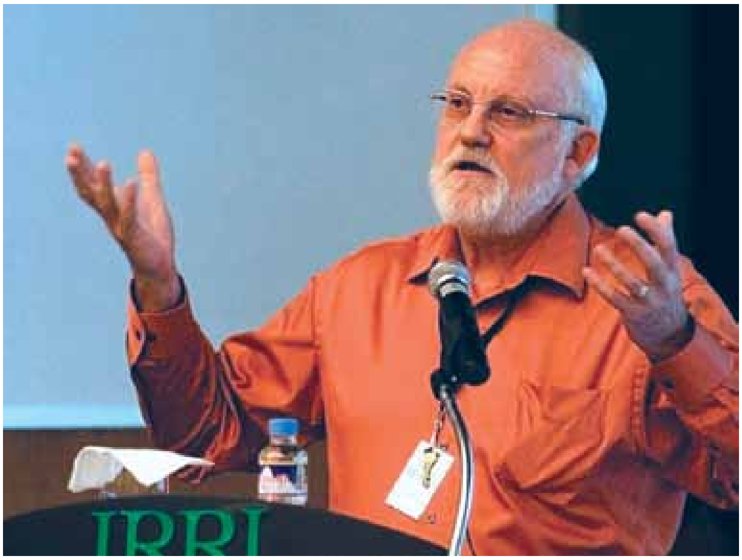
Dr. Robert Zeigler

Rice: Scientific Breakthroughs To Transform Agriculture

April 8—*This is the conclusion of a presentation by Dr. Robert Zeigler, Director of the International Rice Research Institute (IRRI), on Dec. 10, 2012, in Washington, D.C. It was hosted by the Center for Strategic & International Studies (CSIS), on the topic "Promoting Sustainable Rice Production To Meet Growing Challenges." The first part, concerning the importance and history of rice, appeared in EIR, May 10. These are extensive excerpts from the transcript, with subheads added.*



IRRI

"We're trying to compress a millioin years of evolution into 20 years."

We are going to be needing rice varieties that deal with the problems that climate change has thrown at us. We're going to have production practices that are much more efficient in the use of resources, and that require less labor; and we're going to need systems that will sustainably provide us the higher yields that we know we need to realize.

I started out by talking about how wonderfully genetically diverse rice is, and I just cannot overestimate [the value of] that resource that we have at our disposal. It is the secret to solving many of our problems in the future, and we have, in our institute, a collection of over 110,000 different rice varieties.

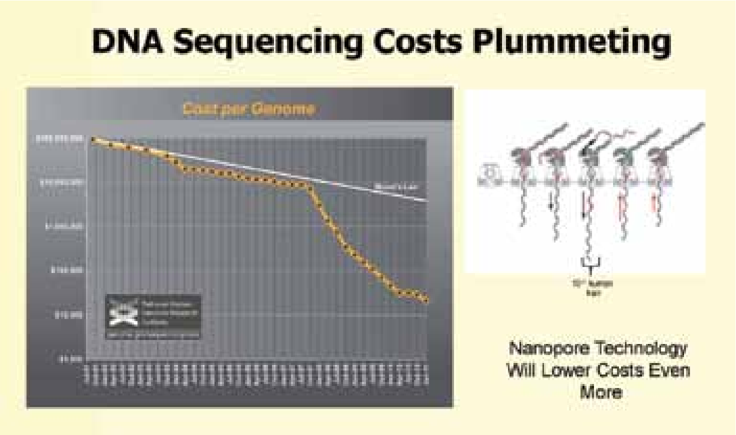
It's a tribute to the vision of the people who preceded me, that they realized that there are thousands of rice varieties being grown around Asia—most of them are fairly low-yielding—but they recognized that each probably had good traits. They also recognized that if they were successful in creating these modern varieties, that these traditional varieties could be lost. And these traditional varieties are the result of thousands of years of farmers' selections. And so, they systematically went out and collected, all across the world, the diversity of rice. And they knew that they didn't have the tools to use that genetic diversity in the 1960s and 1970s, but they had enough faith in science to know that sometime, and probably not in their lifetime, those tools would be developed, and that we could tap the diversity of those traditional varieties.

And that is where we are today. And for the reasons that I mentioned, less than 5% of this had been used in breeding programs; but we have actually now developed at IRRI—and I won't go through this—basically, a very well-designed program to try to understand the genetic diversity that is within the rice species and its relatives, and then analyze that in a way that we can take that through to solve real world problems.

So, it's a way of linking very basic discovery research, that's publishable in journals like *Science* and *Nature*, but is directed toward solving real world problems. And I'll give you some examples of that.

One of the key breakthroughs that is giving us the ability to tap into the genetic diversity of rice, is the plummeting cost of DNA sequencing. You're all familiar with Moore's law: that every 18 months, the power of computing doubles, or the cost is cut in half—the

FIGURE 1



DNA Sequencing Costs Plummeting

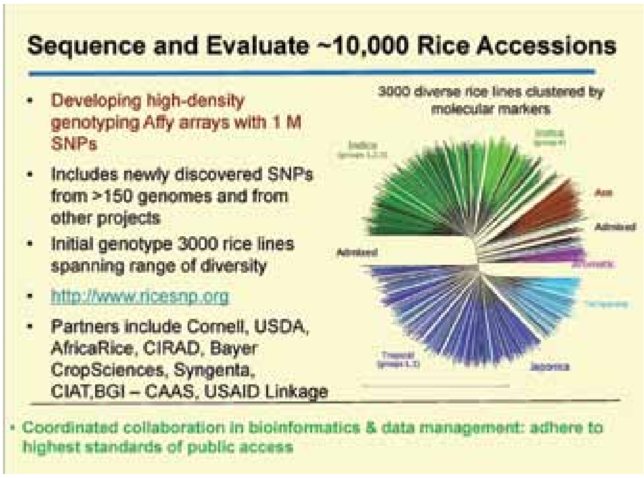
Nanopore Technology Will Lower Costs Even More

Courtesy of Robert S. Zeigler

DNA sequencing is following that law pretty closely. Recently the cost has just fallen off the roof, fell over, dropped (**Figure 1**), and it's becoming really, really affordable to do a large amount of sequencing. And there's a next generation of sequencing that is coming, that will allow us to do the human genome for $100; a rice genome for $25. So things are completely transforming before our eyes.

And we have already started to analyze the genome of rice. We're embarking on a program to sequence 10,000 rice lines from our gene bank. I keep on my desk a 2002 issue of *Science* magazine, where the cover of that magazine is a beautifully terraced rice field in China, and it was announcing the sequence of the first rice genome. It had taken over 15 years, it cost millions and millions of dollars, and I keep it there as a reminder that we're talking now about sequencing 10,000 rice lines in about two years.

FIGURE 2



Sequence and Evaluate ~10,000 Rice Accessions

- Developing high-density genotyping Affy arrays with 1 M SNPs
- Includes newly discovered SNPs from >150 genomes and from other projects
- Initial genotype 3000 rice lines spanning range of diversity
- http://www.ricesnp.org
- Partners include Cornell, USDA, AfricaRice, CIRAD, Bayer CropSciences, Syngenta, CIAT,BGI – CAAS, USAID Linkage

3000 diverse rice lines clustered by molecular markers

- Coordinated collaboration in bioinformatics & data management: adhere to highest standards of public access

Courtesy of Robert S. Zeigler

And we've got a good start (**Figure 2**). Just this pretty little diagram shows how—the different lines and the branches on it are more distantly related individuals within rice, and we're starting to peel back an enormous amount of diversity; and as we understand where rice fits in those different clusters, we can ask more sophisticated questions about traits and performance.

A very important part of the rice genome work that we do to understand this genetic diversity, are the wild relatives. We have in our collection—there are, I think, 13 different genomes of rice, relatives of rice that all evolved from a common ancestor. We have all of those in our gene bank, and they all look like weeds that grow by the side of the road. And the reason is, because they probably are weeds that grow by the side of the road, weeds in the rice fields, etc.

But they also have a lot of very, very interesting traits in them. Some of these have drought and salt tolerance; disease, insect resistance; heat tolerance; even cold tolerance. Now let me try to give you a lesson in plant domestication in a minute and a half.

Lesson: Plant Domestication

Way back in evolutionary time, there was a set of predecessors to rice. Wild relatives, its ancestors. And they had a whole bunch of different traits (**Figure 3**). I

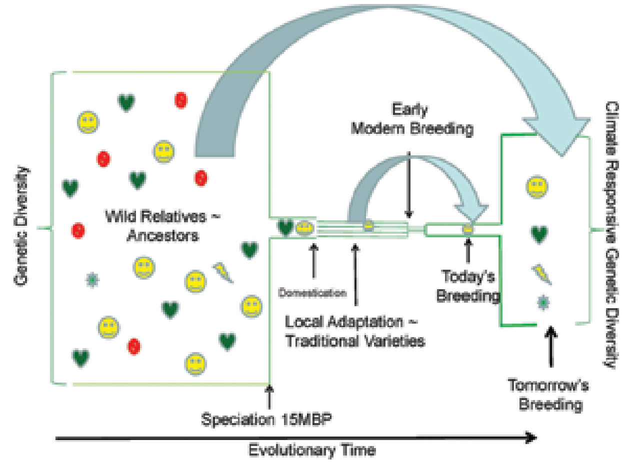
FIGURE 3

Wild Species of *Oryza*: The Resource to Meet Tomorrow's Challenges

- ☐ Drought, salt, flood, heat…
- ☐ Insect resistance
- ☐ Disease resistance
- ☐ Yield and nutrient use

Courtesy of Robert S. Zeigler

FIGURE 4



Courtesy of Robert S. Zeigler

put these in yesterday—they're really corny, I know. And some of them are really good, some of them are pretty lousy, but there's a whole bunch of different traits or genes that are in there. There was speciation which took place about 15 million years ago, when the ancestors of rice, including its wild relatives, started to diverge.

One of those ancestors was the rise of *Oryza rufipogon*, that was the wild relative from which rice was identified by our ancestors. A few of the good traits were captured. And then, with domestication, we went through a series of bottlenecks, and some of the good traits went with one variety, some with another, but they're all spread out. And then, modern breeding came along, and the bottleneck got even smaller (**Figure 4**).

So, as we domesticated—because we didn't know, our ancestors couldn't select what they couldn't see or directly experience and feel—they left behind a lot of things that were good. They just didn't know they were there. They were trying to leave behind what was bad as well.

And then, modern breeding narrowed that pipeline even further. Today, we're going back into the landraces that generated those 3,000 lines that I showed. We're trying to bring some of those good traits back, that were left behind, but what is really, really, really exciting, is that we now have the genetic tools to go back into the wild relatives, and bring back a whole set of traits that were completely left behind in the original domestication event. And that, to me, is one of the most promising breakthroughs.

And just this year—and I'll show you an example of that—we finally made the last crosses; we are now able to make viable crosses between every single *Oryza* species, and domesticated rice. And basically that opens up a huge reservoir of genetic resources for us.

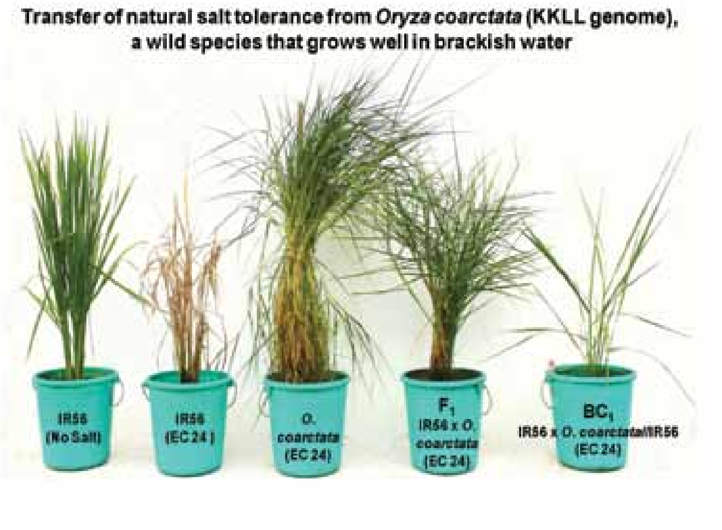
Traits that Came Over

Question: Do you want to just talk a little bit about the traits that came over?

Zeigler: Okay. The traits that came over were [related to] yield; were the ability of the rice grain to stay on the head, rather than falling off—because for a weed, or a wild plant, distributing grain is the best thing; for a farmer, it's the worst thing for it. Grain size. Something called shattering, the ability for the grain to stay fixed. The ability to flower at a certain time. Many different traits like that.

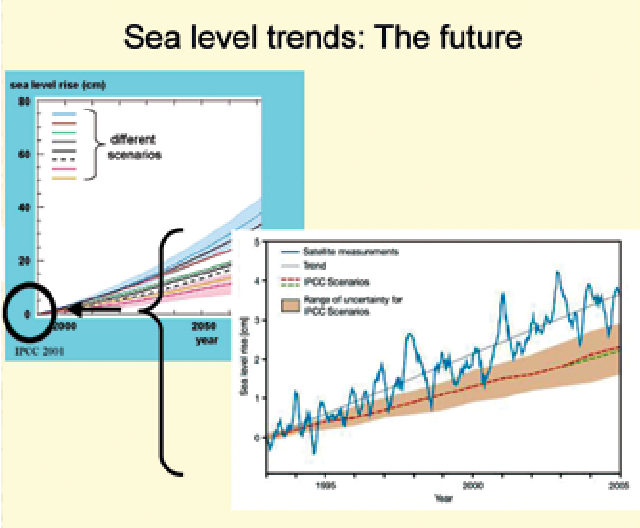
Here's an example of a really tremendous breakthrough (**Figure 5**): *Oryza sativa*, which is the rice species that has something called the A genome, and it's a diploid. This *Oryza coarctata* is a tetraploid, and has two different genomes that are very different from rice's genomes. Here's a modern rice variety grown in normal water. Here's a rice variety grown in what is salty water, almost seawater. Here's its little wild relative growing

FIGURE 5



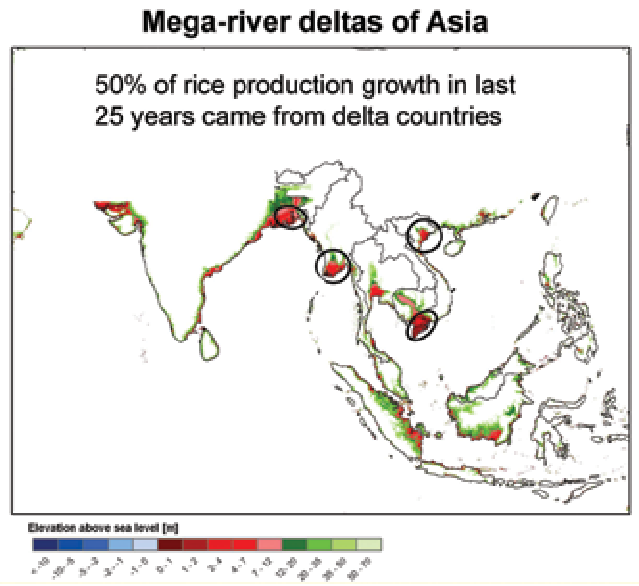
Courtesy of Robert S. Zeigler

FIGURE 6



Courtesy of Robert S. Zeigler

FIGURE 7



Courtesy of Robert S. Zeigler

quite happily in what is effectively seawater. And our breeders—well, one and his team—have actually succeeded in making a cross between the domesticated rice and this wild rice, and it's looking pretty scrawny, but it's a whole lot better than being dead, okay?

And this is something that required just an enormous amount of work. They do something called embryo rescue. They do the crosses. They do thousands and thousands and thousands of crosses. They look at each one under the microscope. They see where there is a little bit of signs of life. They cut that out, they put it on a hormone-rich growth medium, and if they're lucky, a plant grows. To get that one plant—this one is the second from the right—they had to do 15,000 embryo rescues. They got one plant.

So, it is a tremendous investment. But once you've got it, then you've got a bridge to go back, and it's just an enormous breakthrough. I get all goose-bumpy about it.

And that's really important, because if we look at sea-level rise—this was the worst-case scenario of sea-level rise in the IPCC [Intergovernmental Panel on Climate Change] study in 2001 (**Figure 6**). Here's where we are today. Sea-level rise is actually worse than was predicted in the worst-case scenario.

And sea level is pretty important, because rice is grown across Asia in these mega-deltas, and a delta is, by definition, at sea level (**Figure 7**). And so if sea levels rise, we have more salt water intrusion. So, we're going to have to deal with salinity in a big way, and I believe we have the tools to do it. People thought it would be impossible, but I think that is the case.

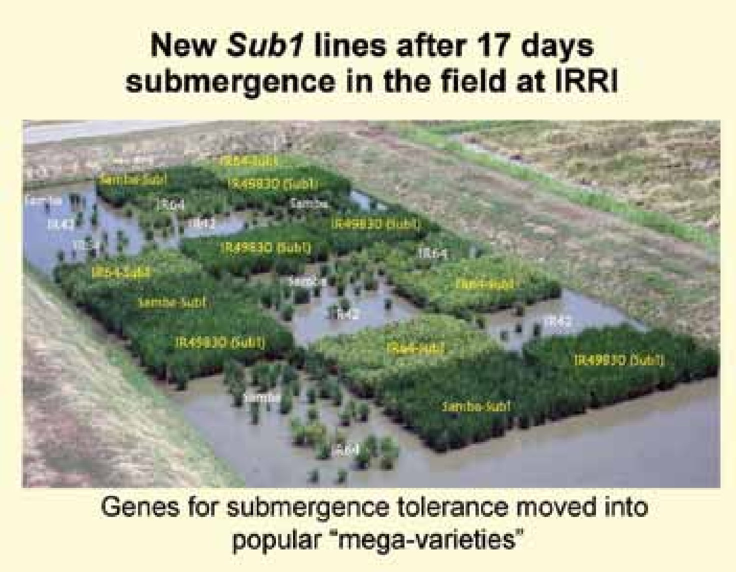
Flood and Drought Tolerance

Now, associated with sea-level rise in some areas, and also a problem rice farmers have been facing since time immemorial, is flooding. And we have very large areas that are exposed to floods every year. You've read about them in Thailand last year, but they are events that occur on a regular basis; about 10 million hectares per year are lost to floods. Even more favorable areas will experience short-term flooding, so it's a problem. And our breeders identified rice material in 1978, from eastern India, that was tolerant of floods. You could submerge it and it would survive. And they spent a couple of decades trying to get it into a rice variety that people would like to eat, and would be worth growing.

Unfortunately, they spent two decades or more trying to do this with virtually no success: low yields, poor grain quality. They produced the first variety they thought was good, and they gave it to people, and they said, this rice is so bad that the dog wouldn't eat it. And, so, back to the drawing boards, so many times.

But eventually, using some molecular techniques—non-GMO, sad to say—they were able to identify the

FIGURE 8


New *Sub1* lines after 17 days submergence in the field at IRRI

Genes for submergence tolerance moved into popular "mega-varieties"

Courtesy of Robert S. Zeigler

FIGURE 9


Sub1 varieties: help poor farmers to cope with perennial flooding

Eastern Uttar Pradesh

Major support from Japan USAID, B&MGF enables us to reach 3,000,000 farmers in 2012r...millions more over the next few years

Released in Bangladesh, India and Philippines...Nepal in February 2011

Courtesy of Robert S. Zeigler

gene in that, FR 13A, and move it into backgrounds that farmers liked, the varieties they liked.

And here's an illustration of an experiment in IRRI, where that gene, called Sub 1, Submergence 1, is put into the background of a number of highly desirable rice varieties (**Figure 8**). The varieties without the gene in it are in white, and ones with it are in yellow. You don't need to be a statistician to tell you which one is working, and which one isn't.

We took that out to eastern India, in 2008, and put it out in this farmer's field—we just had a couple of kilograms, that was it. This farmer's field experienced two, possibly three floods (**Figure 9**). His neighbors basically laughed at him, and told him that he should plow that up. That's what that field looked like on Oct. 31. As expected, it completely recovered.

And we got very good support from the Bill and Melinda Gates Foundation, USAID and Japan, and this variety is now reaching 3 million farmers in South Asia this year.

I'm going to go out on a limb, and people are always talking about how we need a second Green Revolution. I have gone on record, today, and in a letter to the Gates Foundation, I'd say that the second Green Revolution has started; that it started on July 31, 2008 at 1:17 in the afternoon, when this picture was taken, and that farmer decided not to plow up that crop, and give it a chance.

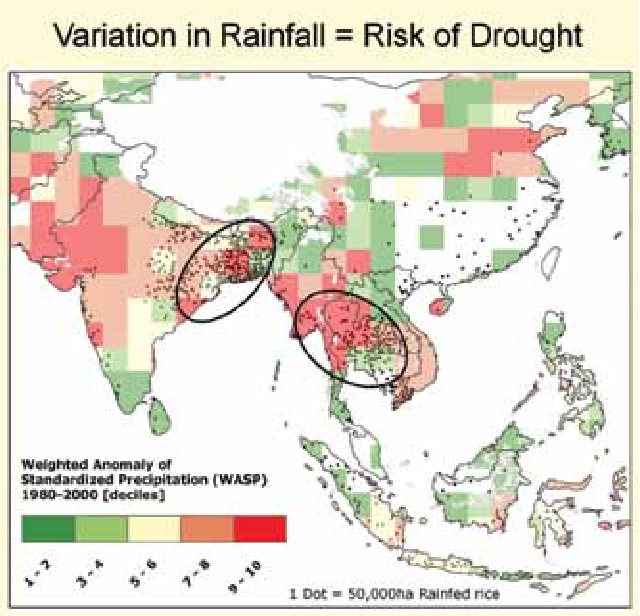
Now, drought, another problem facing rice farmers (**Figure 10**). This is an example of areas that are expected to have much more problem with drought in the future. We've been working quite a bit on that. We just got back some data this year from eastern India, and we've got rice varieties that have pretty reasonable drought tolerance—not quite as spectacular as the flood tolerance, but better than a kick in the teeth. And the farmers really like it. They like the way it tastes. Interestingly enough, the buffalo really like the straw—they seem to prefer the rice straw. So, it may end up, we might have a two-fer, in which case we could have improved the milk production; and what's best is, our breeders have combined these drought tolerance genes with flood tolerant genes of the same variety.

When I joined IRRI in 1992, I headed up a program that was focused on these very difficult environments. One of our breeding targets was to develop drought- and flood-tolerant varieties in the same variety. People thought we were completely nuts. It was 20 years in the making, but it's been done. And it's again an enormous breakthrough.

Poor Soils, and 'Convenient Convergence'

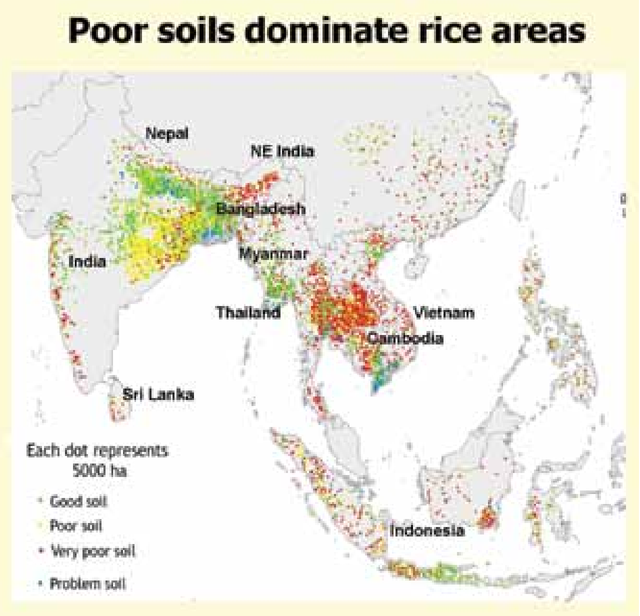
Poor soils (**Figure 11**): Another problem—the take-home message here is that green is good, all other colors are bad—that is the problem across very large areas of

FIGURE 10



Courtesy of Robert S. Zeigler

FIGURE 11



Courtesy of Robert S. Zeigler

rice production. Our scientists just published a paper in *Nature*, last September, in which they were able to demonstrate that they have actually isolated the gene that does confer tolerance to low-phosphorous soils, and it is related to root growth. And so they've got a trait, and a mechanism, which is extremely important.

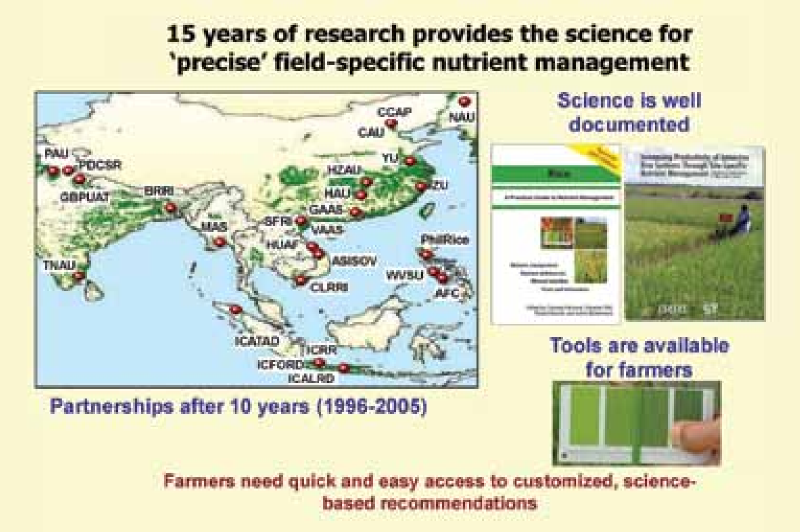
The Sub 1 gene was published in *Nature* in 2006, I believe, and I don't want to go into this, but it's a pretty significant breakthrough, and it's nice for rice, but problems with phosphorous are really serious for maize and legumes. And if we can get that gene from rice to function in maize and soybeans or Phaseolus beans, it could have a massive impact on agriculture, particularly in Sub-Saharan Africa.

So, when we look at climate change in terms of rice varieties, we've got a number of traits that need to be improved, and we're making very good progress on a number of them.

And, way back in the day, back in 2005, it occurred to me that the challenges that are being presented to us by climate change, are the same ones that the poorest farmers experience every day in their fields. And I came up with the term a "convenient convergence"—and this was before Al Gore came out with his show, so then, I felt that people would think I stole it from him. He didn't steal it from me. Anyway, so I can use it again now.

But it is. It's a very "convenient convergence." We can deal with problems of today's very poor people, at the time as we're anticipating problems that will be more widespread in the future.

FIGURE 12



Courtesy of Robert S. Zeigler

FIGURE 13

"Nutrient Manager" using interactive voice response (IVR): Precision farming on < 1 ha

GSM mobile phone

1. Call toll-free phone number with voice recording

IVR implementation box

2. Select a local language
3. Answer 10 to 12 questions with key pad to obtain farm profile
4. Complete in about 8 minutes
5. Transmit answers to model on high-end (cloud based) server
6. Generate advice specific to farmer situation
7. Deliver customized advice as SMS message

Courtesy of Robert S. Zeigler

Crop Management

I'd like to switch gears a little bit towards crop management. Since about the early 1990s, we started asking questions about, how do you tell how much nutrient a rice plant needs in a particular situation? So, my colleagues set up a number of experiments across Asia. They're very carefully monitored, and we asked the question: What is the right amount of fertilizer for rice, and how do we know what it is?

Now, I just want to highlight something here before I forget. This is work that was started in '92. Remember, the work that identified the impact of night temperatures started in 1963. The Sub 1 work started in 1978. So, we're talking long-term programs here. You don't have quick fixes to big problems.

Anyway, they started to look at these, and they came up with all kinds of great tools, and great science, and came up with tools that they thought were available for farmers, and the problem was, that it was great stuff for scientists, but no farmer ever adopted any of it. It was just too complicated for them (**Figure 12**).

So what they've done is, they recognized that, while farmers don't necessarily like to flip through books, and can't access the Internet, almost all of them had cell phones now. And basically, they connected some very, very sophisticated backroom software to cell phone apps, where farmers can actually work with an ag agent, and answer very few, a dozen or so questions about their fields, and get a specific fertilizer recommendation for their particular field. It sounds too good to be true, but it's working actually very, very well (**Figure 13**).

And we're actually rolling out apps based on html-5 that will work on any platform, and this is going out. It's already rolled out in the Philippines. It's in the last stages in Indonesia. I was with the Secretary of Agriculture in India; he wants a big effort to try this out in India, to see if we can get site-specific nutrient management in India.

So, again, translating many years of research into ways that they can be used by farmers. And we're developing country-specific, and really, region-specific applications of this across the region, and even in West Africa.

But to me what's really exciting about this cell-phone technology, or smart-phone technology, is, I think it is a transformational technology, in that it can replace the defunct extension systems that we see across the world. The extension systems were built in the 1950s and '60s; they were great at the time. They're almost without exception in very bad condition now.

What I see is the development of an ag service industry in the private sector, with small entrepreneurs; and they will be able to build business models on this. And we've got a lot of interest in access, not just to a fertilizer recommendation, but to credit, access to credit linked to a fertilizer recommendation; access to crop insurance. I think the world is the oyster of innovators who want to create new business opportunities for themselves, and opportunities for farmers. So, I'm pretty excited about this.

And I was inspired by how a farmer can better apply fertilizer to his or her crop, but it's growing organically to answer a whole other, much broader array of issues.

Now, just a word, to let you know: In a knee-jerk response to the food crisis we had a few years ago, there's been a lot of pressure by governments to increase rice production. And it's almost a panic. And so that pressure has transformed into, instead of growing one crop a year, grow two; instead of growing two, grow three; add more fertilizer, spray pesticides, get as much as you can out of the field. And we're actually finding what we would have predicted: it's actually causing severe disruption in the fields.

So, we can't just go whole hog-wild, and get the highest yield we can, because we disrupt the ecological balance in the rice paddy. I could talk for an hour about that, but I just wanted to let you know that we're not blindly thinking about yield. We know that it has to be done in a sustainable way.

And after forever ignoring rice production, the private sector is starting to pay attention. And we've been working with some companies to develop standards of best practices. We know that they're taking a commercial interest in rice; that's something completely outside our control. But if the big guys are going to move into it, at least there should be some standards by which their participation can hold them accountable.

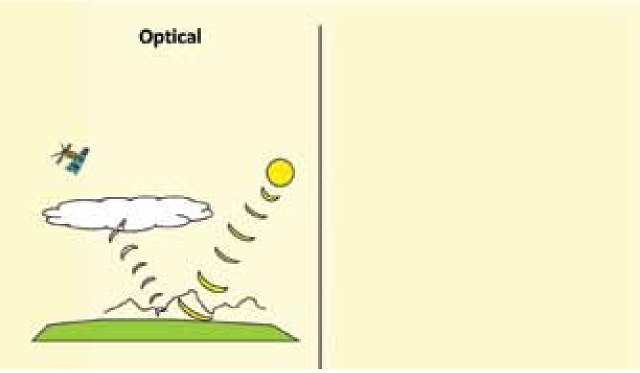
And so we're working to develop, with UNEP [United Nations Environment Program], a set of best practices, and then develop some kind of program—it's still very unclear—where, as multinationals and regional companies enter in more aggressively into the rice business, they actually have some standards that they can try to enforce.

Policy Questions: Global Rice Supplies

Now, when we think about global rice supplies, which I think about a lot, it's a big policy question. What do policymakers need to know? And when do they need to know it? And we need a lot of real-time information, if we can get it. But we don't. What we have today are data that are two years old, and it's very difficult to make immediate policy decisions. In particular, we need to know, what is the area we expect to harvest this year? And when will it be harvested? When was it planted? What do we expect the yield to be? Do we have any estimates of that?

And we're working on remote-sensing tools that are allowing us to ask some very, very interesting questions, and get some more interesting answers. And up until recently, we've been dependent upon optical satellite imagery, where you're depending on reflected sunlight, and if it's cloudy, you don't see anything. Remember, rice is grown in a monsoonal environment, and it's cloudy most of the time, so you're not seeing anything. So it's very difficult to get remotely sensed imagery (**Figure 14**).

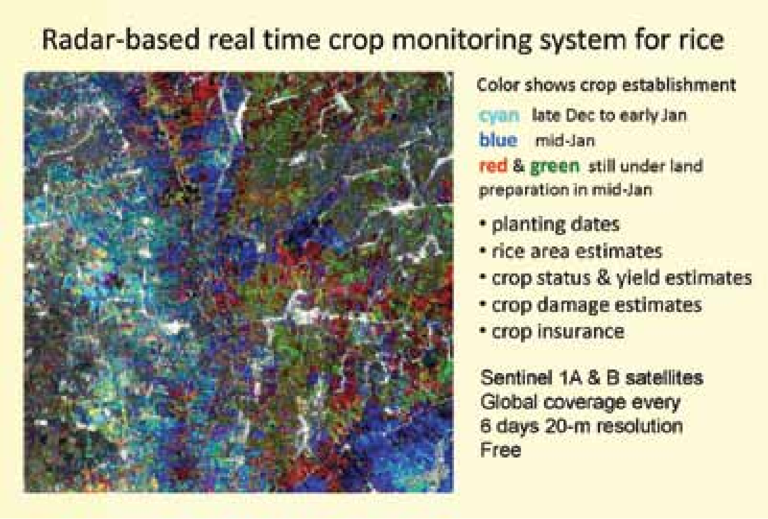
FIGURE 14



Courtesy of Robert S. Zeigler

But what has come on the market now, that's affordable, are radar satellites, or microwave. Basically, they're cloud penetrating; it's like the cloud isn't there. It bounces back. You get a signal from the Earth, and by the very nature of rice, and the differences between bare earth and vegetation and water, through radar imagery, you can map out very accurately where rice is growing. And we're rolling that out in the Philippines, and this is what our radar maps look like (**Figure 15**). Each of those little tiny pixels is a rice field, and we're down to about a 20-meter resolution, which is much smaller than any rice field, and the colors are different

FIGURE 15



Radar-based real time crop monitoring system for rice

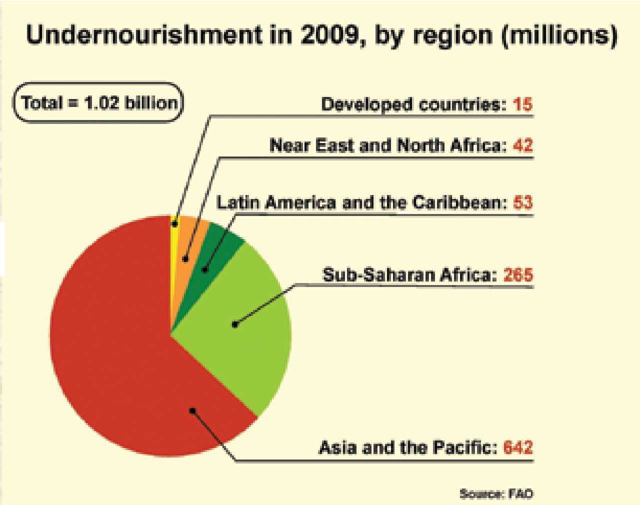
Color shows crop establishment
cyan late Dec to early Jan
blue mid-Jan
red & green still under land preparation in mid-Jan

- planting dates
- rice area estimates
- crop status & yield estimates
- crop damage estimates
- crop insurance

Sentinel 1A & B satellites
Global coverage every
6 days 20-m resolution
Free

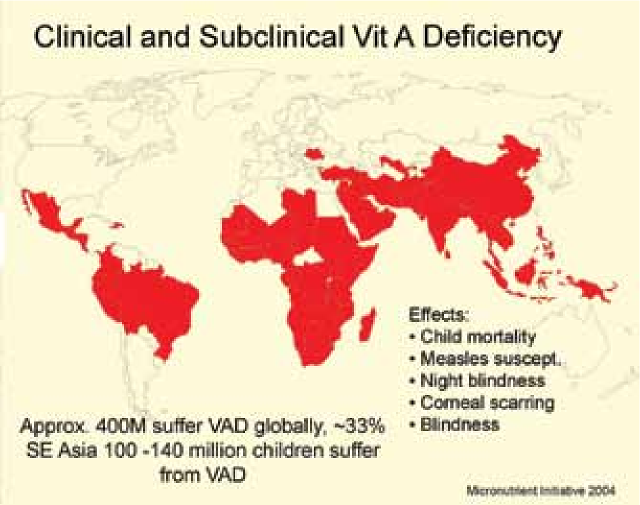
Courtesy of Robert S. Zeigler

FIGURE 16



Courtesy of Robert S. Zeigler

FIGURE 17



Courtesy of Robert S. Zeigler

dates of planting. And we know that when you plant at different dates, because of day length and sunlight, and all the other things that we've known about for years, you've got a pretty good idea of what the yield's going to be.

We're working with a Swiss company, a bunch of geeks in Switzerland, to work out the algorithms that translate this incredible volume of satellite information, and the European Space Agency has launched two satellites, Sentinel 1A and 1B. 1A is radar imagery, and the imagery is going to be completely free, and we're going to get coverage of the Earth every six days at that very fine resolution. So, we're going to have a very dynamic picture of what rice production is like in the world, and that is going to be an incredibly useful tool.

That will feed into a global rice information system that we're developing, that will allow us to get a very big picture of what's happening with our global food supply. And it's going to feed into policymakers, but obviously, people who trade rice, etc., will use that information. We talk to our Indian and Chinese colleagues, for whom these data, rice area, etc., are state secrets, and they sit there scratching their heads about what does this mean, as this information comes on line and becomes available.

Nutrition: Golden Rice

Now, just a quick word about two big areas that I want to make a point about. One is nutrition, and the other is really pie-in-the-sky stuff.

Undernourishment is obviously a horrible problem that I talked about earlier, a consequence of poverty. Asia and the Pacific—despite the headlines and pictures of Sub-Saharan Africa—Asia and the Pacific are really where the problems still are in this world (**Figure 16**).

Vitamin A deficiency is particularly bad (**Figure 17**). In Southeast Asia alone, anywhere from 100 to almost 150 million children suffer each year from vitamin A deficiency. And the consequences of vitamin A deficiency are well known, and they are severe. Night blindness: several hundred thousand children a year go blind from vitamin A deficiency. A year later, half of those children are dead. It's a horrific problem that we've been trying to solve with supplements for decades, and it is still an enormous problem.

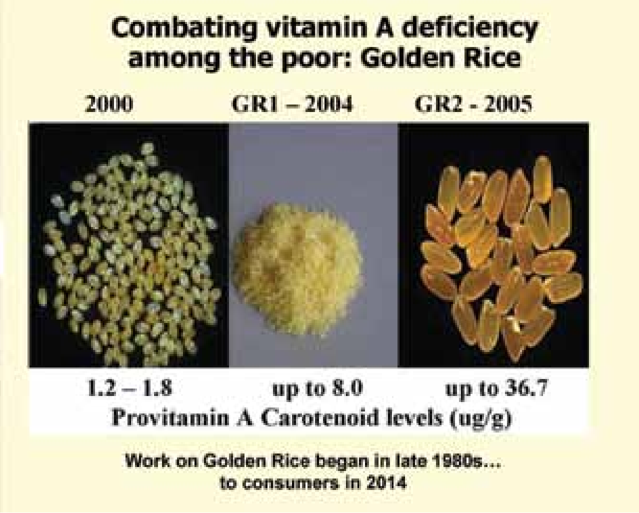
In 1986, a friend of mine suggested that if we could develop a rice that had vitamin A in it, or beta carotene, to be more precise, we could solve one of these horrible problems. Ingo Patrykus started doing this in the late 1980s, out of ETH (Swiss Federal Institute of Technology) in Switzerland, and actually did create golden rice in the late 1990s, a prototype (**Figure 18**). It was GMO transgenic; and the question was always, if you could produce the golden rice, would it produce enough vitamin A to be nutritionally significant? And Greenpeace had a field day. The original announcement was that the rice produced a very small amount of vitamin A, of beta carotene, but a small amount is a heck of a lot better than zero. And basically, it was a proof of concept.

Well, our colleagues kept plugging away to increase the levels of beta carotene, and now, we have very good levels of beta carotene in rice. A study that came out last August, published in the premier nutrition journal, the *American Journal of Clinical Nutrition*, demonstrated that the beta carotene in golden rice, was as effective as the dissolved beta carotene that is commonly distributed as supplements. And that one bowl of golden rice, normal serving size, would provide more than half the vitamin A required. So, it's an enormous, enormous demonstration.

We're working with the Bill and Melinda Gates Foundation, and the Helen Keller International, to roll out golden rice, in late 2013.

Again, remember, the idea started in 1986.

FIGURE 18


Combating vitamin A deficiency among the poor: Golden Rice

2000	GR1 – 2004	GR2 - 2005
1.2 – 1.8	up to 8.0	up to 36.7

Provitamin A Carotenoid levels (ug/g)

Work on Golden Rice began in late 1980s...
to consumers in 2014

Courtesy of Robert S. Zeigler

Improving Photosynthesis

Now, just one last pie-in-the-sky sort of thing—back to a little evolution: The grasses are all related, but they have a different kind of photosynthesis. There are crops like maize and sugar cane that have a more modern photosynthesis, which is how they capture the sunlight, and convert it to grain. Rice has a more primitive photosynthesis.

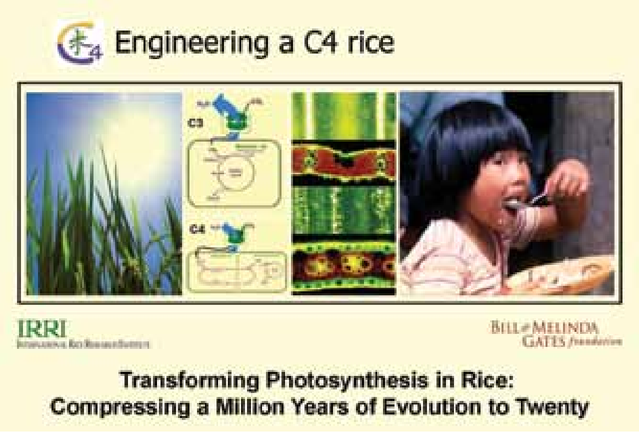
The newer, C-4 plant—which this is called in maize—for the same inputs, you can get 50% more yield, much higher fertilizer-use efficiency, much higher water-use efficiency. So, we are undertaking an effort to convert rice from a photosynthesis of a C-3 plant to a C-4, and that is a real pie-in-the-sky sort of thing (**Figures 19 and 20**).

And basically, we're trying to compress a million years of evolution into 20 years. Basically, can we direct evolution of photosynthesis in the new rice plant?

I won't go into this, but it's quite a complex undertaking; but what's very interesting, and what gives us reason for optimism, is that the trait of that different photosynthesis evolved independently over 60 times in the plant kingdom (**Figure 21**). So, it can't be that difficult. Sixty different times it evolved. It's like having different kinds of eyeballs—not just eyeballs, but entirely different kinds of vision, converging and developing, independently around, which actually has happened.

So, again—this is kind of a geeky way of saying it—but Roland Sage has said that with this kind of thing happening, it's one of the most amazing examples of convergent evolution in history. So, as I said, it can't be that difficult. We're just going to try to accelerate it a little bit.

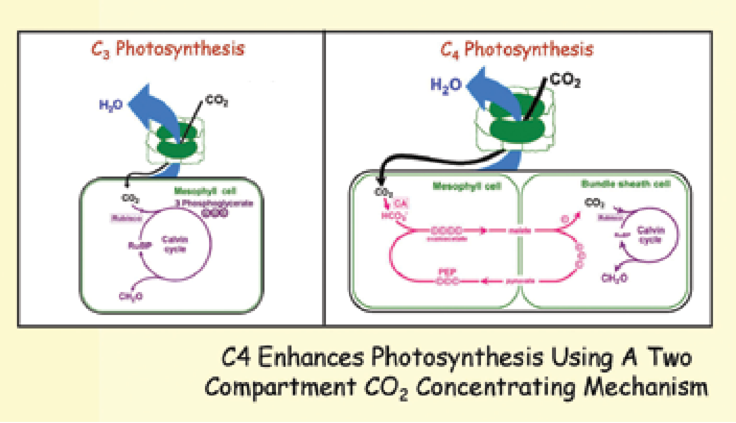
FIGURE 19


Engineering a C4 rice

Transforming Photosynthesis in Rice:
Compressing a Million Years of Evolution to Twenty

Courtesy of Robert S. Zeigler

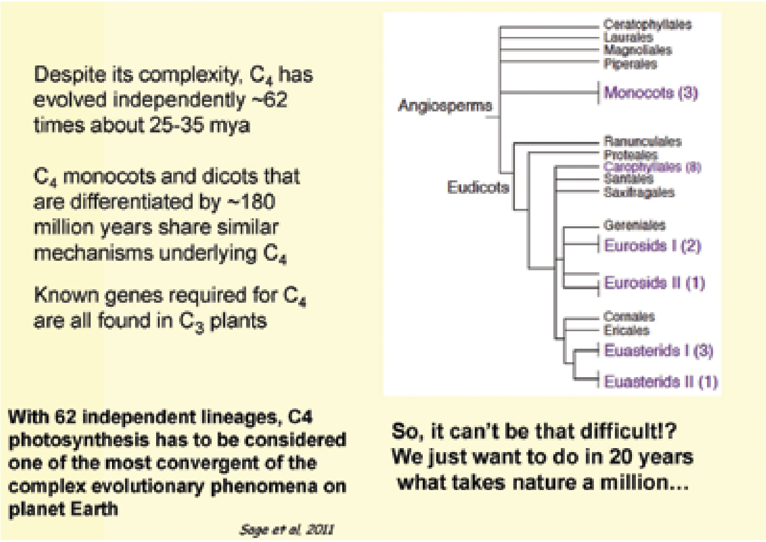
FIGURE 20



C4 Enhances Photosynthesis Using A Two Compartment CO_2 Concentrating Mechanism

Courtesy of Robert S. Zeigler

FIGURE 21



Despite its complexity, C_4 has evolved independently ~62 times about 25-35 mya

C_4 monocots and dicots that are differentiated by ~180 million years share similar mechanisms underlying C_4

Known genes required for C_4 are all found in C_3 plants

With 62 independent lineages, C4 photosynthesis has to be considered one of the most convergent of the complex evolutionary phenomena on planet Earth

Sage et al. 2011

So, it can't be that difficult!? We just want to do in 20 years what takes nature a million...

Courtesy of Robert S. Zeigler

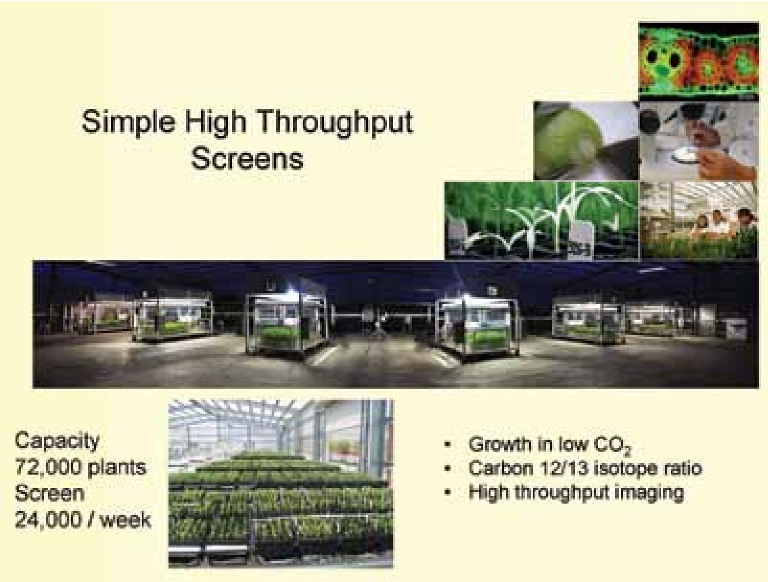
And we know that all the pieces, all the parts, are in rice and its relatives already; we just have to put them together to get them to work in the right way. It's some pretty neat stuff, and I won't go into it, but we've had to build some entirely new kinds of equipment to do this (**Figure 22**).

But the best part is, we've brought together the finest minds in photosynthesis around the world. We were able to convene the people. These guys were awash in money. They've got so much NSF [National Science Foundation] or equivalent money, they don't need to work on this project, but the opportunity to see their best science transform agriculture is really exciting to them, and it's great actually meeting at IRRI with this group (**Figure 23**).

So, just to summarize: Pretty obvious. We've got a lot of work to do. We have to address all the problems that climate change is throwing at us, plus our overall problems. History gives me a reason for optimism. I think that if we make the right investments, we can actually solve a lot of these problems, but it's got to be done by a next generation of rice scientists. Old guys like me are not going to do it. And we need a good link between, I think, science and policymakers, so that policymakers see that science is a worthy investment.

And we really need to excite the next generation of scientists, that agricultural plant science research, agricultural research, is cutting edge research. You don't need to go into finance. You don't need to go into biomedical pharma; you can actually have a tremendous career and gratifying life in agricultural science. So, with that—I went on probably longer than I should have—but I just wanted to share some of the exciting work that's happening. It's a great time to be involved in research.

FIGURE 22



Simple High Throughput Screens

Capacity
72,000 plants
Screen
24,000 / week

- Growth in low CO_2
- Carbon 12/13 isotope ratio
- High throughput imaging

Courtesy of Robert S. Zeigler

FIGURE 23

Courtesy of Robert S. Zeigler