RICE SCIENCE TO ENSURE GLOBAL NUTRITION AND FOOD SECURITY

AUDIO TRANSCRIPT

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PRESENTERS

Dr. Robert Zeigler, International Rice Research Institute

PRESENTATION

Sahara Chapotin: Well, it's really great to see everyone here and a real honor to be able to introduce Dr. Zeigler, who is the director of the International Rice Research Institute. For those of you who don't know, that's one of the CGIAR centers, the International Agricultural Research Centers located around the world who have the mission of supporting agriculture and doing agricultural research in support of developing countries. IRRI, the Rice Research Center, is based in the Philippines, and it works in over 25 countries around the world. It's a very longstanding partner to USAID. We support research activities and we work with IRRI collaboratively in supporting research activities around the world, including also some of the technology-scaling activities that have been one of Administrator Shah's priorities in the last couple years. Notably, there was work done in Bangladesh led by IRRI around scaling rice seed that was quite successful. Dr. Zeigler has had a long and illustrious career prior to working at IRRI, where he has been the director for almost ten years now. He has worked in the Republic of Congo and Colombia and Burundi and Mexico, in the United States. He has a number of awards, but one jumped out at me, and that was the Global Innovator Award from Time in 2007. So, please join me in welcoming Dr. Zeigler. Thank you.

[Applause]

Dr. Robert Zeigler: Thank you very much, Saharah. Is it rolling? Can you hear me? Okay. Yeah, it's great to be here and I really appreciate you all coming out on a Wednesday morning, six days before the end of a fiscal year. I think some of you are probably running around quite like, I don't want to say chickens with their head cuts off, but like crazy. But anyway, it's a pleasure to talk with you about Rice and about the research that we're doing at IRRI and with partnerships around the world, and give you an idea of really some of the great opportunities that science is offering to address some of the greatest problems that are facing us around the world.

As Sarah mentioned, I hail from IRRI. We've been around since 1960. We were founded by the Ford and Rockefeller Foundations in response to tremendous concerns about global food security that were bubbling up in the 1950s. A very straightforward mission: addressing poverty and hunger, nutrition and well-being of rice farmers and rice consumers, taking into account that increasing productivity of the rice paddy today requires that any measures that are taken assures that the paddies of the future will also be productive, so environmental sustainability is the key element. An institute like ours can only do as much through partnership. It's very, very important that we engage, and, as Sarah mentioned, we've got offices in 17 or 18 countries around the world and activities in many more, so that's a very

key part of our approach. We are a member of the CGIAR centers. Three centers have programs on rice, and we've joined together to form the Global Rice Science Partnership, and the work that I'm talking about today is encompassed within that global partnership strategy.

Well, what is rice, besides being tasty? I think it is perhaps the oldest domesticated crop. It is unbelievably diverse genetically, and I'll talk about that in a bit, but it is more than just a food. Although it is the staple for most of the world's poor, it is embedded in societies and cultures across Asia in ways that most of us can barely begin to appreciate, and that colors many of the approaches that farmers take and policymakers take, and I'll try to come back to that issue. A very important part about rice is that it flourishes in the monsoonal environment. Half the year, over much of the world, the environment is not very suitable for most of our major crops. Torrential rainfalls, stagnant water on the soils would wipe out a maize or a wheat or a cassava. Rice, on the other hand, flourishes. It's very happy being up to its knees in water, and thank you very much. So, rice will be around for the foreseeable future. It's also grown by very small farmers. The vast majority, overwhelming majority of farmers are small, a couple of hectares at most is considered a decent size farm, a lot of animal power, reliance on human labor, but there's going to be some major pressures on how rice is grown when you consider what's happening with the economies in Asia, in particular. Will people be satisfied working as day laborers in a rice paddy over the next generation? The answer is no, they won't, and so there will be changes that will have to take place.

I mentioned that rice permeates the cultures of Asian societies, and that was something that I've been talking about because I'd sensed over the years of really how deeply decisions around rice policy, et cetera, take place, so I was really gratified to see this paper come out Science last May where it talked about the rice culture, that those communities or those societies wherein rice is the major source of food are organized differently than those cultures that depend upon annual crops like wheat or maize. The amount of social investment that's required to grow rice – irrigation schemes, drainage schemes, et cetera, transplanting a crop by hand requires pooling of labor, et cetera − permeate through a society and help build its values. This was quantified in quite a striking illustration to me about how when we think about how technologies will change, how policies might adapt, that we have to take into account this very, very deep role of the rice culture, and it's passed on from generation to generation. Long after a family no longer cultivates rice, it still carries, like all cultures carries with it that rice culture, and I was really gratified because it wasn't me just waving my arms saying that rice is different, but at least I've got something published in Science.

IRRI is famous for leading the Green Revolution in rice in Asia, and it did transform Asian agriculture. In the '60s, yields were very low, a ton and a half per hectare; today, almost three times increase in yield has led, really, to major transformations in Asian economies, and it can make a very solid argument, and

people do, that the economic miracle that took place in Asia was built on a foundation of abundant and affordable and reliable rice supplies, and I think that's something to keep in mind. The Green Revolution was built on changing the plant's architecture. It was a science-driven approach; that is, people got together, asked the question, "What do we need to do to change the rice plant so that it will go from a ton and a half to four or five tons on farm fields?" At the time, if you added fertilizer to the rice, it just grew tall, grew more leaves and fell over, and your yields were actually lower.

So, our scientists redesigned the rice plant, semi-dwarf – you added fertilizer, it added more grain rather than leaves and stems. That, I believe, was a great example of demonstrating that science could do what people did not believe was possible. Back in the '60s, Paul Ehrlich and colleagues were arguing that there was no hope for Asia, that the future was in Africa, that Asia was a basket case, forget it, it would never be able to feed itself, but we proved them wrong. It's been a steady progress of technologies, I won't go into it, but it wasn't a silver bullet. Many, many activities and contributions in plant protection, better crop management, fertilizer, pest management, et cetera, have gone to continually raise production levels in the world in rice.

Now, if we look at the production, or consumption – I'm sorry – of rice around the world, you see here the darker areas are the increasing per capita consumption, the darkest over 75 kilograms per person per year; that's a very large amount of rice. People eating rice two, three, four, five times a day, and not surprising, concentrated in South and Southeast Asia, but note the increasing importance of rice in sub-Saharan Africa and also in Latin America. When you superimpose poverty statistics on that, each dot represents a quarter of a million people living on less than $1.25 a day, it's clear, in my mind anyway, that any effort to address large-scale, rural poverty, particularly, but also urban poverty, we'll have to take rice into part of the equation.

Now, when we talk about poverty, it's not just $1.25 a day. It struck me when I was traveling in northwestern Bangladesh, I came across a field where there were all these piles of dirt out in the field, and I asked my colleague what was there. He said, "C'mon out. It'll be kind of interesting." So, we went out into the field and looked at these holes that were dug in the rice fields after the harvest, and I don't know if you can see it back there, there's a little tube here in the ground, but what that was, he explained, was that after the harvest, the very poor in the village go out and look for the rats' nests by finding a hole in the top of the ground, and they dig out the rats' nests and they steal the grain from the rats. I thought that, to me, really communicated what real poverty was if you're fighting with the rats for your food.

Of course, the consequences of poverty – malnutrition and all of the cascading impact of that – that's really what we're talking about, so when we're talking about

dealing with poverty, we're talking about lifestyles and future generations, and I think it's always important to keep that in mind, and, also, where poverty is. In China, we all think of Shanghai and Beijing and the Olympics, and all of that. But, if you remember that map of poverty, China was pretty densely covered with poverty dots, and this was a picture on the cover of what was then the International Herald Tribune in May of 2013, and I was really struck. This is from Yunnan, China, and this is a typical rural family, obviously very poor, but I just wanted you to note that the one appliance they have is a rice cooker, so there's that evidence that if you're going to have some spare money, make sure we can cook our rice well.

Global rice per capita consumption has been stable for the past 25 years. The conventional wisdom was that as incomes rise, people will eat less rice and rice will be less important, and you don't have to worry about meeting global rice supplies, but, in fact, supplies per capita consumption has remained the same. So, if nothing else, population growth will continue to drive rice consumption worldwide. If you look at sub-Saharan Africa, rice consumption is the fastest-growing food in the region. It is expected that in about 10 to 20 years, rice will replace maize as the staple in sub-Saharan Africa, and if in the next ten years we are successful in our plans or our efforts to double rice production in sub-Saharan Africa, in ten years they'll still be importing the same amount of rice they are today, so the consumption demand is enormous. That's summarized here. You can see this is what we're projecting out. We're revising this. This is a prediction we made in 2010. We're advising that the numbers are going up, the demand is increasing more than anticipated back then. Red is Asia, blue is Africa, and you can see the demand from sub-Saharan Africa increasing quite substantially. Climate change: no joke. It will hit rice particularly hard. We've got temperatures, rainfall patterns changing − you all are aware of that − sea-level rise and weather hazards, all of these conspire particularly to hit rice, and I'll talk about why and what we're doing about that in a few minutes.

So, where is the world's rice going to come from? Okay, we've got a very heavy demand, everything tells us we need more. The vast majority of the world's lands that are suitable for rice production, certainly in Asia, are already being cultivated to rice, so we're going to have to increase the productivity on our existing lands. But, if you look at what's happening in Asia in terms of urban growth, urban sprawl, land use patterns, et cetera, land is moving out of rice. Labor is moving out of rice. If you have a chance to be up to your knees transplanting rice in the mud or working in a semiconductor manufacturing factory, I can tell you what job you're going to pick. Okay, so there's labor constraints and water. Competition for water is extremely important. If a government is faced with the choice of providing water for, for example, Metro Manila at 20 million people or more, or a rice irrigation scheme in Central Luzon, I can tell you what they're going to pick. All that water will always go to the urban before it goes to rural uses, and we see that pressure across Asia, so there will have to be major changes in production

practices just to stay where we are, and where we are, if you look at those poverty statistics and certainly the associated nutrition, is not good enough. I just want to highlight that if Asia is food insecure, the world is food insecure.

Now, Africa will come onboard probably 20 years from now to produce more and more rice, but we've got a lot of ground to catch up until then, so I think, and this probably comes as no surprise, we need another Green Revolution. I'll argue that that second Green Revolution has already begun, but it has to be even more science-based than the first one. By science-based, I mean we have to systematically tap into the simultaneous revolutions that have been taking place around us in plant biology, genetics, and genomics. We need to be able to link what's happening in the soil – the soil biology, soil chemistry – with overall system performance, and we have the tools now to begin to do that. Believe it or not, we can take a cup of mud from a rice paddy and essentially pour it into a DNA sequencer and get an idea of what the component of the micro-flora is in that rice paddy, which is a major determinant in how nutrient availability transpires over time, so a lot of opportunities there.

The computation and communications revolution is essential to being able to make sense out of all of our genomics data, our systems analyses, et cetera, so we have an intertwining set of revolutions that are taking place that will enable us to address questions to a degree of sophistication that were really undreamt of just a decade or so ago. The key, though, in my opinion, and I came to this conclusion as a scientist, it was a very difficult thing to swallow, if we're going to have anything make a difference, our policymakers are going to have to understand the potential and the need that our technologies offer and address, and we're going to have to be able to communicate effectively to policymakers. Let me talk a little bit about the actual science. We'll talk about first the genetic resources.

I mentioned that rice is unbelievably genetically diverse. Multiple domestication events is actually probably still going on in farmers' fields today, unlike our other staples. We hold in trust at IRRI a gene bank that holds over 117,000 different rice varieties. Farmers have selected over the millennia an enormous array, but very little of that has been used in our breeding programs. But we did, in cooperation with the Chinese Academy of Agricultural Sciences and Beijing Genomics Institute last May released the full DNA sequence of 3,000 rice lines from that gene bank. When I joined IRRI as DG in 2005, the cover page of Science Magazine was the sequencing of one genome of rice. The cover page, a big deal; beautiful photograph, if you remember it. Now we did 3,000 and we're in the process of doing − the next target is 10,000 so that we fully sample the genetic diversity of the rice species. We're using those sequences in a systematic way to identify function and how those genetic traits can be manipulated to improve the rice crop. Major effort involved in understanding what that sequence means, a global effort to characterize the sequence lines for every trait you can imagine – high-throughput phenotyping we call it − but that's the key to it.

Sequence by itself is very interesting for an evolutionary biologist in Harvard, but without plant performance data in the field, it's almost useless to a plant breeder, so that's the steps we're taking forward on that. We get just gorgeous descriptions of what the rice species look like, breaking down into various subgroups, telling us where it was evolved and selected, guiding us, if we're looking for particular traits, where we can go. The _____ varieties here, for example, are pocketed. They're domesticated. The sub-species in Eastern India and some areas where environments are particularly tough, and we find in there sources of tolerance to drought and flooding much more frequently than you would see in the japonicas, where in North Asia you don't have those kinds of issues, so helping us understand and target our work more effectively. Some of the traits we're going to be looking for, we are looking for, have found that will be particularly important in our changing climates are drought, flood tolerance, heat tolerance and salt tolerance, keeping in mind that rice grows in delta areas, and deltas are, by definition, at sea level, you are going to have with any sea level rise stronger storm surges and increasing problem with salt in rice production.

Let's look at the rice deltas for a minute. We've got about 50 percent of the growth of rice production in Asia has come from the delta countries, particularly vulnerable, so we have to pay particular attention to these. Where you have most of the lowland rice in the world, you have a lot of tendency to flooding. Modern irrigation schemes try to mitigate the probability of flooding, but, over much of the world's rain-fed areas we call them, particularly in South Asia and in the inland valleys of Africa, flooding is very common. We lose tens of millions of hectares of rice every year to floods, and, although, as I said, rice likes to grow up to its knees in water, if it goes completely under water, it will drown like any other plant, so dealing with floods almost paradoxically is one of the main issues we have to look at in rice. Even a short-term flood can be a problem.

Our scientists did identify tolerance in flooding from our gene bank a number of years ago, and it took quite a long time to transfer the flood tolerance to a variety that farmers would like. We could do the crosses and we could do the improvement and we could get flood tolerance into a rice variety, but there were so many other terrible traits associated with it: low yield, very poor grain quality. One person told me after tasting the early flood-tolerant varieties, "This rice is so bad the dog wouldn't eat it." Anyway, so that's no good. Basically, it took the development of the tools of molecular biology, marker-assisted breeding to allow us to transfer the gene for flood tolerance into rice varieties that farmers would grow, and here's a great slide.

This is a set of varieties in yellow, or actually in white, that have had the flood tolerance gene transferred to them, and those are shown in yellow, and this was after this pond – this is at IRRI – being completely under water for 17 days. If you could imagine a flood where the standing water is more than two weeks above a crop field, and then, when those floodwaters recede you actually get a crop that

recovers, you've got a better imagination than me, because that is an enormous insult to a crop to be completely submerged that long. But here, you can see those varieties with the flood-tolerant gene came back and grew very nicely, and this slide I really like because it reinforces my decision in undergraduate school not to focus too much on statistics, because you don't really need a robust statistical analysis to tell you which ones are doing better than the others. But we took this out to farmers' fields- This was back in 2005, 2006 at IRRI when things were looking pretty good, but the acid test, of course, is in farmers' fields.

So, we took this out to South Asia in the Firozabad district in UP in Eastern India, planted this out. This is 2008. This is Mr. Asha Ram Pal. This field, this had been exposed to two floods, and this is what his field looked like. This is the flood-tolerant rice, and this is how it looks after a flood. His neighbors were telling him that he should just plow it up, he's not going to get anything from that field, and we said, "No, c'mon, hang on. Just work with us here and give it a chance to come back." This is what that field looked like July 31st. So, out in a farmer's field exposed to real-world floods, we get this kind of recovery. Working with USAID, the Gates Foundation, the Government of India, the Government of Japan, by 2015 we expect to reach 5 million farmers. We've hit 4 million farmers of seed distribution at the end of last year, which is quite a phenomenal achievement. We're moving it, obviously, in Bangladesh, in Nepal, other areas where floods are good also are important, also moving to sub-Saharan Africa for the inland valleys. I'll go out on a limb and I'll say that the second Green Revolution actually began July 31 at 1:17 in the afternoon, 2008, when Mr. Powell did not plow in that field and showed the courage to try the new technology.

The efforts behind getting a flood-tolerant rice out to scale is something that can't be understated. We started with 10 kilos of seed in 2006 in India, a bag of seed you can hold in one hand. To get that multiplied up and distributed to millions of farmers requires quite a commitment and an investment, and it required the engagement of the National Research System but then the National Seed System, the Government of India – when we took the senior people out to show them what this technology meant in these environments, they were stunned and bought into immediately. So, we've actually, through the engagement of the Government of India, National Food Security Mission, as well as the private sector becoming excited about finally having something new in rice for these difficult environments, we've been able to move this seed quite substantially.

Something else that really struck me, and I've been working in these rain-fed, difficult environments since the late '80s, early '90s, they target those regions where stresses are the most severe: floods and droughts. We would always say we were working for the world, for the poorest of the poor, et cetera, but it really struck me when Alain de Janvry, who is a very well-known ag economist out of Berkeley, sent a team to do an analysis of the impact of this work in Eastern India, and the concluding paragraph makes this statement that literally gave me goose bumps

when I read it. It said, "This study indicates that scheduled casts are likely to be a major beneficiary from the spread of Swarna Sub-1 in India." The scheduled casts are the untouchables. These are the lowest of the low in the totem pole. They get the worst land in the village. But these are the people who will differentially benefit from the application of some of the most powerful tools of molecular biology. I mean, think about that. It is an amazing feat that we are actually now able to develop technologies that will hit these toughest areas and benefit the poorest of the poor.

Flood is not the only thing that bothers them. Drought is a serious issue that we expect, and we are developing drought-tolerant varieties that are performing quite well. A yield advantage of a ton to almost a ton and a half in some cases, in severe-to-moderate drought doesn't sound like a lot but it's a difference between having at least enough rice to eat or having to sell off your livestock or pull your kids out of school. So, we're seeing major progress in that stress, as well, and, oddly enough, we're able to combine flood tolerance and drought tolerance. Now, one would think, "How can that be?" The really difficult part that the people face in some of these rice-growing environments in Asia and sub-Saharan Africa is that they might get hit by a flood one part of the year; the same year, they can get hit by a drought, so they can have a flood and a drought. Having only a flood-tolerant line or only a drought-tolerant line in some years isn't enough, so we've been able to combine the flood- and drought-tolerance into single varieties, and that seems like almost a contradiction in terms, but physiologically the have completely different mechanisms and completely different genetic pathways, so actually it turns out that it's much easier than any of us thought it would be. That will be, I think, a major transformational force, as well.

What we're seeing is a set of traits that are coming along – drought tolerance, flood tolerance – and let's think about heat. Rice is already growing near its thermal maximum at about 33 degrees. If temperatures exceed that during flowering, then the rice grains are sterile. They only need a couple hours of peak temperature right at flowering, and rice flowers at noon, near the hottest time of the day, so it doesn't seem like a very good strategy, so even moderate rise in temperature will be problematic for rice. We looked for years and years and years to try to find tolerance to high temperatures, and nothing was there, so we thought maybe it's just better to just run away, as my friends in West Africa say. By running away, what that means is in looking through our gene bank, we found rices that flower at 8:00 in the morning, so you can have a hot day but if your flowering is done by 9:00 in the morning, you're not going to worry about that high temperature. It's just a very narrow window of susceptibility. Here's a rice variety. These little things are anthers sticking out. This is a rice in full flower, 8:30 in the morning, normal rice variety, hasn't even woken up yet, and a simple trait like this should enable us to avoid the heat tolerance.

Just a last word on how we use the gene bank. We're also conserving traditional varieties, and we've linked up with an NGO called Eighth Wonder that will take the rice from the beautiful Philippine rice terraces in Banaue and market them in Washington, D.C. and Portland, Oregon and Seattle, Washington at 10 to 20 times market price so these farmers can get some benefit from their hard work, and they're organic, too. They're organic, they're tribal, they're everything, and so people will pay a fortune for them, which is great, I think.

Now, the wild species. I was going to talk about the dinosaur extinction and that sort of thing, but it would take too much time. But, basically, rice is domesticated from a number of wild relatives, and it's a pretty closely-linked set of species, and we have over the years identified quite a few traits that are in these wild relatives that are not in domesticated rice. Our scientists have done an incredible amount of work over the past 30 years to make crosses among these wild relatives that look like weeds growing by the side of the road but have valuable traits in them. The reason they look like weeds growing by the side of the road is because they probably are. If you drive through a road in the wet, monsoonal Southeast Asia, you'll see these guys. But they carry great traits. Our breeders have been able to make crosses using conventional means to get traits from these rice varieties into a suitable rice variety for farmers to grow.

Here's an example. This is a modern rice variety here in normal irrigation water. This is the same variety growing in water that's about half the concentration of salt of seawater. This is a wild relative, Oryza coarctata, that's growing in that same concentration quite happy, thank you very much. This is a cross between this and this, and tolerating the salinity very well, and this is a later generation. Basically, we've been able to transfer a high level of salt tolerance of a wild relative of rice that grows in mangrove areas into a rice background that a farmer would grow. In these areas, coastal areas where we have saltwater intrusion, particularly during the dry season, you have floods from typhoons, et cetera, salinity, which limits rice production, will no longer be a limiting factor, so it could be a major tool in helping us deal with the impact of climate change.

Of course, some traits are not found in wild rice or even its wild relatives. Rice is very low content of vitamin A, or beta-carotene, the reason being that rice can synthesize its own vitamin A whenever it needs it, and so it doesn't carry it in the seed, but it is a deficiency. Vitamin A deficiency is very serious in rice-consuming countries, particularly. We've got hundreds of millions of people who suffer vitamin A deficiency around the world, catastrophic impacts of blindness and immune system suppression, et cetera as a result of vitamin A deficiency. There's an effort that began back in 1984 to develop rice that would create or carry beta-carotene in its grain. Beta-carotene is converted by the human body into vitamin A. That also confers a yellow pigmentation, so the grain is yellow. It's been called golden rice. We are working on adapting the trait into varieties that will be high enough yielding, productive enough for farmers to grow and get that into their

consumer stream. It's been a much more difficult process than any of us thought at the beginning, including all you have to do to get through regulatory approval, because it is a transgenic crop or a GMO.

One of the questions when golden rice was created, the prototype came out in the early '90s, one question was, "Can it produce sufficient vitamin A equivalent to beta-carotene to make a nutritional difference?" and Greenpeace had a field day with us because the first golden rice materials that came out, the proof-of-concept, had very low beta-carotene content, so a very low vitamin A equivalency in it. They pretty much ridiculed us saying, "This GMO is no good because this is how much rice you would have to eat for a child to get enough vitamin A." Of course the problem is they didn't recognize that this was a prototype technology, it wasn't the finished product, and through quite a bit of work of tweaking the systems, et cetera, we have actually been able to up the content of beta-carotene in golden rice such that if a child eats 50 grams, a normal serving of rice and golden rice, they would have more than half of their daily intake requirement for vitamin A. Basically, it could be a normal part of any diet to meet vitamin A needs. Now, this has been a real challenge, and it will continue to be a challenge because we have regulatory procedures we have to go through. We have to go through regular varietal approvals, et cetera, and then there's the hurdle of public relations and moving a GMO, and that's going to be a tremendous, and it continues to be a tremendous learning process for us.

Now, all that work about breeding, I said that one of the keys is to have effective partnerships. We have decentralized breeding activities in Africa, South Asia, Southeast Asia, and I don't show it here, and in South America through the Global Rice Science Partnership, where materials are moving very effectively around the world in partnership with national systems and, increasingly, the private sector. All right, now variety isn't everything. You have to be able to manage your crop properly to get a decent yield out of it. I'll just give you a couple examples of water management and nutrient management. Water, while rice loves water, it does end up using quite a bit of water in Asia. Almost half of the water used in Asia goes to rice production. Now that's a lot of river water that wouldn't be used for anything else, but still a pretty phenomenal amount. There's increasing pressure to use water more efficiently, and we're expecting pretty significant shortages over the next couple of decades in water availability.

We have a number of water-saving options that we're working on in terms of intermittent irrigation, growing rice more like wheat, et cetera, all of which can reduce water use dramatically in rice. However, it's not simply an issue of, "Well, just use less irrigation water," because what happens is as you change the amount of water that's used in growing rice, the soil chemistry changes, the environment in which pests and pathogens live changes, the weed composition in the fields change. So, there's a huge, if I can say, can of worms that's opened up because nematodes can become a problem that you have to address as soon as you start to

monkey with something so fundamental as the water supply of a rice field, but it's a reality, and that's why we have research institutions.

Now, nutrient management. Those of you who are aware of some of the issues around intensive nutrient management in Asia, particularly nitrate pollution of groundwater in southern China, realize that that's a problem. We started looking quite closely over a period of about 15 years at how farmers are managing nutrients and how we could adjust this nutrient management, and developed some very quick and easy tools that you can see here that farmers did not adopt in large numbers. It was cumbersome, it spoke scientific language, et cetera, and, gradually, over the years, we've come to realize the tools that we offer for farmers to make decisions will have to be something they're comfortable with. Increasingly, farmers are comfortable with cell phones, oddly enough, and so we have developed very sophisticated decision-making tools that farmers can access using a cell phone. This isn't a push kind of thing that says, "Apply 25 kg of N." No. It goes into a discussion with the farmer, "What rice variety are you growing? What did you grow last year? Are you irrigated or are you rain-fed? Are you using well water or river water?" All these things that come together to allow a farmer to make a much more intelligent decision about nutrients.

We found that in Indonesia we can increase farmer income by about $100.00 a year using this, which is pretty significant. But more importantly, we've realized that farmers are willing to access all kinds of information through their phones, not just nutrient management but also crop protection, market information that we all know about. We're looking at putting together a platform, a crop management platform that would not be farmer-by-farmer but would actually form the basis of business models for entrepreneurs and crop management advisors in rice-growing areas that would allow them to offer suites of management options to rice farmers, and eventually connect to the credit markets, and possibly then, as credit risks drop, connect to the insurance market, crop insurance. So, if we can have documented adoption by farmers of best practices, their credit risk drops, their suitability for insurance increases, and we might crack one of those nuts that have threatened us.

That brings me to our stakeholders. At the end of the day, as hopefully has come across, farmers are really the ultimate users of our technologies. We opened a regional East African hub in Burundi working with women. When the peace accords were signed in Burundi, people who turned in a weapon were given a job or given cash or given some sort of compensation to reintegrate into society. The women who cooked for the rebels in the camps didn't have a weapon to turn in, and they were out of luck, so we started working with these women, getting them into cooperatives to grow rice seed – rice is becoming very popular in Burundi – and this quote just struck me. We were talking with one woman who said, "In my family, we were eating only once a day, and now we eat twice a day," and she was ecstatic. I mean that's the level of poverty we're talking about, but we can impact with these kinds of people.

Finally, a quick word on policies. I said that I came the hard road to understand the policymakers have to understand the opportunities offered by technology, so we need to be able to plan for what's coming down the road, understand how much rice is going to be grown where and when. We're going to talk about supplies, availability, food security strategies. We're doing a lot of work on remote sensing and crop growth modeling to work with this, and we're using satellite imagery, radar cloud-penetrating satellites to map, in exquisite detail, the distribution of rice production around Asia first, and eventually worldwide. It's cloud-penetrating radar. I won't go through it in any detail, but the idea is that in a monsoonal environment, if you're using standard optical satellite imagery, all you will see for the entire growing season is clouds, which don't help you very much. But radar imagery passes through the clouds, and, through some very great manipulation of algorithms on the imagery, we can predict with extreme accuracy the area of rice that's planted, and, connecting with crop growth models, we can predict the yield.

So, we can do all kinds of work with remote sensing linked with our knowledge of the crop and crop growth models to give policymakers a real-time idea of what rice production is going to be compared to what you can get from FAO tables, which will tell you what rice production was two years ago, or USDA models, no offense, that depend on someone calling up and saying, "What do you think the rice yield is this year?" Just an example, in the Mekong, this is very fine, we're down to about three meters resolution. Green shows the area. The colored areas show the planting date. Planting date is one of the key determinants of yield, day length and expected cloud cover. Connecting with crop models, we can actually give very, very accurate yield projections, and we can adjust yield estimates every couple of weeks as satellites fly over. Those are just yield estimates down to a field level, which is really quite astounding.

Also, incidentally, the satellite imagery allows us to get an idea of what happens in a disaster. Typhoon Haiyan that devastated the southern Philippines in 2013, there it is, FAO, and I'm not banging FAO, but came out saying, "Because of the storm, thousands and thousands of tons of rice were lost." We were able to get access to our satellite imagery. Blue is where the floods were, green is where rice fields are; the rice fields were not flooded. Then, by the way, we told the Secretary of Agriculture the rice, according to our satellite imagery, was 95 percent harvested three weeks before the storm anyway, so basically no losses, but much better ability even to deal with disasters. We're looking at, in addition to developing our technologies to improve productivity of rice, production of rice, provide the information so the decision-makers can put together intelligent policies that will respond to the realities of production and shifting production in ways that can help them design policies that will benefit the broader society, taking into account the needs of both the rural and the urban sector.

As we look to the future, I'm an optimist, we've got a great set of technologies coming along that will allow us to address some of the biggest challenges facing

us. A lot of changes will be taking place within the rice markets and the rice systems, but we can adapt to them. There's going to be great demand for those, and that notwithstanding, catastrophic losses will occasionally occur, and we're developing tools that not only will allow us to deal with challenges facing day-to-day rice production but also catastrophes that we expect to face us. I just want to remind you of the Chinese saying, "The precious things in life are not pearls and jade but the five grains of which rice is indeed the finest." So, with that, thank you very much, and happy to take questions.

[Applause]

For those of you who don't want to work or are tired sometimes of working in a bureaucracy and would like to take a break and come out and work with us in the Philippines, we have lots of postdoctoral positions and that sort of thing available for young scientists, et cetera, so all right.

Julie: Thank you so much, Bob. A really fantastic presentation, and we'll open up to questions.

[End of Audio]

QUESTIONS AND ANSWERS

Julie: We have about half an hour or so for questions. I just wanted to quickly flag for those of you in case anyone has to leave early, there's a survey on your chairs or that will be shared on the webinar and it's just always helpful for us to have these whether or not you've attended events before. You can just leave them on your chairs or leave them on the table out there. All right. So we traditionally often take a question from online from our webinar audience as the first question so why don't we do that and then we'll come back to the in person audience.

Interviewer: Thank you, Julie. I've got a couple questions about specific rice varieties from Samba Kawa in Liberia. Are you also working on rice that does equally well in salty mangroves and in freshwater lowlands like you did for drought and flooded conditions? And for marketability any mention of rice in sub-Saharan Africa that's resistant to milling breakage?

Dr. Zeigler: Yeah. I probably went over it a little bit fast. I was conscious of time. But yeah. We are specifically working on incorporating very high levels of salt tolerance in rice, in commercializable rice varieties. If freshwater has electric conductivity of zero and seawater and electrical conductivity of low 50s, mangroves would be around mid20s to 30s. We're developing rices that will grow happily in about electric or EC levels of 30 to 35 which is very salty so that's in mangrove areas. I do want to make sure that we don't – that as salt tolerant varieties are developed that mangrove swamps aren't cleared to grow rice because that would be an ecological problem to put it mildly. But still the salt tolerance is something very important in these areas.

The head rice recovery or milling recovery or milling breakage is a big problem with rice. One of the nightmares of breeders is to develop a high yielding rice that when it is polished it breaks apart into crumbs. Rice as my picture of the rice grain showed, people like to eat whole grains and the way it feels in the mouth and all of that are very important. Wheat you grind up and maize you grind up pretty much into a flour so it doesn't matter what happens when you process it. Rice it's very important that the grain remain intact and there is quite a bit of variation within rice and its ability to tolerate polishing. And so we pay a lot of attention to rice that stays intact and that's a very important trait.

Julie: A question here in person? You've got one? And if you wouldn't mind sharing your name and organization as well.

Nohemi Voglozin: Hi. I'm Dr. Nohemi Voglozin. I got my PhD at the University of Maryland Baltimore County and I did my research on African rice, oryza glaberrima, and how the genetic diversity of oryza glaberrima is related to environmental variables in Benin, West Africa. And thank you very much for your presentation but I haven't really heard you talk about oryza glaberrima that much and we all know that oryza glaberrima is the second species that is domesticated but it's also really endemic to West Africa. But I would like to know what your organization is doing to make oryza glaberrima as known as oryza sativa because oryza sativa is grown all over, is grown worldwide whereas oryza sativa is grown only in West Africa. But oryza glaberrima has a lot of really great characteristics that might be used helpful to for varieties. So what does your organization is doing to help with that?

Dr. Zeigler: Yeah. We're actually doing quite a bit. We're working with Africa rice in Benin. The main thrust of both our work is to take the traits of oryza glaberrima. It's one of the relatives of rice and as she indicated was domesticated independently in West Africa river areas or swampy areas. It has many traits and we are doing interspecific cross across oryza glaberrima and oryza sativa to move traits into, from glaberrima into sativa and the question of actually a breeding program to improve glaberrima that's more in the arena of Africa Rice Institute. We ourselves are not doing that but in all honesty almost all of the focus is on moving traits from glaberrima into sativa rather than improving glaberrima itself.

Interviewer: Yeah. We've got a couple of related questions. The first is from Madeline Smith. Can you talk a bit more on the behavior change research focused on the acceptance market approaches or incentives, etcetera to increase the uptake at scale of golden rice? And the related question is from Romana Roschinsky from Boca University in Vienna, Austria. I wonder about the societal acceptance of golden rice since rice is such a key element of cultures in Southeast Asia. Do housewives and kids like it? Any experiences?

Dr. Zeigler: Yeah. I think we've – there are two components to the acceptance. One is – I suppose there are three. One component is taste. Is there any taste difference from golden rice? The second would be its appearance. Is there anything about the golden color, yellow color, that would put people off? And then the third is for some it being a GMO.

The – we've done studies with golden rice taste panels under red light where white rice and yellow rice are indistinguishable and there have been no taste differences. The appearance all of our surveys indicate that whether rice is yellow or not if it's not off colored brown like it's gone moldy, if it's just a nice clear yellow people find no problem with it. As a matter of fact they're intrigued by it. And if you go to just about any market in Asia you'll find rice that is already colored yellow, saffron, so it's not outside the norm to eat a yellow rice and that's something. So surprisingly enough our research into acceptability, etcetera around the color yellow indicates that with a little bit of public awareness about the health benefit of golden rice we're not expecting that much resistance there.

The issue around GMO again is going to be a communications issue. Once golden rice passes all the regulatory processes there is no safety or health issues. It's a question of what sort of propaganda the anti-GMO lobby will launch and that's something that we're obviously thinking about and how best to deal with that. You don't want to be in a situation where you're saying that – I mean it's not, it's a very challenging prospect to think about how to deal with the anti-GMO lobby 'cause they're not constrained by facts or truth so that makes it easy for them. And then you don't want to be in a situation of denying something. "No, I don't beat my dog" sort of thing. You know what I mean?

So it's – we actually – we have a lot of work going into this in communication development and that sort of thing. But we really don't want to get too far ahead of ourselves because we want to make sure we have a product that farmers will grow and that will be productive enough before we get in too much into the communications. And I'm frankly disappointed honestly by a lot of the work that our friends who are pro-golden rice go out and make a lot of noise about it and we don't have a product that's ready yet to be quite honest.

And so people are getting all their expectations up and we're saying "Well hang on. It's going to take a while." And it's just the nuts and bolts of getting a rice variety that will yield enough that farmers will grow and get a decent income. Nothing to do with anything about golden rice per se. It's just the rice breeding challenge in general.

John McMurdy: My first question – and I'm John McMurdy from here at USAID. My first question is on the trajectory of hybrid rice and how that is or is expected to affect kind of

rice seed systems. My second question is as long as we're talking about controversial things, USAID has a few programs in its missions that are supporting SRI projects, System of Rice Intensification. I think it would be interesting to hear IRRI's position on that for the group.

Dr. Zeigler: Yeah. Hybrid rice is something obviously transformed rice production in China. It was a government mandated technology. Hybrid rice in the tropics for various reasons that are not completely understood doesn't perform as well as it does in temperate areas. We are working and many – we are working. We have a consortium of private and public to try to improve the productivity of hybrid rice in the tropics.

The private sector typically is not interested in the rice seed sector because farmers can save their own seed and private sector is used to the model of hybrids where they sell seed every year and they have a guaranteed revenue stream from their hybrid sales. And so the private sector is attracted to a hybrid rice model but farmers don't really, aren't really that attracted to hybrid rice 'cause it just doesn't to be quite honest and some of our breeders would kill me. But if you look at the adoption rates of hybrids in India where they've been pushed for 20 years since the early '90s the adoption rates and when you take away where there's a subsidy farmers aren't taking them up.

And the farmers are not idiots. They're not going to take up a technology that's no good or that doesn't provide for them a benefit that is commensurate with the cost. I think that there is reason for optimism. We can develop better hybrids I believe that are attractive to farmers and I think they're of interest for a couple of reasons. One, it's much easier to manipulate traits with hybrids. You can actually – you have much more flexibility in varietal development with hybrids so that's attractive. And frankly the private sector I think is needed to have a dynamic seed industry. And I'm working with some companies to try to develop a viable seed model or seed industry that doesn't demand hybrids but it's a tough sell. So I think that hybrids will play a more important role in the future but it's, again, it's not a trivial thing.

Now SRI, that's the System of Rice Intensification, something that was developed by Jesuit priests in Madagascar in the early '90s. I actually saw it when I visited Madagascar there in the early '90s. Popularized by Norman Uphoff, a guy I worship at his feet in terms of his communication skills. The concept is a started out as a very rigid prescriptive approach to intensifying rice production. And I

won't go into all the details but there was a very strict recipe of what you need to do and if you do this you will get higher rice yields. Every component of SRI is known through classical agronomy work over the past 50 years to contribute to improved rice yields. That's never been a question.

The question has always been around SRI is – or one notable exception. You could not use mineral fertilizer. You could only use organic fertilizer, manure or composted plant matter. The problems around SRI are not that if you do it the way they say you'll do it you'll get higher yields. Nobody questions that. The question is, is it practical? I mean many of the restrictions are so strict that farmers don't or cannot adopt them.

Labor demands are too high. Almost no farmer has enough animals to provide the necessary nitrogen using manure alone. You have to be a very wealthy farmer to have that much manure. Labor required for weeding, hand weeding, you have to be a wealthy farmer. To control your – you need very very precise control of water to be able to add water, remove water, add water. Almost every rice farmer as soon as they get water on their field the last thing they're going to do is take it off. Ok? They've got the water. Thank God. And then take it off and put it on again?

So it's the practical application of SRI that's the problem. And then the other issue that it's just a major irritant to almost all of us is spectacular claims of outrageous yields, of 20 tons a hectare or 25 tons a hectare. I mean it's physiologically not possible. So but what I like about SRI and I think that we need to take out of the positive page of, many positive pages out of the playbook is that they have engaged NGOs and the sectors and the government to go out and engage with farmers.

And what that means is that regardless farmers are paying closer attention to their crop and when farmers take up, you see these adoption figures of SRI, it's always modified SRI. It means they add a little nitrogen fertilizer, change the spacing. Well we don't actually remove the water. We transplant two or three seedlings instead of one, etcetera. But the point is that they're paying close attention to agronomic practices that they weren't paying attention to before and that is all for the better. There's a question back there.

Interviewer: Back to our online audience. This question comes from Duncan Bowen from Michigan State University at the Feed the Future Food Security Policy Innovation

Lab. You mention that policy is important for technology uptake. What do you need policy makers to do and what tools and communication channels do you find most effective in reaching them?

Dr. Zeigler: I think one of the biggest challenges around for policy makers – well there's a set. One of the, we have in many different countries a lot of well-intentioned policies that I think are counterproductive in terms of subsidies for inputs, fertilizers, subsidies for irrigation, water, etcetera that lead to misuse of these inputs and they're not sustainable. So I think we need our policy makers to take a hard look at their incentives and what they're actually trying to incentivize. They all want enough – we like to say if the price of rice raises ministers of agriculture fall. So all of these policies around to try to keep people in their jobs at the political level to put it crudely.

But I think a reassessment of our policies around inputs and I would include the enforcement of pesticide regulations. We're seeing a resurgence of misuse of particularly insecticides across rice growing areas in Asia, particularly following the rice price spikes that started in 2007 or 2008. And there are plenty of regulations on the books around controlling how pesticides are sold, etcetera. They're not being enforced and we're seeing outbreaks that are pesticide induced in rice pests. So I would say one of the biggest policy areas that I want governments to pay attention to is rationalize your policies and regulations about input and that includes subsidies, etcetera.

Second I think that's really important it's a tougher sell is rice trade. I'm a real advocate of free trade, open trade in rice. Governments do everything they can to try to make sure that they have enough rice for their own country and that means that you have a very opaque market. The rice trade is thin enough as it is. I think from 10 percent maybe up to sometimes 14 percent of global rice production is traded. And nobody knows really how much rice is produced. Nobody knows how much is entering the trade. Governments, they're the biggest exporters, can block exports like that.

What triggered the crises in 2008 was that in late, mid 2007 Vietnam, the world's number two rice exporter, blocked its exports because it was worried about food inflation, cancelled contracts. India, world's at that time number one rice exporter, blocked its exports. And so immediately the rice trade seized up. Nobody knew how much rice was available and if governments can come in and disrupt the trade you basically have anarchy in the rice trade and so prices are unpredictable. Some

people will make a lot of money but you know who will be the ones who lose. It will be the poor people as usual.

So I would like to see – and we've been working with __ and Asian Development Bank to try to look at how we can create a rice exchange at least for Asia so you could have a rice market. And yes, futures would, futures market would develop, etcetera. Some people would speculate. That's fine. Let the speculators win and lose. But if we could develop a rice exchange in which farmers could participate we could have a situation where we could open up the overall rice market. So two big policy areas, the inputs and the second one the rice trade, rice market.

Julie: We have time for a handful more questions. I know you had one before.

Chris Delgado: Hi. My name's Chris Delgado. You partly, you've really partly answered the question but I want to push you a little further. I mean given the problems of getting the private sector, particularly the formal private sector, interested in selling rice seed and given the concentration of production in the Asian tropics, what is the right strategy for the public sector really to pursue to get the private sector to take over increasingly a share of the burden and kind of a second green revolution?

Dr. Zeigler: Yeah. What I'm arguing is that, one, I think the – we need to move away from the mega-varieties. One of the consequences of the green revolution that basically swept over irrigated rice or areas where there was good water control was you just had a handful of varieties grown. So one variety or two varieties might have been on 30 or 40 million hectares. Ok? And farmers could save that seed. Not much was coming out. And you didn't have much, to be quite honest, a lot of innovation in the rice variety turnover.

So what I see is particularly we see many different traits becoming available. We're looking at what's going to be coming out of the sequencing program. What I see happening is that we will be finely, more finely slicing the rice growing environment and the rice market. Much wider variety of quality characteristics for different market segments. Much finer tuning to different rice production environments. This is a recipe that will encourage the taking up of rice seed production by small and medium seed companies. The multinationals won't be interested in it but if you go around Bangladesh and Eastern India and Western and all over India, there's a lot of small companies that are growing vegetable seed that are growing cotton seeds, etcetera and they would like to produce rice but there's nothing in it for them.

So what I see, sort of my dream, is a situation where the public sector creates a flow of new trades coming in. These can be incorporated into different, many different varieties that are for niche markets that are plenty profit margin for small and medium size seed companies partitioning the environments and actually enriching the overall rice production environment and something that would be attractive to small and medium size seed companies producing inbred rice seed. Enough of a stream of new trades coming through. There will be enough innovation, enough motivation or incentive for farmers to buy new seed. They may not buy seed every year but if they buy seed every other year or every third year there are so damn many of them that there will be a big enough market. Ok.

And so that's – and I've talked with a lot of the – a lot. I've talked with a number of seed, small seed companies in Eastern India and in Bangladesh and they're really interested in this model and they think it will work. And they're dying to get their hands on new materials. What they don't want is to be producing in swarna, swarna-sub-1 where we created the flood tolerant varieties. I mean that was produced in 1978 and it's still out there. I mean farmers like it but it's not a great variety. It's got a lot of problems.

The seed companies don't want to be producing a variety that's been out there for almost 40 years. They want a new product. And I think that that's, and I think what with our, what's coming out of our sequencing and phenotype area, I think we can actually reinvent the rice seed industry. And that's my story and I'm sticking to it.

Julie: All right. We'll take one more from online. I've got many more than one but hopefully we can follow up with you after the seminar.

Dr. Zeigler: Sure.

Julie: A historic question for Bob. As the director general of area. How much of the green revolution in Asia should be attributed to IRRI's technology advances and how much to the concurrent shift from water buffalo to power tillers? Without that adjustment would it be possible to cultivate enough area in a timely manner to take advantage of the technology?

Dr. Zeigler: God, that's a great question. No, it's a great question because what people don't understand and this person clearly does is that there's a whole set of other revolutions that take place and one of them was the mechanization. And I would say that the original two wheel power tiller that actually enabled a lot of this if you go back was actually designed in IRRI, a very cheap one. Kubota refuses to fund IRRI's work because they can't get into some markets in Asia because our stupid little power tiller that's so cheap is the one the farmers use. But more importantly threshing, the ability to thresh a crop. If you're getting – if you're used to getting a ton and a half and all of a sudden you're getting five or six tons of rice and instead of getting one crop you're getting two or three crops a year and one or two of those crops is when it's raining, the ability to thresh that grain is a real challenge.

And so there are a whole bunch of associated technologies that accompanied the higher yielding varieties. There was the tillage, the need to till land in a timely fashion. There was the ability to thresh just to name two. And those two, and therein lies the real secret of the green revolution. It wasn't just more grain. It was developing an entire economic sector in the rural areas. Machinery shops to repair those tractors and sell them spare parts, the thresher – who makes the threshers? Who stores the rice?

All of that, all of that is what – it's an economic revolution. And so the questioner really hit the nail on the head that you have – you can have a transformational technology but it is accompanied by a whole set of other technologies that enable that to function. Somebody investing in a power tiller wouldn't work if they were getting only a ton of rice a hectare. So they feed back. Really it's beautiful and books have been written about it but it's really, it's a great question.

Julie: I think we have time for just one final question in person. I know I had seen you raise your hand a while back so…

Sophie Kelly: My name is Sophie Kelly and I'm an AAA fellow with the State Department African bureau and I was wondering if different rice varieties vary in their capacity to be stored for long periods of time so like for instance things like mold or breakage in storage. So when you're considering increasing the yield of rice and I realize that a lot of this rice will be consumed immediately but is storage a factor?

Dr. Zeigler: Yeah. Storage is certainly a challenge and to my knowledge we have not looked at genetic variation of storability. The key to storage life of rice are the conditions that it enters into storage. Has it been dried properly? Is it down to a low enough moisture content? And then the actual conditions of the storage containers. Will

they keep insects out? Will they keep the humidity down, etcetera? So it's more how the grain is handled.

And I confess, I don't think we've actually looked at the characteristics that would determine storability. It would probably be – we have looked at differences in if you dry rapidly will the grain crack and then break in milling and there are differences for in that but it's pretty complex genetically. And I would guess that the actual starch chemistry could help, could determine how fat a grain would dry. But again it's all back down to moisture. What is the grain moisture when you put it into storage? It has to be below a critical level and then to a large extent oxygen for insects.

Julie: All right. We are at the 11:00 hour and so I'd like to thank Bob again for a really fantastic presentation.

Dr. Zeigler: Well thank you. I really enjoyed it. I thank you very much for your attention. It's been fun.

[End of Audio]