Transgenic-facilitated Drought Tolerance in Corn

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RR = Roundup Ready; YGCB = YieldGard Corn Borer; RR2 = Roundup Ready Corn 2; YGVT = YieldGard VT; YGRW = YieldGard Rootworm; RR2Y = Roundup Ready 2 Yield; RRF = Roundup Ready Flex

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Agriculture is at the Center of Many of Society’s Most Important Debates

- **Global food security**
  - Enhanced productivity
  - Increased yield
  - Sustainable production

- **Water availability**
  - Drought-tolerant crops

- **Biofuels**
  - Yield technologies to help meet demand for both food and fuel

- **Global warming**
  - CO₂ footprint
  - Fertilizer use
U.S. Domestic Corn Usage has More Than Doubled in the Past Decade

U.S. CORN FOOD, ALCOHOL, AND INDUSTRIAL USE & BEGINNING STOCKS

USDA:ERS Feed Grains Database
Meat Consumption in Developing Countries Increases Pressure on Crop Production

66% increase

Poultry
Pork
Beef

FAPRI, 2009
Demands on Available Water Supply Continue to Pose Challenges

RESTRICTIONS ON IRRIGATION DEVELOPMENT (AS OF 12/16/2008)

STAY ON WELLS AND ACRES

PRELIMINARY STAY ON WELLS AND ACRES

AT THE SAME TIME AMERICAN FARMERS ARE BEING CALLED UPON TO MEET GROWING DEMAND FOR GRAIN, AVAILABLE WATER FOR IRRIGATION IS ‘DRYING UP’
Although Corn Faces a Myriad of Challenges, Drought Is the Most Damaging

Flowering Stress: 6.28 mt/ha
- Reduced Kernel Number
- Increased Barren Plant Count
- Increased Disease

Grain Fill Stress: 8.8 mt/ha
- Reduced Kernel Number
- Increased Barren Plant count
- Reduced Stalk Strength

Well Watered: 16.64 mt/ha

- Corn uses about one-third inch of water every day during pollination
- Four days of visible wilting between boot and milk can reduce yield by half
- Between the end of vegetative growth and soft dough, corn requires about 7 inches of water
- Eighty-five percent of U.S. corn suffers from varying degrees of drought stress at some time in the growing season

Drought Tolerant Corn Products Target the Needs of Farmers in Different Regions

<table>
<thead>
<tr>
<th>Western US Dryland</th>
<th>Drought “Insurance”</th>
<th>Reduced Irrigation Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>KS, NE, TX, CO, SD, ND 10-13 M acres corn</td>
<td>Central, E. and S. Corn Belt 30-50M acres</td>
<td>KS, NE, TX, CO, ID 12M acres</td>
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</tbody>
</table>

- D1 Targets a Yield Advantage in Western Great Plains Dryland Production
- D2 Adds a Yield Advantage in Drought “Insurance” Market When Drought Occurs
- D2 Provides Opportunities in Irrigation Market
Ideal Drought Field Testing Networks Consist of Uniform, Predictable Testing Sites with High Quality and Consistent Data Return

Attributes of an Ideal Field Drought Testing Program:
1. Accurate, repeatable stress episodes (across seasons)
2. Lowest possible within-field variability
3. Environments that predict market performance

Managed Stress Environments enable selection for drought traits

Target Environments enable selection for adaptation and performance

Dual Evaluation
Factors Affecting Success of Drought Field Testing Sites

• Weather patterns
  – Predictable rainfall
  – Low occurrence of other abiotic stresses
  – Low probability of hail & severe storms

• Soil uniformity
  – Soil type
  – Water holding capacity
  – Predictable levels of sub-surface water

• Uniform irrigation systems
  – Control drought stress timing & severity
Leveraging Multiple Tools for Drought Research Site Selection

- GIS-based weather & stress probability maps
- Direct assessment of soil uniformity
  - High resolution soil type mapping
  - Soil electrical conductivity mapping
  - Multispectral bare-soil imagery
- Assessing uniformity of plant growth
  - Thermal infrared imagery
  - Vegetation indexes
Large-Scale Breeding Screening Takes Place to Arrive at the Right Combination for Farmers’ Fields

TESTING FOR DEVELOPMENTAL ATTRIBUTES AFFECTED BY LOW WATER

Screening vast pools of corn germplasm to develop the best hybrids with respect to attributes like:

- Flowering
- Silking
- Grain fill

GOOD PERFORMANCE IN THESE AREAS WILL HELP DICTATE THE BEST HYBRIDS FOR THE TRAIT
DEKALB® Product Study Confirms Farmer Observations

• DEKALB® Commercial Product Study
  – 40 years of commercial hybrids (1967 to 2006)
  – Improved hybrid grain yield for both normal and drought conditions
  – Opportunity to make additional progress for hybrid grain yield under drought stress
Marker-assisted Breeding is Key to Accelerated Rates of Corn Yield Improvement

Breeding rate of gain in 248 germplasm populations

Source: Eathington et al, 2007
Agricultural Management Practices Can Help Make the Most of Available Soil Moisture

CONSERVATION TILLAGE HELPS RETAIN MOISTURE, MAKING MORE AVAILABLE TO PLANTS

Eight years of research in the Western Great Plains demonstrates that strip tillage:

- Improves soil quality (organic matter, # worms, water uptake rate, # soil pores)
- Improves fertilizer utilization
- Increases roots by 33 - 44%
- Yields equal or better than conventional tillage

Source: Mike Petersen, Precision Tillage Specialist, Orthman Manufacturing
Maximizing Water Use by Protecting Corn Roots

SOIL PROBE ANALYSIS OF WATER USE BY SIMILAR GENETICS IN COLORADO

The benefits of root protection are easy to see.
Plant Water Utilization is a Complex Trait

COMBINING BIOTECHNOLOGY & MOLECULAR BREEDING TO DEVELOP IMPROVED WATER USE

BUILDING A FAMILY OF GENES CONVEYING DROUGHT TOLERANCE IN CORN

COLLABORATION WITH BASF The Chemical Company
Over-Expression of Plant Nuclear Factor Y (NF-Y) B Provides Drought Tolerance in Maize

- Gene identified using screen in Arabidopsis
- NF-Y transcription factor subunit
  - complex binds CCAAT box
- Drought tolerance observed in greenhouse and field
  - Reduced leaf rolling
  - Improved photosynthesis
  - Cooler leaves
  - More grain yield

NF-YB over-expressed in corn produces a cooler plant

Source: Nelson et al. (2007)
CspB RNA Binding and Chaperone Activity Observed with Sustained Productivity under Drought Stress

ARABIDOPSIS
CONTROL                      WITH GENE

CspB binds corn RNA in vivo

CspB levels are greatest in rapidly growing tissues

Increased kernel number and plant growth rate

Increased Yield Under Water-Deficit Stress
Mitigating the Effects of Drought

UNDER A WATER DEFICIT, CspB GENE CONFERRED TOLERANCE

Chlorophyll content (+2.5%) & photosynthetic rate (+3.6%) were significantly increased over control (N=432)

A significant increase in number of plants with kernel-bearing ears (+4.0%) and number of kernels per plant (+11.7%) improved yield (+7.5%)

Source: Castiglioni et al. (2008)
CspB Conveyed Yield Benefits in both Managed Trials and Target Environment under Drought Conditions

Reproductive Water-Deficit Stress

Yield (t/ha)

Hybrid 1  Hybrid 2  Hybrid 3

Transgenic  Non-transgenic

Vegetative Water-Deficit Stress

Yield (t/ha)

Hybrid 1  Hybrid 2  Hybrid 3

Transgenic  Non-transgenic

Multi-location
Managed
Irrigation
Water-deficit
Conditions

Multi-location
Western Dryland
Market

Source: Castiglioni et al. (2008)
2009 Trials Identified Hybrids with Significant Yield Improvement even under Limited Stress Conditions

2009 Monsanto Drought Testing Network

2009 yield data from sites identified as having drought stress.

All differences significant (p<0.05)
Additional gains from breeding, agronomic practice improvements and new biotechnology products bring yield potential to ~300 bu/ac by 2030.

CORN YIELD POTENTIAL TO 2030 IN THE UNITED STATES

- USDA Yield
- Historical Trend
- Agronomic
- Advanced Breeding
- Biotech
Average Sub-Saharan African Corn Yields are Among the Lowest Globally

2008/2009 CORN YIELDS BY COUNTRY

IMPROVED AGRONOMIC PRACTICES, BREEDING AND BIOTECH CAN ALL PLAY A ROLE

Source: USDA FAS Oct 2009
To Successfully Deliver Water-Efficient Maize for Africa, it Will Take a Strong Partnership of Technology Providers

THE PARTNERS

• African Agricultural Technology Foundation (AATF) is leading the project
• CIMMYT and Monsanto will bring best in global maize germplasm, testing and breeding methods, and biotechnology
• National Ag. Research System (NARS) participation is a crucial part of testing products and bringing WEMA to Sub-Saharan African farmers

THE TECHNOLOGY

• Best global germplasm to combine new sources of drought tolerance and African adaptation
• More rapid gains in conventional drought tolerance through molecular breeding
• Additional drought tolerance obtained through state-of-the-art biotechnology

DEDICATED TO DELIVERING WEMA
First WEMA Data from One Trial Set in South Africa

Yield and Test Weight

Pollen Shed and Silking

Kernels per ear

- Gene
+ Gene

Uganda
Kenya
Tanzania
Mozambique
South Africa
Agriculture will continue to be the biggest consumer of available water, but Monsanto, along with others, are working to “squeeze more food from a raindrop”