Genetic Approaches to Crop Adaptation

Panel Discussion and Q&A

Moderator: Brian Fowler
University of Saskatchewan
Saskatoon, Saskatchewan

Panelists:

Brian Rossnagel
University of Saskatchewan
Saskatoon, Saskatchewan

Wilf Keller
Genome Prairie
Saskatoon, Saskatchewan

John Clarke
University of Saskatchewan
Saskatoon, Saskatchewan

Brian Rossnagel: I enjoyed all three presentations. They were well done, concise and to the point. This session is really about applying plant physiological changes in plant breeding. And plant breeders, one way or the other, have done that. One of the criticisms that I often have of some of the things that we heard about this morning is that almost every plant breeder has as a main objective achieving higher yield. And young plant breeders are often reasonably successful fairly quickly, if a decent array of germplasm is available. But, you quickly find out that you actually bred for late maturity in tall, weak-strawed plants. It depends on your environment. If you are in central United States where the growing season is essentially limitless in relative terms, that's not such a big problem. But if you are here in western Canada, or in other northern climates particularly, this can be a problem. We need to keep in mind—a good point made by Michael Metzlaff—that when you change one thing you *always* cause a cascading affect and change all kinds of other things. And usually as a young plant breeder you are really keen and you take all kinds of data, you collect all kinds of information and you do make progress. But, if you push too hard, say on one of the yield components, you may achieve that gain but you may lose in something that counts elsewhere. You also have to remember that yield is not the only criterion for a plant-breeding program. It depends on the end-product usage. For example, by significantly increasing grain size you will get that higher yield for the producer but it may no longer be suitable for his market because the particular shape of grain or its constituents may no longer be to the end-user's liking. So we have to remember that.

I recall, about 20 years ago, sitting on a panel in a lecture hall and being told by a similar group of individuals that the plant breeders in the room would not be needed within 5 years. And some of us took that as a bit of a slight. This is one large community and we need to work together. Traditional plant breeding can and will play a major significant role in delivering technologies through germplasm. Regarding Tim Sutton's work at Adelaide: the boron story is a classic in our community. It was one of the first demonstrations of the use of what I call juvenile, simple, marker-assisted selection, because that major gene is pretty simple to deal with. I would also point out that the first boron-tolerant varieties in Australia were released without anything that we would call modern biotechnology. They came from simple, plain old plant breeding started by the barley breeder back in the 1970s and early '80s. It's a great system and now, in barley at least, almost every breeding system I am aware of uses some form of molecular-marker-assisted selection. And it's all about making what we at the end of the process do more efficient in being able to utilize the germplasm we have refined.

On the drought side of things, one aspect that I found really interesting this morning is that not one of these speakers, all of whom are scientists, made any suggestion about growing plants without water. On the other hand, various persons at various levels of industry and in academia allow the media to mislead the public, in my opinion, by giving the impression that we'll somehow—through the magic of transgenics—be able to grow plants without water. I've been patiently waiting for someone to tell me that we are going to grow plants without light. This is of great concern to me because it does mislead producers and, more importantly, it misleads the people who fund research.

What the speakers talked about on drought I would refer to as "protection." If under drought conditions plants are beginning to die, if a plant can survive for a few more days and precipitation does come, that can save your crop. We see that here in Saskatchewan consistently, with barley and wheat. Barley is notorious for being a crop that, under drought stress and/or heat stress—usually drought here along with a little bit of heat—that says, "Oh the hell with this," moves to reproduction, and bang, it's done. In comparison, wheat will hang in there and fight a lot longer, probably another week, and if rain comes, an inch at the end of that week, it will yield well. However, it then is later maturing and in our environment that's a serious limitation. That's one of the things that Malcolm's company has recognized. We need to be aware of where a technology will work and where the environment will allow its expression to have a positive effect and not just sort of equal. A positive aspect is that few of the traits being looked at show negative affects in the absence of stress. It's like dealing with a bonus and selling that to farmers isn't always easy. We have all kinds of varieties that are resistant to diseases, but many farmers will take the chance of using an older, less-expensive variety because disease may not be a big problem that particular year. They may live to rue that when the disease shows up, but in a year like this in Saskatchewan disease is not a big problem. We won't have enough moisture here to have much disease.

The other thing that I want to caution people on with regard to drought and salinity is that salinity is largely salt-induced drought stress. Michael had a slide with some expression patterns, and the drought and salinity clearly had a huge amount of co-linearity, which is not surprising because the salinity effect is largely drought. But developing a barley line that will handle drought better for Australian farmers is not at all the same as developing a barley line for Saskatchewan farmers, because of differences in the growing environments. The barley in most of Australia is planted around the same time as ours is and about the time we are pushing combines through the field their material is flowering and setting seed having sat through a long period of time when it's at risk from drought and it's important that it can hang in there until it rains. However, at the end of the day, these plants may or may not be more water-use efficient. That's the real key. The material that Michael and Malcolm were talking about on the biomass side—I see that as very interesting because that may be the better use of the same amounts of nutrients, water, and obviously energy from the sun and so on to give us actually more biomass, which we can then use for the purposes that Malcolm talked about. I would suggest that where plant breeders have been most successful in grain crops, is in changing harvest index of the existing biomass. If you look at total biomass yields of most of our grain crops, they haven't changed a whole lot. We have just altered the amount we are getting off the field as grain. Despite what Malcolm said about their direction—addressing the energy end of things—I think there may be possibilities in looking at germplasm that has higher biomass—initially with lousy seed yields. Perhaps a good plant-breeding effort could move some of that into higher grain yields. If that happens, it must be due to more-efficient use of the various inputs.

The key is to think of these things as protectants. It's a matter of having plants that are more able to tolerate these various stresses, whatever they might be, and then be able to respond *if* things work out well. I like the Bayer approach in trying to reduce wasteful photorespiration. I think that C4 rice is a bit of a stretch. If you do make a C4 rice plant then it's not going to be rice anymore, and it will have the problems of growing C4 plants in C3 plant environments, and so on. But tinkering with and adjusting the wasteful photorespiration process is something that has always struck me, as a plant scientist, as something very useful to consider if you have some relatively simply inherited genetic material that can alter that and it doesn't do a whole bunch of other nasty stuff.

These things are about making plant breeding more efficient so we get things done faster. On the other hand, in terms of plant breeding, is it that critical that we do it faster? In a medical emergency with somebody dying, it's important to be fast. But as a barley or oat breeder at the University of Saskatchewan, if we produce a better variety in a slightly shorter period of time, it's probably not going to make that big a difference globally or even to local producers. The key is that we need to produce new varieties on a routine basis and keep making those improvements.

Wilf Keller: Like Brian, I found these presentations excellent. We saw some good examples from all of the speakers on the subject of gene discovery and taking forward these products, prototype plants, validation, and the implications are that these can certainly be moved into plant-breeding programs and many are already in that system. There's no question that rapid progress has been made over the last decade. I like the point made by Dr. Metzlaff on plant breeding being redefined, and I think we are going to see an acceleration of the discovery end of this whole area of plant biology. DNA sequencing was mentioned and, in fact, the cost of DNA sequencing is going down so quickly and the ability to sequence cheaply and sequence effectively in centers like Saskatoon, for example, is a reality. We can expect complete genome sequencing to become a standard protocol even for public plant breeders. How we will use all this information, I will come back to.

There are other supporting technologies. Metabolomics was mentioned. Is it possible to have biomarkers as well as gene markers for given traits? There are many new and evolving tools. Some that were not mentioned are available to breeding groups and crop improvement groups include laser-capture microscopy and high-definition transcriptomics. I'll cite the example of the Plant Biotech Institute here in Saskatoon, where early-stage embryos are excised and gene expression assessed. This has allowed investigators to identify transcription factors that affect traits such as seed size, which have been relatively difficult to work with. These are at an early stage, but I think we are, indeed, going to see a redefinition of plant breeding.

Integrating all of this new information will be a challenge. I prefer to view it not as genomics and biotech silos and the traditional plant breeding silos. This is all about modern plant breeding research and taking it through to commercialization. That integration will be critical. Twenty years ago during the biotech debate, through naiveté many of the biotech people said that the trend would to test-tube plant breeding, dispensing with traditional breeders. They felt that they could have done more with the money we were spending. We need to have integration and communication. This not about technologies that replace each other, but about plant-breeding research and we don't want to make the same error in the genomics era as in the biotech era of the 1980s. There is a tremendous opportunity to move forward in a concerted, open innovation pipeline that has plant breeding at the commercial outlet. And this will not be public versus private, but discovery research linking more effectively to commercialization and developmental research. But I have one concern at least from the overall Canadian perspective. Decisions have been made in Canada to downsize breeding programs, particularly public breeding programs. Many plant breeders have retired or are thinking about retirement and I am concerned that we may not be able to capture the value of these genomic technologies without breeders. There needs to be a public-policy re-examination about plant breeding and how significant it is, otherwise we are going to see constraints in the innovation pipeline for new varieties.

My third observation is around the broader issues, and transgenics have been mentioned. Indeed we saw examples in the work from Australia, Germany and Performance Plants showing that transgenic plants in the field have potential to make contributions. There are lots of issues around that. It's a subject for a whole conference. But we need to re-examine this in some of our key crops, particularly our small grains—wheat, barley, oats, pulse crops—that are grown here in the prairies. Are we going to ignore the use of transgenics or are we going to move forward and actually adopt them? I know that this debate has been ongoing, but I think it's time for a serious societal reexamination. A study from North Dakota State University has shown that, over the past 15 years and particularly the last 5 years, corn and soybean acreage have continually moved north and west right to the Canadian border, implying that this correlates directly with the development and application of new genetic technologies in corn and soybean. We need these in all the crops, not just corn, soybean and canola. If we want to have a diverse system of crop production and, speaking from the Canadian perspective, if we want to be competitive at the international level—because we do market high-quality products and we need to continue to be competitive—we must adopt these technologies, integrate them and, of course, market them.

John Clarke: I also enjoyed the presentations and seeing the advances in knowledge and the integrated approach to this research that is making rapid progress. Now, as a wheat breeder, I've been excited by the potential for marker-assisted selection for probably 20 years, and I think it's now coming to the point at which we are actually applying marker-assisted selection particularly for simply inherited traits that would otherwise be difficult and expensive to measure. For example, we are making rapid progress in durum wheat with low cadmium-accumulating varieties. But not all crops receive similar investments in biotechnology and supporting research. Although wheat is grown worldwide, the research is very much in the public domain, relying on the whims of politicians and we seem to be unwilling to make the necessary investments required for crop improvement.

Following up on some of the comments that Brian and Wilf made, the integration of these research efforts is extremely important and, as scientists, we've recognized that for a long time. Certainly recent advances reflect the importance that we have placed on integration. However, at the political and science-management levels, there is a tendency to seize upon the more attractive or "sexy" aspects of research, therefore, the integrative approach isn't necessarily funded as well as it should be. This translates not only into the actual practical research, but also to the training of graduate students and right now we have a real deficit in terms of new plant breeders. The low numbers of graduate students coming into universities and agricultural colleges who are interested in pursuing plant breeding are shocking. As we try to replace retiring plant breeders in Agriculture Canada and other agencies in Canada, we just can't find qualified people to step into these important positions. So we have to keep in mind that training and emphasis of research dollars to support these activities is very important.

The pace of change is becoming very rapid, due to advances in DNA-sequencing technologies and we are at the point where we can sequence or map populations very quickly. Tim Sutton showed that significant effort is needed to develop the necessary phenotypic information to make practical use of that information. I can't imagine screening 5,000 RILs[1] over the number of environments that that group has managed to do, and, again, this comes back to how funding is applied. The phenotyping aspects have been seen as less important in the process up until now, therefore we don't have a lot of phenotypic information that can be used to take advantage of the sequence information that we can now generate.

[1]Recombinant inbred lines

Brian Fowler: We are going to open up for questions for the panelists and also the speakers. I have one quick querie while people are thinking about how they are going to phrase their questions. In all developmental programs, you need leadership and traditionally in variety development plant breeders have been providing the leadership. In this new integrated system, who should take on the leadership? The biotechnologist or the plant breeders? What kinds of change should we be making? I think that's very important because, if you don't have leadership, you are not going to have any direction. Anybody want to take a crack at that?

Malcolm Devine: I work in a small organization where we have everything from basic gene discovery at the front end through to validation in the crop. We are not a seed company. Neither are we a plant-breeding company. We don't introgress our traits into finished varieties or hybrids. Unless you are a basic gene-discovery scientist funded to do that kind of work, it is essential to have what you might call a product concept. What do you want to come out of this at the end, to be introduced? Certainly if you are in a commercial organization that is what you think about, and many of the breeders I know working in the public sector are thinking about commercialization: what traits do farmers need and what new traits and new varieties will farmers pick up on to help their productivity, profitability, *etc*. It's important that there be a clear product concept. In my experience, someone at the back end of the process—the plant breeder or agronomist—ultimately should call the shots about what goes forward and what doesn't. All research companies comprise people with strong wills. You have sales people who want to sell hybrid canola in the field. You have plant breeders who want to develop the best germplasm possible. But, at the front end, you have scientists who want to develop new technology and push it. And there's always this struggle between technology push and pull. Having the push from the scientists bringing new material and new ideas in is good because it can, if they are successful, invigorate and add substantially to breeding programs. But ultimately, if you must pick someone to be in charge—and I think it is helpful to have one person or group in charge—it should be those who are responsible for developing finished varieties.

Michael Metzlaff: I agree with Malcolm. It has to be the breeder. But, even as a molecular biologist I would call myself a breeder. We have new tools that we can give breeders. What we may need in the future is a new—how shall I say, I have to be cautious—a new type of breeder who has a lot of knowledge in molecular biology as well understanding of what is going on in the laboratory. Breeders and molecular biologists speak different languages and often don't understand each other. We have to change that to be successful. But the leader has to be the one who knows what the farmer needs, what the product should be, and we can help with the enormously useful tools of new technology.

Tim Sutton: In Australia we have been reasonably successful in promoting and building a team of the new type of breeders, to use that term. Most of the young breeders coming through now are well trained in molecular biology. They have skills in classical plant breeding and know a lot about molecular biology too. They will achieve technology integration. Our system for funding applied research is very much driven by breeders and farmers. If you are a farmer in Australia and you grow a grain crop you pay a compulsory levy on the farm-gate value that goes into a fund that's distrubuted to research organizations to work on problems that are relevant to cropping, and farmers have a big say in that. Breeders are involved in the discussions with farmers that decide where that research investment goes. The breeders definitely should drive a lot of what the molecular biologists work on.

Metzlaff: I forgot to mention that molecular biologists have to know breeding, and that is missing. When I studied plant genetics in the 1970s, it included a lot of breeding and I still gain from that. I still know what breeding is. But then, since the 1980s and '90s the new type of plant molecular biologist doesn't know a lot about breeding. So, to be fair, it has to come from both sides, otherwise it will never work.

Keller: Having a targeted program, led by a benign breeder, is acceptable. But, bear in mind that there has to be a discovery element, that creativity, to keep injecting new ideas. They may not fit the target that the breeder has at a given point in time, but certainly the team leader must include discovery research. Otherwise we are going to be in a mess 25 years down the road. Certainly you need to have that teamwork, but here in Canada our breeders are overloaded. I don't think they have the time to provide that leadership because they are running too many programs. We haven't strengthened the breeding programs to the extent that they require. That's an issue as far as I'm concerned.

Fowler: Do either of the plant breeders want to make a comment or do you want to quit while you are ahead?

Rossnagel: We haven't had a lot of experience in this part of the world with private breeding programs until the last two decades with canola, but most of the successful breeding programs have involved teams. As someone said, breeders seem to get the recognition because they are the ones who release the varieties that everybody gets excited about and makes money on. But, in any team, you need leadership and benign leadership is sometimes useful and sometimes less benign is useful. A key issue is understanding the differences between growing a plant and growing a crop. People who just grow plants in pots often don't appreciate how different it is growing a whole group of plants. I would agree with Tim that our Australian friends have done a pretty good job of training plant breeders who have dual experience. We have been trying to do that in our institution as have the University of Manitoba, Guelph and others. But, the fact is, many of those new breeders are very good on the molecular side, whereas traditional plant breeders who have been around for a while see slippage in understanding field and farm aspects. We now have graduates who have excellent training in molecular genetics, although sometimes I wonder how much they understand of Mendelian genetics, which is the key. So you end up with folks who handle *Arabidopsis* real well, but don't appreciate it when somebody says, "Yeah, but that doesn't really matter when you get to the field."

Darby Harris (University of Kentucky): Tim, did you screen for the *Bot* mutation in a high-boron system?

Sutton: Right. The *Bot1* gene that provides tolerance to high levels of boron comes from the land race 'Sahara' and it's a naturally occurring tolerance mechanism. That's an important point, especially when you think about application to breeding. We screened about 7,000 plants. It's basically a process of elimination where you have a large marker interval and you saturate that with markers and you eventually walk your way in using a technique called progeny testing, which tells you the direction of the tolerance locus from a certain recombination point. And you end up walking into an interval that corresponds to the maximum amount of recombination you can get from the size of your population.

Harris: Okay, and there may be a number of genes in there, but then you look at candidates?

Sutton: Right. Then you can use either of two approaches. You can then look at the syntenous region in rice, which is where rice really comes in handy and you can ask the question, "What genes are located in that syntenic interval in rice?" If your interval is small there may be three. If it is large there may be 500. Are any of those good candidates? In the case of the *Bot1* story, the gene is not located in a syntenic position in rice, so the neighboring genes in that interval in rice are present in barley, but there is nothing that correlates with our *Bot1* gene. So, we ended up cloning *Bot1* using a forward genetics approach combined with candidate gene-reverse genetics.

Harris: Okay. I may not have gotten this right. Once you determined which gene and then you sequenced it, you noticed a couple of different nucleotide variations, one in the transmembrane and one mutation in the cytosolic. But that wasn't really what was giving Sahara its boron tolerance—.

Sutton: It's really two fold. There are nucleotide differences between the Clipper and Sahara alleles, and we have shown that they affect the ability of the protein to transport boron, at least in a model system like yeast. But then there is the other side—the gene is also much more highly expressed in the tolerant genotypes. So there's polymorphism and there are differences in expression that overall translate to the tolerance that you see in Sahara.

Harris: Malcolm Devine, I'm interested in the allele for increased biomass. You showed a nice video where not only was the *Arabadopsis* inflorescence meristem delayed in coming out, it seemed to me like it might be a delayed flowering that led the *Arabidopsis* to stay in the vegetative state. Because I'm in a cell-wall lab, I've come across this and tried to note the mutations that cause that. I know that the FLC[2] locus was one of the originals. In a few other cases, transgenes have increased biomass. Are you at liberty to say whether you generated that via a transgene or a mutation?

---

[2]Flowering locus C.

Devine: Yes, it's a transgene, but I cannot be very specific in my answer. You mentioned FLCs, so you know the network of flowering loci, *etc*. This gene is associated with them and our assumption is that it plays a role in that same pathway. And, you are right, it governs the transition from vegetative to flowering with over-expression of the gene in this case. Of the different examples I showed, by the way, some were down-regulated, some were knockouts, some were over-expression. I didn't identify them as I went through the talk, and perhaps I should have, but, in this case, it is an over-expression of one of those regulatory genes. It's a down-regulator in that network of genes, a transcription factor, and by over-expressing it you delay the transition.

Dan Pennock (University of Saskatchewan): My question has to do with the higher incidence of extreme events, drought, precipitation, flooding. Some of the issues we heard are present at the start of the growing season like salinity or boron, whereas drought or heat or flooding are events that cannot be predicted over the long term. Brian raised the point that we are developing products that will require premium pricing, to provide protection in situations that farmers don't know with certainty will occur, but will probably increase in frequency with climate change. Is there a reason to believe that farmers will pay a premium price for something geared to one specific issue, like drought or heat, when, in fact, there could be a gamut of climate-induced changes that may affect crop production?

Devine: If it's a single extreme, almost catastrophic, event, you can put all the genes in the world into that plant and it won't help. If you have no rain for 18 months, I don't think you can grow a crop. You can't get something out of nothing. You are right in what you are alluding to, and Brian's comments earlier were correct. There are no miracle genes. All genes have small, incremental effects. It will be hard to protect plants against massive climatic or weather events. Maybe provision of flooding tolerance will be possible, and some interesting work is in progress on that. About 6 or 7 years ago, when I was still working for Bayer in Belgium on the stress program that Michael talked about, we were talking one day about the competition in this area. The usual suspects came up—Monsanto, Pioneer, *etc*.—and someone based in the United States said, "Crop insurance." He was absolutely right. Crop insurance is the competition. A farmer may pay more for a better variety from Bayer or someone else or take out a better crop-insurance policy. That was a reality check. It made us think what the value of the trait is because now we had something to compare it to. If you are introducing something completely new into the market place, you don't know where it should be priced. Was the first IPod worth $1,000 or $50? If there is something you can benchmark against, then you can estimate your price range and work back to see if it is actually worthwhile. That Bayer and others are still working on this suggests that they have done the business calculations and it is worthwhile. But, they are looking at traits on a crop-by-crop basis. Bayer, Monsanto and the others specialize in a few major crops. They're not going to put a drought trait into all crops. They will put it into those in which it will have most value, which correlates with most benefit to farmers. It may not be marketed in all regions. Cotton is grown in some rain-fed regions and some dry regions. From the contact I have with seed companies, they are looking for traits that will increase average yields over time. For example, a new trait in corn marketed in the Midwest might have an average yield benefit of 5%, recognizing that in some years it will be zero, in some years it will be 2% and hardly measurable, and in some years it might be 10%. A marketing package will be developed to show farmers that, although they won't need this every year, over time it will benefit them.

Fowler: I'd like to bring Brian and John into this discussion because they have very practical experience with catastrophic events on a regular basis. One I can think of is early fall frost, and as plant breeders you are dealing with the question of maturity all the time. Brian, you have developed early maturity varieties. What's your opinion on the tack that would be used or the reaction of farmers to these things"

Rossnagel: Steve Shirtliff is an agronomist in our department, and he and I work together on the oat program. He is doing a lot of innovative things on oat, which is one of those lost-in-the-hinterlands crops. Few work on it. Herbicide companies don't even try to develop herbicides that will work on it. One of our major issues is wild oats as a weed and Steve has done a lot of work on that. We go out to farmers' meetings and one of the question that often comes to him is, "You've talked about how to manage my 100 bushel to-the-acre oat crop, and that's good, but lots of times I get 60 bushels." and Steve's response, and it's the most correct I've ever heard, is, "That's what crop insurance is for." Because at those sorts of yield levels in today's agricultural system in Saskatchewan, and western Canada in general, there is nothing you can do management-wise. Perhaps irrigation would solve it because it's almost always drought that creates that problem.

As Brian indicated, we've released some extremely early-maturing barley varieties that can be planted very late. We released those for situations like this year's; farmers who spent a fortune trying to grow canola have already lost it, and then last weekend we got an inch and a half of rain so they could actually replant. However, if they plant canola, they are going to spend a lot of money again and the probabilities of harvesting a good-quality crop and getting a good price are low because of the maturity issue. These barley varieties are cheap to plant and can produce decent yields within that narrow window. We had absolutely zero uptake of those varieties by farmers because, when they go to plant in May at the normal time, they don't expect to need them. There was no incentive in the seed-production business to produce that seed because most of the time they won't sell it. I've had phone calls in the last couple of weeks requesting those particular varieties and my answer to them is, "It doesn't exist because you didn't buy it before."

Bruce McPheron (Pennsylvania State University): Those of us in the US land-grant system, directors of research and experiment-station directors, meet annually and a perennial topic on our agenda is whether we can continue to afford investing in the facilities that preserve our plant-genetic resources. Part of the money for that support comes out of our budgets, and it perennially becomes a discussion of the pipeline for plant scientists and for plant breeding in general. And so, I would turn to a broader question: "Is it possible that climate change provides the imperative for a reinvestment in the plant sciences and in plant breeding efforts in particular?" I'm struggling with this because, clearly, the traits we have been focusing on don't seem to be sufficient to capture the attention of decision-makers and funders in providing that investment, particularly in the public sector. The private sector has found an excellent business model with selected crops, but we've all agreed that there aren't enough crops included in the portfolio. Then again maybe we will be asking this question again next year when we are at Davis and the topic is diet, nutrition and health. Will that be the imperative that will lead to an expansion of investment in the plant sciences? Perhaps that's rhetorical at this point, but is it something we should come back to as an overarching consideration? Is there something about the drama of response to this issue that we can seize upon to guide investment?

Fowler: Is there a response to those comments? It was mentioned to be rhetorical but certainly important.

Metzlaff: I'm an optimist. I think things are changing already. When I gave talks in the past on transgenic traits—herbicide tolerance, *Bt*, *etc*.—laymen in the audience saw little need for them. But, now when I speak about drought tolerance and yield, things like that, people are much more attentive. We can bring things forward only if need is perceived in the population. Everybody sees that climate change is occurring. Everyone who has a garden sees that summers are hotter. People are starting to listen and think, "Yes. This is something that we may need in the future." But maybe that's the optimistic view.

Devine: There is a tremendous case to be made right now for more investment in this area. Plants underpin all aspects of life on earth. You said your meeting next year was on food, health and nutrition. What's behind all of that? Plants. So, investment in plants is as important as ever. And preserving existing genetic diversity is incredibly important. And I say that as a biotech person. Without a strong base of natural genetic diversity, we have nothing.

Rossnagel: Molecular genetics provides new capabilities for evaluating germplasm collections. I have the world collection of oats sitting at the Canada Research Center right here. As an oat breeder, I have gone there only two or three times, but only as a last resort because it's so hard to figure out which is the best line to choose. We have some incredible tools now to do association mapping, and so on, that 5 years ago were impossible. The only way to do that was to grow out the 21,000 lines that we have and look at them. Sadly, we will probably find out these collections aren't as diverse as we think they are.

George Wagner (University of Kentucky): Dr. Devine, your comments about the Indonesian work that seemed to focus on night temperature remind me of the fact that my agronomy colleagues tell me that the highest corn yields are obtained on the Colorado plateau if they are irrigated, because of optimal day temperatures and the cool nights. Are we focusing on root respiration here?

Devine: I would have to go back and read the publication that I was referring to. Whether it's root respiration or above ground, I don't recall reading it. I'm sure it must be in there. It was a PNAS paper of a year or two ago.

Metzlaff: And we don't know yet in our work with photorespiration. We don't have the link to yield yet, although we see biomass increase.

Wagner: But have you expressed roots versus leaves?

Metzlaff: Not yet. We will do that.

Mark McLellan (University of Florida): I want to make a comment about the conversation regarding plant breeders and gene jockeys. I enjoyed that because it's happening every week in my organization. I know that many other schools are really struggling with this. We struggle with it at the top level, the department-chair level and we struggle with it mightily at the faculty level. As director of the experiment station, for the past year I have worked hard to build a marriage between my biotech folks and my breeders. I have about twenty breeders in my organization and going back over a couple of decades, of course, the breeders were the main show and biotechnology was coming on strong, we were building that capacity. Now as state funding is reduced and we are in the hunt for dollars, the breeders struggle mightily to bring in external grant dollars. Biotechnologists seems to grab that pretty fast, so there are dynamics there. The only counterbalance to that is royalty flow. Finally we are in a game where we have millions in royalty flow, which really are making a difference. But still, I am a food scientist by training and this reminds me of the difficulty food scientists and nutritionists have. We speak different languages. We don't even understand what each other is talking about and often we are in the same department. I find that same situation with my breeders and my geneticists. I have attempted to bring those two organizations together, and asked them to consider a marriage, and they said that they'd rather just date. They don't see eye to eye. And so, we are in the hunt for solutions. My latest attempt is to put a pile of money in the center of the table and say, "You can get to that, but only if you come hand in hand. If a gene jockey and a breeder work together then they can tap these funds." And that seems to be getting some traction. On behalf of all the universities, we are open to ideas here because I do believe the next-generation breeder has got to be someone special. Not traditional. And yet the comment was made about slippage. We *are* seeing slippage in skill sets. Again, we are open for ideas and answers.