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Drought Tolerance in Maize: An Emerging Reality

by

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Introduction to Feature Article on Drought Tolerance in Maize

ISAAA is pleased to present a special feature on the status of drought tolerance in conventional and biotech maize by Dr. Greg O. Edmeades.

The proverb "Water is the staff of life" reminds us that water is important and precious. Agriculture currently uses over 70% (86% in developing countries) of the fresh water in the world. Water tables are dropping fast in countries like China, and water supplies will continue to shrink worldwide as global population will grow from the current 6.7 billion to more than 9 billion people by 2050. Whereas people drink only 1 to 2 litres a day, the food and meat we eat in a typical day takes 2,000 to 3,000 litres to produce. Both conventional and biotechnology approaches are required to develop crops that use water more efficiently and are more tolerant to drought. Given the lack of water and its cardinal role in crop production, it follows that tolerance to drought and efficient water usage should be assigned the highest priority in developing future crops. The situation will be further exacerbated as global warming takes its toll, with weather expected to become generally drier and warmer, and as competition for water intensifies between people and crops.

Drought tolerance conferred through biotech crops is viewed as the most important trait that will be commercialized in the second decade of commercialization, 2006 to 2015, and beyond, because it is by far the single most important constraint to increased productivity for crops worldwide. Drought tolerant biotech/transgenic maize, is the most advanced of the drought tolerant crops under development, and is expected to be launched commercially in the USA in 2012 or earlier. Notably, a Private/Public sector partnership hopes to release the first biotech drought tolerant maize by 2017 in sub-Saharan Africa where the need for drought tolerance is greatest.

Given the pivotal importance of drought tolerance, ISAAA invited Dr. Greg O. Edmeades, former leader of the maize drought program at CIMMYT, to contribute a timely global overview on the status of drought tolerance in maize, in both conventional and biotech approaches, in the private and public sector, and to discuss future prospects in the near, mid and long term. The contribution by G.O. Edmeades, "Drought tolerance in maize: an emerging reality", supported by key references, is included in Brief 39 as a special feature to highlight the enormous global importance of the drought tolerance trait, which virtually no crop or farmer in the world can afford to be without; using water at current rates when the world will have to support 9 billion people or more in 2050, is simply not sustainable. In order to provide the contribution by G.O. Edmeades a broader distribution, an abridged unreferenced version is featured as a companion document to the Executive Summary of Brief 39, with more of a focus on biotech approaches than conventional, more on the activities of the private sector than the public sector, and on sub-Saharan Africa, where there is considerable work on drought underway because of the urgent humanitarian need to boost the yields of maize, which is the staple food for more than 300 million people, a significant proportion of whom is suffering from hunger and malnutrition.

Drought Tolerance in Maize: An Emerging Reality

by G.O. Edmeades

1. Drought and maize: the scope of the problem

Maize is the third most important cereal under global cultivation, after wheat and rice. Maize grain yields in the temperate developed world average 8.2 ton/ha, vs. 3.5 t/ha in tropical less developed countries. In both production environments drought is the most important abiotic stress constraining and destabilizing maize grain production, and is one of several reasons for the differences between mean production levels of temperate vs. tropical regions. In both regions water deficits occur unpredictably throughout the season. Within-field variability in soil texture and depth means that plant-available soil water also varies, and this can result in yield variation of up to 10-fold in a relatively dry year. Since farmers usually plant a single variety in any given field, this implies a need for a good level of drought tolerance in the large majority of hybrids and varieties grown under rainfed conditions.

Most of the 160 m ha of maize grown globally is rainfed, and annual yield losses to drought are thought to average around 15% of potential yield on a global basis. Transient randomly timed water deficits act as a significant limitation to yield in the US Corn Belt in 20% of years. Losses are somewhat greater in tropical countries that rely on a relatively unpredictable rainy season for crop growth, and are somewhat less in temperate areas where irrigation is more common and where rainfall is more evenly distributed throughout the season.

Production in drought-prone regions such as southern and eastern Africa or West Africa shows a strong dependence on seasonal rainfall totals. Maize is a staple food for more than 300 million people in sub-Saharan Africa, and a number of countries in these geographic regions often experience drought in the same season, creating regional food shortages that cannot easily be alleviated by cross-border trade. Production of maize in southern Africa fluctuated from 12.5 million tons in 1992 (a drought year) to 23.5 m tons in 1993. Also between 2003 and 2005 the World Food Program spent US$1.5 bn to alleviate food shortages due to drought and crop failure in sub-Saharan Africa alone. Drought-tolerant maize could play a significant part in meeting the Millennium Development Goals of “halving by 2015 the share of people suffering from extreme poverty and hunger”.

Why not simply irrigate the crop? The prospects of adding additional irrigated land on which maize will be grown are rather dim, given that irrigated land area is projected to increase at a rate roughly equal to or less than the population growth rate. Growth in irrigated area will mostly be in Asia, and most will be dedicated to higher value crops. Energy cost to pump ground water has recently doubled in some countries. Thus, additional maize production will be needed from the drought-prone “marginal” areas of both temperate and tropical countries, but especially in sub-Saharan Africa. Given the recent rise in international maize and fertilizer prices, there is mounting pressure to increase yield and yield stability in environments where there are real risks to production from drought.

Variability in rainfall (and hence in drought) seems likely to increase as the effects of climate change are more fully felt. As temperatures rise and rainfall patterns change, additional losses of maize grain may approach 10 million tons/year, currently worth almost US$5 bn. These trends can be seen already in parts of Central America where rainfall may fall by more than 50% over the next century. Drought and heat tolerant crops will play an increasingly important part in adapting to this variation and to the long term underlying trend towards a hotter and probably drier production environment. As a rough rule of thumb, it has been estimated that 25% of losses due to drought can be eliminated by genetic improvement in drought tolerance, and a further 25% by application of water-conserving agronomic practices, leaving the remaining 50% that can only be met by irrigation.

2. Biotech Product development in the private sector

A survey of published literature and of company websites was undertaken, but does not reveal the detail and extent of private sector investments in transgenic research for drought tolerance. The following is a general idea of the level of activity by a few leading companies based on their public disclosures. Drought tolerance is a complex trait, and a suitable transgenic strategy may well rely on transcription factors affecting a number of genes, or several transgenes engineered into the same construct.

Monsanto is considered to be a leader in transgenic research for drought tolerance in maize, and is scheduled to commence commercial sales of a transgenic drought tolerance product in 2012, and the trait is now in Phase III of testing. Published papers suggest that this transgene was identified from Arabidopsis and the maize homolog was then overexpressed in maize to provide a gene offering 8-22% yield improvement (average: 15%) under a drought stress that reduces yields by about 50%. More recent statements have downplayed these yield gains slightly. The level of improvement depends on the genetic background of the recipient hybrid, and it probably varies with the environment. It does not appear to reduce yields under unstressed conditions – an important requirement for a successful transgene in North America, though the vast majority of transgenes that have been tested do carry some yield drag. A recent publication by Nelson *et al.* (2007) describes the procedure which Monsanto has generally followed in gene discovery, though it seems unlikely that the gene described (At *NF-YB1*) is the commercial candidate. The lead candidate genes almost certainly affect the strength of the source (i.e. photosynthesis) rather than the sink (kernel setting, flowering). The regulatory approval process for North America, Japan and the EU is under way, and permission has been given to test this event in South Africa. Additional classes of transgenes imparting abiotic stress tolerance currently being examined by Monsanto include chaperone proteins belonging to the family of cold stress proteins, CspA and CspB. It seems likely that Monsanto's second generation of drought transgenes, already listed in their trait pipeline, will include candidates from this general class of genes. Monsanto has recently signed an agreement with BASF to further develop drought tolerant germplasm, and it appears that BASF is channelling all its drought-tolerance transgene candidates through Monsanto's seed delivery system.

Pioneer Hi-Bred has conducted an active research program on transgene-based drought tolerance. In 2003-4 Pioneer claimed to have identified an effective transgene that increased kernel setting under stress occurring at flowering, but this product line has been dropped. Pioneer is now testing a possible candidate for a 2013 release. The mode of action of this transgene is not known. Pioneer has good testing sites under managed stress in Chile and California, but no similarly developed locations in sub-Saharan Africa. It can, however, distribute improved seed effectively in that region. The company describes three stages in its release procedure for drought tolerant germplasm. Stage 1 is of carefully screened current elite hybrids showing exceptional drought tolerance (example: 33D11), with products available now. A second stage product relies on native genes selected using directed MAS, with products ready in 2-3 years; the third generation would combine conventional selection with one or more transgenes and deliver a product in 5+ years. This approach implies complementarity between conventionally selected and transgenic drought tolerance mechanisms. New breeding techniques that can shorten selection cycles and speed progress include a non-destructive analysis of DNA from a seed sliver cut by laser from the seed. Pioneer is collaborating with Evogene, an Israeli company specializing in computational genomics to identify putative drought tolerance genes.

Syngenta has a relatively smaller research effort in drought tolerance. They have recently signed a research agreement with Performance Plants Inc. for access to their yield protection technology (YPT). Their website gives no details of when a commercial product involving transgenic drought tolerance may be launched, but it will likely be after 2014. Their testing sites under managed stress are significantly less developed than those of Monsanto and Pioneer, and Syngenta has a weak seed distribution network in sub-Saharan Africa.

Other suppliers of candidate genes include BASF which has a research agreement with Monsanto. BASF purchased the Belgian company CropDesign in 2005 and this provided access to drought tolerance genes for rice. Dow has allied itself with Syngenta, and may supply variants of the yield stabilizing gene coding ADP glucose pyrophosphorylase to Syngenta for testing. Dow also has agreements with Monsanto on multi-gene transformation technology (up to 8 transgenes at a time). Bayer is researching genes that reduce the drought-induced oxidant load that leads to tissue damage (e.g., PARP). It is unclear how this product will be marketed commercially. In general all three companies rely on the major seed companies to provide introgression, field testing and regulatory services. Evogene Ltd has signed licensing agreements with Pioneer and Monsanto. Performance Plants Inc. (PPI) is a small Canadian company that has recently patented its Yield Protection Technology (YPT) that relies on engineered versions of Arabidopsis's farnesyl transferase genes. These increase sensitivity to abscisic acid (ABA), closing stomates rapidly when the plant stresses, and have shown good activity in canola, but only modest effects in maize under drought. PPI has research agreements established with Syngenta and Pioneer, and claims that a drought tolerant variety of maize has been field tested for 2 years. Other candidates include members of the DREB/CBF transcription factor family. While these appear effective at the seedling stage their value for increased grain yield in maize or wheat in the field has yet to be demonstrated conclusively, and over-expression leads to stunting.

There are many other putative drought genes. Most have been tried in maize by transnational seed companies and found to be ineffective under drought in adult field-grown plants, or they have an unacceptable yield drag under optimal conditions. Very few have regulatory packages associated with them. Identification of commercial-quality transgenes that enhance both survival under drought and production under adequate water supply remains a lengthy, tedious and expensive process, but one whose success rate is rapidly improving as genomics and computational biology begin to deliver new analytical tools. Unfortunately progress in rapidly and cheaply measuring phenotypes is occurring at a much slower rate.

3. Product delivery: its challenges and opportunities:

The distribution and adoption of drought tolerant germplasm is an obvious step towards impact in farmers' fields, yet it is often a major constraint to the use of these technologies. In developed countries, adoption will depend mainly on the price of seed, superior and stable yield under drought that occurs at any time throughout the growing season, and competitive yield under unstressed conditions. Seed price and easy seed availability are especially important for resource-poor farmers who have little capacity to accommodate risk, even though they are fully aware of profitability considerations. The occurrence of drought is itself a significant risk, and any new technology that requires additional cash outlay for seeds at the start of the season may impose an unacceptable risk to a farm family's resources. On the other hand, loss of yield potential under well-watered conditions is of less importance than in developed farm economies. Where a farmer can purchase open-pollinated variety (OPV) seed from a neighbour, or retain seed from the previous harvest, seed costs are minimized, so in drought-prone environments this is often the course of action taken. The purchase of hybrid seed each crop season is an example of a cost that many small-scale farmers in risky production areas are unable to justify, even though it can be demonstrated that the risks of crop failure are subsequently reduced by using stress-tolerant hybrids or varieties.

Private seed companies remain the means of choice to distribute drought tolerant germplasm, provided sufficient profit can be made from hybrids marketed into lower yielding and riskier drought-prone regions. Ideally, hybrids with their higher cost of seed should target those areas where mean yields are 2-4 t/ha or greater, leaving the lower yielding areas to OPVs. However, average maize yields in sub-Saharan Africa are 1.6 t/ha, suggesting that hybrids will be used on the higher yield potential areas subject to moderate stress only. Until mean yield levels increase substantially, there remains a need for a diversity of seed systems that deliver drought tolerant germplasm – including NGOs, Government agencies, Universities and private seed companies.

The deployment of drought tolerance in the form of hybrids has many benefits. Commercial seed quality and seed treatments are generally better than those of home stored seed, thus reducing risk of failed plantings. Heterosis is a form of stress tolerance in its own right, so hybrids are generally more drought tolerant than OPVs. The generation and sale of hybrid maize seed, as opposed to seed of OPVs, has provided the foundation for a viable and stable seed industry in a number of developing countries, and is considered an essential step in the development of a stable seed industry.

Public and private seed companies in less developed countries are hampered by a lack of trained staff and quality-enhancing competition, credit constraints, a weak infrastructure for distributing and marketing product, and inappropriate seed policies. As a consequence the maize seed industry in much of sub-Saharan Africa is still unable to offer consistent and well-tested hybrid seed options to small-scale farmers.

Transgenic drought tolerance is likely to encounter additional adoption challenges in less developed countries. The immediate constraint is the lack of an established regulatory framework in many developing countries. At present transgenic crops can be field tested and marketed only in three sub-Saharan countries because regulations governing the safe field testing and stewardship of transgenic crops are not yet in place elsewhere. ISAAA considers the lack of appropriate cost-effective and responsible regulation based on a common sense approach to the actual risks involved is the most important constraint to the deployment of genetically modified crops. Present systems are modelled on risks that experience suggests were overestimated, are onerous and expensive to implement, and beyond the reach of the vast majority of private and public seed institutions in the less developed world. Thus the precautionary principle on transgenic crop regulation in its present form is hurting resource-poor farm families – the very people it was designed to protect.

A second challenge lies with adoption when transgenic crops look the same as their normal counterparts in terms of seed and product. If the hybrid is generally superior agronomically, adoption usually occurs through word of mouth, and not necessarily because it is a drought tolerant product. If its superiority is evident only in dry years this will require a major branding approach – something that the hybrid seed industry is skilled at executing. The complexity of managing, breeding and exercising stewardship over transgenic crops suggests that seed supply is beyond the capacity of most farmer groups, and beyond a number of Government seed agencies in less developed countries. Some have concluded that investments in public biotechnology must be matched by policies that encourage commercial seed system development that empowers the farmers to fully utilize this new technology through improved seed and accurate product information. For transgenic drought tolerant maize to achieve anything like its potential in sub-Saharan Africa where it is desperately needed, these changes need to occur at an accelerated pace.

a. *Public sector*

While the relatively small private seed sector is gaining experience and confidence in sub-Saharan Africa, innovative approaches are needed to ensure that seed of stress tolerant maize hybrids and varieties reach those most in need. As an intermediate step to generate confidence among farmers, CIMMYT and cooperating national programs and seed companies have successfully used the Mother-Baby trial system in southern and eastern Africa as a means of generating farmer participation in selection, adoption and seed production. Systematic collaboration among institutions on farmer participatory variety selection has provided an effective method for production and dissemination of improved stress tolerant OPVs. National programs, CIMMYT, IITA and private seed companies have collaborated to evaluate and then release seed in a number of countries, and the most promising of these new drought tolerant varieties, ZM521, is now thought to occupy over 1 million ha in southern and eastern Africa. The success of this combined selection, testing and seed distribution scheme has been the driving force behind the development and funding of the Drought Tolerant Maize for Africa (DTMA) Project. This project has an ambitious vision: Within 10 years, generate maize germplasm with 1 t/ha yield increase under drought stress conditions, increase average maize productivity under smallholder farmer conditions by 20-30% on adopting farms; and reach 30-40 million people in sub-Saharan Africa, potentially adding an annual average of US$160-200 million of grain in drought-affected areas. It involves extensive inter-institutional cooperation on policy advocacy, impact monitoring, training, varietal testing, seed release and scaled up seed production. The project is upgrading the drought tolerance of a number of widely used varieties as well as developing new varieties, and on-farm variety trials are being conducted at ~400 locations in target environments. A major goal is to engage and strengthen the emerging national or regional private seed sector. Around 80 seed companies operating in sub-Saharan Africa are actively participating in testing and marketing DTMA-generated drought tolerant hybrids and varieties, and in developing the trust of their clients. The project will develop inbreds and make them available to all who request the seed – on the principle that if a company has exclusive rights to a successful line it will not have to compete based on other factors important to customers and to the long term survival of the company. South Africa has a mature maize seed industry, and is providing advice to emerging companies in the rest of the region.

b. Private sector

Transnational maize seed companies (Monsanto, Pioneer, Syngenta, and to a lesser degree Pannar, SeedCo and Pacific Seeds) are represented in most of the larger, higher yield potential markets in the less developed world. They have an advantage over national seed companies in that they can transfer adapted germplasm from one region to another and reduce product development overheads. Furthermore, the larger transnationals have extensive research budgets and networks for positioning products that attract research agreements with suppliers of complementary technologies, such as candidate gene constructs. In short, they are uniquely positioned to develop and distribute high quality transgenic hybrid seed, and to position these hybrids in appropriate markets. The comparative advantage of transnationals will lessen only when regulatory requirements are less onerous, when MAS and MARS become less expensive, and when agreements on intellectual property can be negotiated more readily. However, because transnational seed companies operate only in the larger markets in areas where yields are relatively high, there is a good opportunity for national seed companies to establish a market niche comprising smaller market segments, and meet real needs through a balanced portfolio of stress tolerant hybrids and elite OPVs.

c. Private/public partnerships:

Partnerships between private and public sector research organization are a strategy often proposed but rarely executed. Several successful private-public partnerships have been negotiated and managed by ISAAA. One important joint venture of this nature has recently been launched in eastern and southern Africa involving Monsanto as the main technology provider, CIMMYT as the source of key phenotyping sites and adapted maize germplasm, and

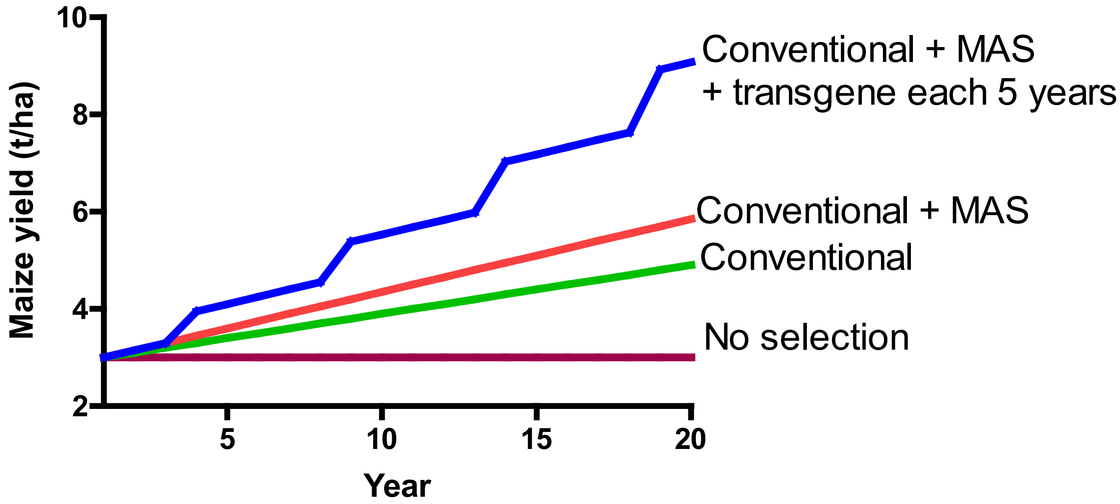

Figure 1. Projected cumulative genetic gain over a 20 years in maize being selected for drought tolerance using conventional selection methods (100 kg/ha/yr), conventional plus marked-aided selection (MAS) (150 kg/ha/yr) and conventional plus MAS plus a transgene introduced every 5 years. Each transgene boosts grain yield by a further 15%. Effects of each intervention are considered additive.

national programs and seed companies as partners in testing and delivery of drought tolerant maize hybrids. The Water Efficient Maize for Africa Project (WEMA) is funded by the Bill and Melinda Gates Foundation, and is currently completing its first year of operation. The African Agricultural Technology Foundation (AATF), a Nairobi-based not-for-profit organization, will serve as the implementing agency, and will spearhead efforts to ensure regulatory compliance of Monsanto's drought tolerance transgene in target countries. This five year project deploys an elegant combination of new technologies directed at improving drought tolerance in maize germplasm adapted to a drought-prone region of eastern and southern Africa. It builds on the effectiveness of conventional selection for drought tolerance in maize as practiced by CIMMYT and national co-operators, using MAS to increase rates of genetic gain and Monsanto's lead transgene designed to provide an incremental jump of around 15% in grain yield under drought. The Monsanto MAS technology is being used, based on whole genome selection, and could double rates of genetic gain for drought tolerance. Crosses between lines carrying the event and tropical lines from CIMMYT are taking place. The effect of the transgene should simply add to that obtained by CIMMYT through conventional selection, though it is untested in tropical maize backgrounds. The transgene is planned for release in Sub Saharan Africa in 2017. Monsanto is providing major contributions in kind through advanced techniques in MAS, and a royalty-free concession to seed companies who wish to use the transgenic trait. Target countries in Eastern and Southern Africa are South Africa, Mozambique, Kenya, Uganda and Tanzania. Impact from germplasm improved by MAS should be felt within 5 years, and from transgenic drought tolerant hybrids after 2017. This project presents a unique and important opportunity to bring modern technology to address drought tolerance for the poor, and will help put in place the regulatory procedures needed to bring other transgenes to this needy region.

4. The way forward

a. *Expected rates of progress:*

The recent substantial investment by the Gates Foundation in developing and disseminating drought tolerant maize for sub-Saharan Africa has provided a tremendous impetus to stabilizing and improving maize production in this drought-prone region where maize forms a critically important part of the diet. This builds on a solid research effort led by CIMMYT spanning 35 years. Research of this nature is a relatively slow process, but there are real prospects of increasing the rate of improvement using new techniques. The use of MAS to increase the rate of genetic gain in both the DTMA and WEMA Projects could double the rate of genetic gain, and the availability of a transgene boosting grain yield under drought throughout the crop season opens exciting possibilities. These three approaches – conventional selection, MAS and genetic modification – will likely be additive in effect. The first two provide the prospect of steady improvement over time, and the 15% improvement offered by Monsanto's transgene could be matched by ~3-5 years of conventional + marker-aided selection. The transgene provides a one-off boost to yields obtained by MAS. However, if technology providers such as Monsanto, Pioneer, Syngenta or BASF are persuaded to release newly developed transgenes providing a similar boost to grain yield every 5 years or so, and if their effects are also additive (a good possibility with a complex trait like drought tolerance), then the cumulative effects of transgenes, MAS and conventional selection for drought tolerance can generate very significant improvements in grain yield (Fig. 1). There are large investments being made in the development of genetically modified crops by the private sector in the USA and Europe, and these are being matched by public sector investments in China, India, Brazil and the USA. The recent announcement of a US$3.5 bn investment in genetically modified crops in China over the next decade is the most recent tangible example of this commitment.

b. *Managed Drought Stress Environments, MSEs:*

Reliable drought phenotyping requires MSEs where drought stress is controlled and applied at the designated timing and intensity. The value of MSEs for efficient drought selection in maize has been consistently demonstrated over the past 20 years. Progress can be made using multi-location testing at randomly selected sites in the target population of environments, but only if it is on a very large scale. For less developed countries this is not an efficient way of improving yield under water-limiting conditions. A further investment in centers of excellence in phenotyping for drought tolerance in the less developed world seems fully justified. This opens up the possibility of improving a range of crops for drought tolerance in addition to maize at the same location. It is an initiative that would boost operational efficiency, and should be seriously considered by the donor community.

c. *New genetic variation, new methods:*

The lack of intraspecific genetic variation for staygreen under terminal drought stress, and for root depth management in maize has been documented. Transgenic sources of new variation for these traits will likely be required, along with a careful physiological evaluation of the whole-plant effects of such transgenes. Multiple genes contained in single constructs allow for efficient stacking of traits. New molecular methods are under experimentation such as the use of mini chromosomes where a single heritable piece of the plant's own DNA that includes the centromere region is used to deliver several genes simultaneously. Small RNA fragments are emerging as powerful control elements of stress response in plants.

d. Agronomic interventions:

Improved crop management methods can complement the use of drought tolerant hybrids and contribute significantly to increasing and stabilizing yields under rainfed conditions or under irrigation where water supply is limited. Ensuring that planting densities are optimal, tillage is minimal, weeds are controlled and adequate fertilizer is applied at the right growth stage all increase water use efficiency (WUE). Water supply to the crop can be increased by water harvesting methods and the use of mulch. Where irrigation is in short supply, deficit irrigation, or the application of water at less than the potential evapotranspiration rate, can increase WUE at little cost to yield. Partial root drying, where dry and wet regimes are alternated under irrigation to reduce water applied can elicit a drought-adaptive response and may save up to 25% of the water normally applied.

e. Regional regulatory and release initiatives:

There is considerable potential for regional harmonization of regulatory procedures in regions like sub-Saharan Africa. If deregulation of a specific transgene has been approved by one country based on a thorough evaluation using standard protocols, this should normally be sufficient to deregulate that same construct and event when used in the same species in other countries in the region. Release of improved varieties and hybrids could be harmonized in a similar manner across countries sharing common agroecologies, e.g., West Africa.

5. Conclusions

Considerable progress has been made over the past 35 years in directed selection for drought tolerance in maize, building on the gains in this trait arising from multi-location testing during selection. The availability of high quality managed stress environments where small phenotypic differences can be repeatably detected has coincided with the advent of molecular breeding, and marker-assisted selection and genetic modification depend heavily on accurate phenotyping for their success. These tools offer real opportunities for “speeding the breeding”, but come at a cost. Fortunately, well-resourced technology providers in the form of transnational seed companies have shown their willingness to share this technology, sometimes on a royalty-free basis. Linkages between supplier and users of these advanced breeding techniques have been facilitated by generous donor support, and this has been extended to the emerging seed industry in less developed areas such as sub-Saharan Africa. We have a confluence of several key processes that are essential components in the delivery of stable and high crop yields to resource-poor farm families. It is a unique opportunity that should not be squandered.

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