Calcium will probably behave in rice the way it behaves in other crops. That is, it will accumulate in older tissues and sap. Magnesium will relocate from old to young sap however. According to Fageria (2014), rice rarely shows magnesium deficiency (Fageria 2014).

As panicles begin to form, calcium and magnesium demands will increase—so sap-testing at this stage will show the ratios of calcium, magnesium and potassium to each other. Amendments or adjustments can be made to optimize the availability of calcium and magnesium going forward into booting and flowering. Gypsum has been shown to be beneficial for upland rice production, as well as liming when conditions require it. Mid-Atlantic soils tend to be predominantly in the pH range 6.0 to 6.8, so I don't foresee a need to lime them for rice production. In Heinz's soil, the calcium base saturation is 64%, higher than the 47% which has been observed to maximize rice yields in acidic oxisol soils (Fageria 2014). According to some findings, upland rice will consume about 20 and 25 lbs/A of magnesium and calcium, respectively to yield two tons/A of grain (Fageria 2014) and most Mid-Atlantic soils will probably have enough of these nutrients to fill that need.

The sap analysis is showing very low levels of calcium in the sap, as compared to other sap tests from other crops. Apparently rice is like other grain crops in not requiring as much calcium as crops producing flowers and fruit or pods (Fageria 2014). This is particularly true with upland rice. I'm speculating, but I suspect that like in peppers, the ratio of potassium to calcium will NORMALLY be higher in favor of potassium in rice. You will note that the calcium levels in the sap rose slightly in the second test, as the potassium levels decreased. This implies to me that you may be able to apply foliar calcium to take advantage of the lower potassium-competition as potassium is re-located and used. The magnesium, on the other hand, is more like what I am used to seeing in other crops. It is higher in the old sap than in the young sap. In these plants the sap was probably moving the sap from sources and the roots to the sinks in the younger parts of the plants.

SULFUR. Sulfur needs are greatest between establishment and tillering, so the best time to apply it is pre-plant, with any other dry fertilizer amendments. This is especially true for acidic soils where unavailable, reduced forms of sulfur are more prevalent than the plant-available sulfate ions. Although the impact of sulfur on upland rice is not well represented in the literature, it can increase grain yields at relatively low rates in acidic soils [4 lbs/A] (Fageria 2014), so may be required in higher rates in other less acidic soils. Sulfur is not mobile between old and young tissues, but its concentrations are related to nitrogen. On these tests, sulfur levels corresponded with the total nitrogen levels. That is, in the July test, both sulfur and total nitrogen were lower in the old sap. The opposite was observed in the August test. Because both nitrate and ammonium levels declined in the August test, I am thinking that perhaps amino acid synthesis had improved over that time period. Sulfur is one of several nutrients (the others being iron, manganese and magnesium) that are important in the two major cycles that generate amino acid precursors. What's also interesting to me is that all of those nutrients except magnesium, as well as total nitrogen were higher in August than they were in July. In August, ALL of them were higher in the old sap. I can infer from this that perhaps the old sap was rich with nutrients being moved into the source leaves for assimilation, and at the same time amino acids and polypeptides were in the old sap, being exported.

What is interesting though is that sulfur and magnesium are both implicated in photosynthesis. Each of those, and the sugars, were higher in the July test. I am not yet sure how to reconcile it directly to my thoughts on the assumed interaction between the micronutrients and sulfur, and the total nitrogen.

MICRONUTRIENTS. Many micronutrients have limited availability in soils rich with organic matter, because they are bound to its negatively-charged regions. Zinc is largely affected by soil pH, and the soil concentrations of manganese and iron. Excessive levels of phosphorus in particular can result in lower zinc concentrations in plants. I am starting to interpret sap tests with this in mind. Zinc deficiencies in rice are known to occur in seedlings, and tillering plants (Fageria 2014) and zinc is considered "sufficient" at levels of 20-150 ppm dry matter in shoots at tillering (Fageria 2014). Zinc uptake in rice is greatest within 104 days of sowing (Fageria 2014).

Copper uptake by rice increases by 25-30 times between tillering and flowering, and then declines as the copper relocates to the grains (Fageria 2014). One of the main reasons manganese in particular is more available to plants in an acidic soil is because it has several oxidation states that are affected by pH, but the only one available to plants is Mn^{2+}. If conditions are too acidic (reducing), though, it can be found in redox states that are unavailable. There is evidence that most severe manganese deficiencies occur in soils with pH's ranging from slightly below 7.0 to above that (Fageria 2014). Iron is best amended to any plant by foliar sprays, although dicots will release hydrogen ions into the soil, reducing iron into its available divalent form; and monocots secrete siderophores, which chelate iron in its trivalent form (Fageria 2014). Soil with vigorous microbial activity is probably critical for all micronutrient availability because the microbes can gradually create conditions "naturally" conducive to nutrient uptake. Presumably feedback from the plants, and other microbes, as they interact with the soil, perpetuates this "natural" system and optimizes nutrient availability.

Boron is limited by highly limed soils, and soils with pH's above 7.0, and in soils with high organic matter. Rice does not have a high boron requirement in its straw, but needs it for proper grain development (Fageria 2014). To prevent this, boron should be applied pre-plant to the soil, and/or applied with foliar sprays. An effective soil rate is 1 lb/A actual boron; or regular applications of 0.10 to 0.25% foliar boron solutions (Fageria 2014). I would conjecture that most liquid micronutrient packages at labeled rates will provide this amount of boron in foliar sprays.

SOIL & SAP MICRONUTRIENTS. Basically, with the exception of molybdenum, micronutrients become less available as pH increases in soils, and several chapters in Fageria (2014) bear this out for rice as well. Weekly foliar spraying of a low rate of a micronutrient package will most likely address the needs the plants have.

In short, I don't see any patterns emerging from the interactions of the micronutrients with other nutrients and with each other. Having said that, with a longer sampling period over a greater range of rice stages, we may be able to see manifestations of some of the micronutrient interactions I've been recording from the literature. This season I will be paying particular attention to those on ALL the sap analysis I see. And, there are definitely relationships between sugar levels, total nitrogen and micronutrients that long-term sap-testing can illuminate. Of course, there will also be contradictions to what we expect to happen. I am confident we can make very good and sound estimations of what to do pre-emptively as the sap tests come in.

SILICON. Silicon is known to be beneficial to plants, although not necessarily "essential." It strengthens plant resistance to disease, and has important effects on ionic availabilities in plants. Very importantly, it is known to help rice plants resist blast. One of its physiological roles in plants is reducing the amounts of amino acids, which limits nutrients for fungal organisms (Fageria 2014). Calcium silicate has been shown by numerous researchers to suppress the severity of rice diseases including brown spot and blast (Datnoff and Rodrigues 2005). From what I read, you might consider a rate of 1-2 tons/A blended in humus, if it is cost effective. Silicon has also has a role in enhancing general rice nutrition and ionic intake.

Foliar spraying of silicic acid at 15-30 oz/gal has been shown to improve photosynthesis; number of productive tillers; and to decrease spikelet sterility and pest pressure (Fageria 2014). In terms of ionic uptake, silicon reduces the uptake of both sodium (Gong *et al.* 2006) and chlorine (Shi *et al.* 2013), which has implications for rice management in soils or with irrigation water having those ions. In the context of sap analysis, silicon's effects on sodium and chlorine may be directly measurable and observable. Having the capability to observe the effects of efforts to mitigate excessive sodium and chlorine with sap analysis has importance in other cropping systems as well.

The observation that the silicon levels were similar in young and old sap at both sample dates, but overall lower at the later date, suggests to me that the plant was consuming the silicon from the sap. Silicon concentrations in rice plant sap are often many times higher than in the soil solution, indicating that uptake is not passive, but against a gradient and requiring substantial energy. I am speculating here, but this MAY be part of the reason both the sugar and the silicon levels were lower in the second test. Micronutrients vary in the manner in which plants take them up from soil solution; but if silicon IS more dependent on energy for uptake, the lower silicon and sugar levels in the older plants makes intuitive sense.

TIMING OF SAMPLE COLLECTION:

Carl Dischler's take on tissue sampling:

Tissue samples during season would/could be valuable and would tell us if the plants are deficient, but the timing of the "in-season" tissue test normally would not give us adequate time to make the nutrient correction before the rice plant would experience yield losses. Rather than tissue testing prior to green ring or panicle initiation (PI); visual observation is our normal indication. You want to a have a good dark green color which would show that enough nitrogen is available. If visually you have yellowing, it's possible that you need a top-dressing; adding more units of nitrogen (N).

According to Carl, there's a key timing prior to panicle formation. So your initial thoughts on sampling this stage are correct. The plan of sampling at pre-tillering, or tillering, and again prior to panicle initiation may help us establish nitrogen levels we can monitor to detect potential deficiencies.

Maximum tillering occurs 60 to 100 days after seeding, and starts about 20-30 days after seeding (Arraudeau and Vergara 1988). These time-frames may be shorter with transplants. You might consider a pre-tillering sample two weeks after transplanting to assess nutritional needs. At this stage, I suspect nitrogen, potassium and micronutrients will probably be limiting to tiller formation. We will examine the proportions of anions and cations to each other, and the relative amounts of nitrogen in "young" vs. "old" tiller samples. Micronutrient interactions and APPARENT, ESTIMATED effects on whole plant physiology can also probably be observed at this point in the phenology.

Panicle-formation can begin at about 70 days after sowing (Fageria 2014), so a sap sample collected around the time of estimated maximum tillering may be useful to gauge performance. I am thinking that another sample as the grain fills can give us an idea of how the plants are mobilizing nutrients for the various aspects of grain-fill, and the progress of the sugar development and movement.

Assuming there are 70-80 days to flowering in upland rice, as determined by Juliet Candog-Bangi in the Philippines, there will be five 2-week sampling periods. By my count, I have identified three discrete sampling times, corresponding with key stages in the crop phenology. I have found that the best resolution of the plant performance is gained with as many sap-tests as possible—so there is no need to limit your sampling to three times. I would actually encourage you to sample as much as possible, but not miss these estimated "key" timings.

REFERENCES

Arraudeau M A and B S Vergara. 1988. A Farmer's Primer on Growing Upland Rice. International Rice Research Institute, Los Baños, Philippines.

Candog-Bangi, J. 2011. Agronomic Characteristics of Selected Indigenous Upland Rice in Arakan, Cotabato. Paper presented during the National Research and Development Conference, Grand Regal Hotel, Davao City, Philippines, April 28-29, 2011.

Datnoff L E and F Á Rodrigues. 2005. The role of silicon in suppressing rice diseases. APSNet Feature February 2005. http://www.apsnet.org/publications/apsnetfeatures/Documents/2005/SiliconRiceDiseases.pdf Accessed 01 March 2015.

Dischler C. Personal email correspondence received 6 Feb 2015.

Fageria N K. 2014. Mineral Nutrtion of Rice. CRC Press. Boca Raton FL. Kindle Edition.

Fageria N K, O P de Morais and A B dos Santos. 2010. Nitrogen use efficiency in upland rice genotypes. Journal of Plant Nutrition 33: 1696-1711.

Gong H J, D P Randall, and T J Flowers. 2006. Silicon deposit in the root reduces sodium uptake in rice (Oryza sativa L.) seedlings by reducing bypass flow. Plant, Cell and Environment 29: 1970-1979.

Shi Y, Y Wang, T J Flowers and H Gong. 2013. Silicon decreases chloride transport in rice (O*ryza sativa* L.) in saline conditions. Journal of Plant Physiology 170(9): 847-853.

Makino A. 2011. Photosynthesis, grain yield and nitrogen utilization in rice and wheat. Plant Physiology 155: 125-129.

Hopefully you will find this breakdown useful, and a point for departure into further discussion. I will continue to seek new and relevant information that I can pass on to you.

Thanks, and please don't hesitate to contact me with comments and questions. I appreciate the PDF's you sent me Heinz, and will also study them more closely as well. One of them in particular is an extensive description of irrigation, which I look forward to studying in more depth.

Nic

NORDEN
AGRICULTURAL llc