International Fertilizer Industry Association

ANTICIPATED IMPACT OF MODERN BIOTECHNOLOGY ON NUTRIENT USE EFFICIENCY: CONSEQUENCES FOR THE FERTILIZER INDUSTRY

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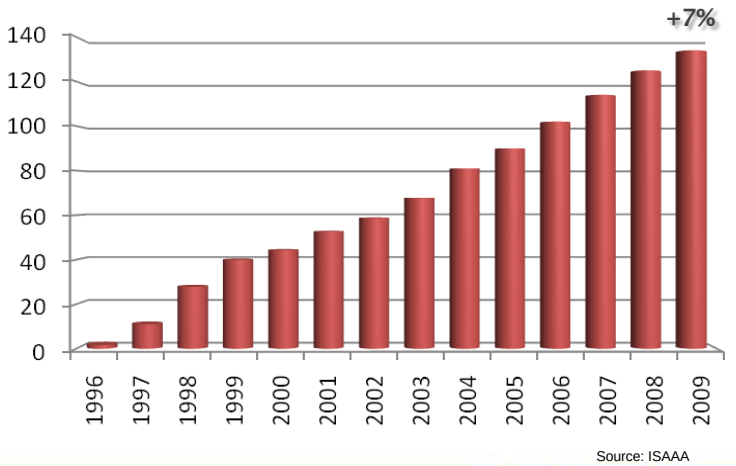
Genetically-Altered Crops Are A Fact (Mha)



Source: ISAAA

Distribution of the Genetically-Altered Crop Area in 2009 (Mha)

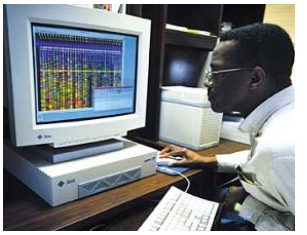
by country	by crop	by trait
▪ USA: 64.0	▪ Soybean: 69.2	▪ Herbicide tolerance (HT): 83.6
▪ Brazil: 21.4	▪ Maize: 41.7	▪ Insect resistance (IR): 21.7
▪ Argentina: 21.3	▪ Cotton: 16.1	▪ HT + IR: 28.7
▪ India: 8.4	▪ Rapeseed: 6.4	▪ Others: <0.1
▪ Canada: 8.2	▪ Others: ~0.6	
▪ China: 3.7		
▪ Paraguay: 2.2		
▪ South Africa: 2.1		
▪ ROW: ~2.7		

Current traits have little impact on fertilizer consumption

Source: ISAAA

Main Traits in the Pipeline

- **Drought tolerance**
  expected commercial release of the first maize varieties in 2011
- **Increased yield**
- **Resistance to additional pests**
  e.g. resistance to anthracnose, aphids, nematodes
- **Nitrogen use efficiency**
- **Output traits**
  - **Remedy to deficiencies**
    higher vitamin and iron content
  - **Improved nutritional profile**
    improved amino acid and fatty acid composition
  - **Improved processing properties**
    ethanol value, modified starch, higher solid content, improved fiber quality



Courtesy of Syngenta

How Do Genetics Impact Fertilizer Consumption?

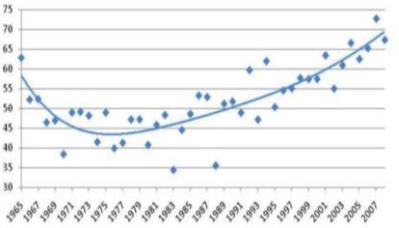
- **Improved yield**
  → higher nutrient requirements
- **Improved yield stability** (e.g. insect resistance, drought tolerance)
  → greater incentives for investing in inputs
- **Adaptation to unfavourable conditions** (e.g. tolerance to drought, salinity, flood, acidic soils)
  → additional area to be fertilized
- **Improved nutrient use efficiency** (nutrient uptake, translocation, metabolism or storage)
  → lower requirements per unit output
- **Varieties with new traits**
  → specific requirements to optimize expression of the traits

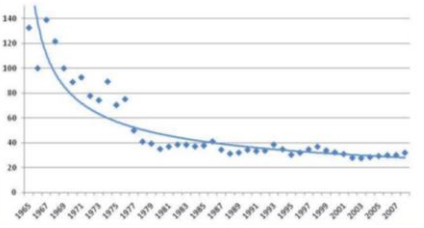
Courtesy of Monsanto

Nitrogen Use Efficiency: The Context

- **Low average nitrogen use efficiency in field conditions**
  global average: ~40% recovery in the year of application
  …but >80% can be achieved in experimental conditions
  → significant potential gain
- **Different scenarios between developed and developing countries**

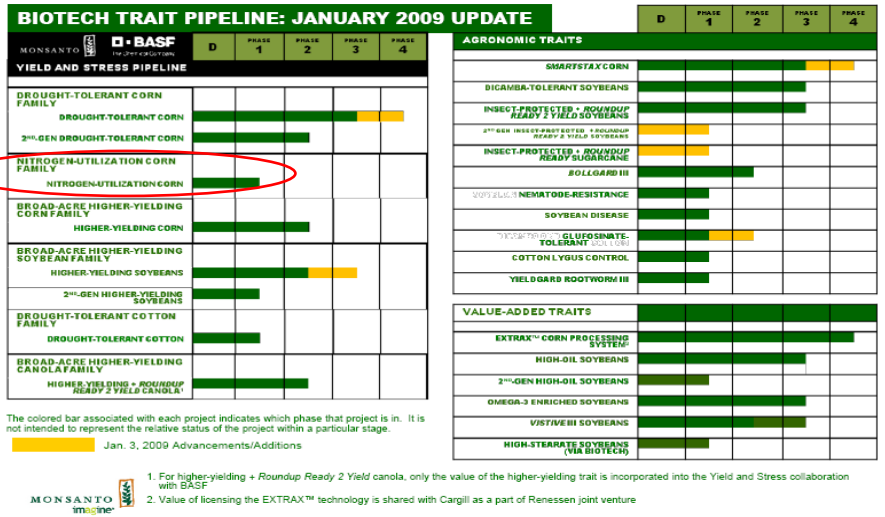
Evolution of nitrogen use efficiency of maize in the USA (left) and cereals, oilseeds and potatoes in China (right), measured as partial factor productivity (kg harvested product / kg N applied)



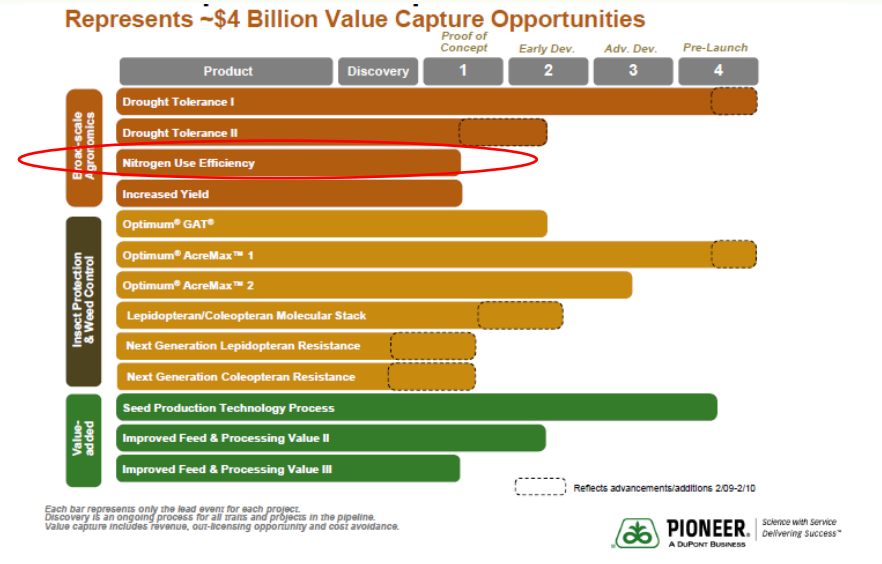


Source: IFA

Monsanto's R&D Pipeline



Dupont-Pioneer's Corn Genetics Pipeline



Syngenta's Corn Traits Pipeline

	Early development	Late development	Initial launches
Input traits			
AgrisureViptera			2010
Dual: above ground			2011
Dual/dual			2012
2nd generation CRW			2014
Seed Care			
Avicta Complete Corn			2010
Output traits			
Enogen			2010
Abiotic stress			
Drought tolerance*			2011*
Nitrogen use efficiency			post 2015

* Native traits followed by GM

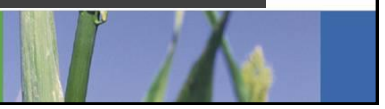
syngenta GLOBAL

Nitrogen Use Efficiency: The Other Actors

- **Other major seed companies**
  e.g. Limagrain/Vilmorin
- **Start-ups**
  - Arcadia Biosciences (JVs with Pioneer, Monsanto , Vilmorin)
  - Evogene (JV with Monsanto)
- **Public research**
  several agronomic research institutes and universities
- **… but some have discontinued their research**
  e.g. CIMMYT

Main target crops:

- maize
- … but also rapeseed, wheat, rice, etc.



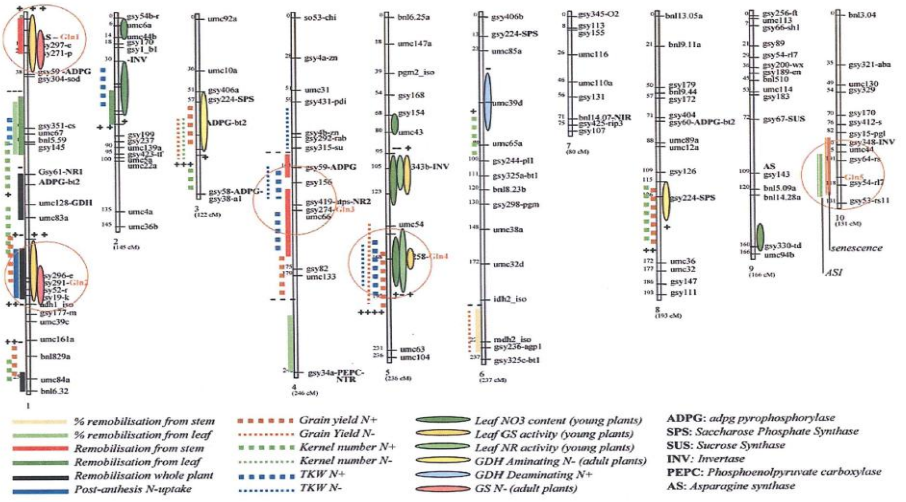
Nitrogen Use Efficiency: What Do We Know?

- Nitrogen use efficiency in plants is a complex trait that depends on a number of internal and external factors
- The molecular basis for organism-wide regulation of nitrate assimilation is not yet fully understood
- Nitrogen use efficiency has been already indirectly improved by nature and through 'conventional' breeding
- Genetic variability in nitrogen use efficiency has been reported in many crops: maize, wheat, rapeseed, etc.
- Several options for genetically improving nitrogen use efficiency:
  - Increase uptake efficiency (e.g. overexpression of transporters)
  - Increase physiological use efficiency (e.g. over-expression of nitrate reductase, glutamine synthetase, alanine amino transferase)
- Biotechnological interventions to improve crop nitrogen use efficiency have met with limited success so far

Courtesy of Syngenta

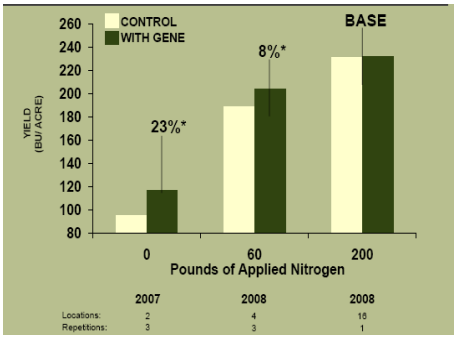
Nitrogen Use Efficiency: Complex Genetic Control

Location of QTLs for physiological traits associated with N use efficiency in maize (Gallais and Hirel, 2003)

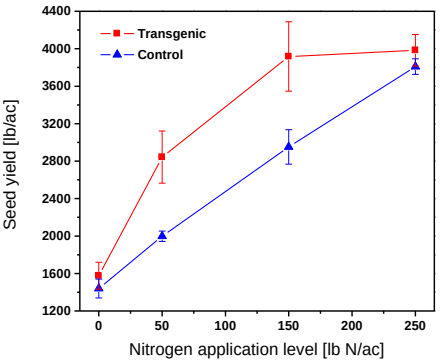


Nitrogen Use Efficiency: What Potential for Improvement?

Nitrogen-Utilization Corn Tested by Monsanto



Nitrogen Efficient Rapeseed Tested by Arcadia Biosciences



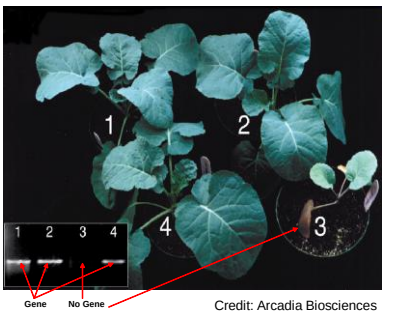
All companies are still at the 'proof-of-concept' stage

→ Commercial release unlikely before 2015 (rapeseed), if not 2020 (maize)

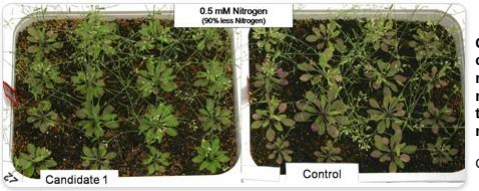
Examples of Nitrogen Use Efficient Plants

A control leaf without the nitrogen stress transgene (left) compared to a leaf with the nitrogen stress transgene (right) from plants grown in a nitrogen stress environment.

Credit: Dupont Pioneer



Credit: Arcadia Biosciences

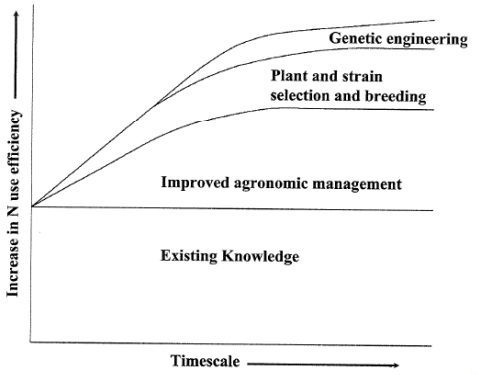


Genetically modified Arabidopsis plants over expressing a NUE candidate gene remain green when grown under limiting nitrogen conditions (left), while non transgenic plants (control) display signs of nitrogen starvation (right)

Credit: Evogene

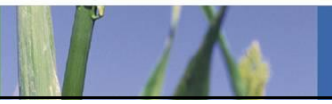
Nitrogen Use Efficiency: Where Will Progress Come From?

Likely impact of research investment in increasing nitrogen use efficiency (Giller *et al*., 2004)



In the short and medium term, most of the gain in nitrogen use efficiency is expected to come from improved agronomic practices

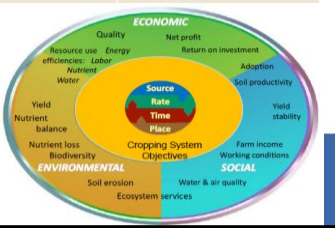
Biotechnology is seen contributing only in the long term, and relatively modestly (less than 'conventional' breeding)



Nitrogen Use Efficiency: Agronomy Is Not Over!

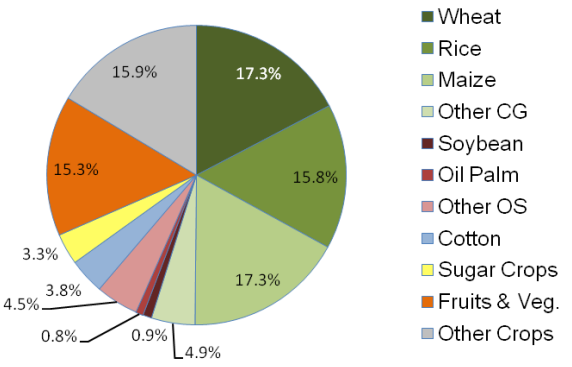
Examples of fertilizer best management practices:
using 'the right product at the right rate, right time and right place'

Right Product(s)/ Source(s)	Right Rate	Right Time	Right Place
• Balanced fertilization *(N, P, K, secondary and micronutrients)* • Nutrient form *(urea, nitrate, ammonium)*	• Soil testing • Yield goal analysis • Crop removal balance • Plant tissue analysis • Crop inspection • Record keeping • Variable-rate application technology	• Application timing • Slow- and controlled-release fertilizers • Urease and nitrification inhibitors	• Application method • Incorporation of fertilizer • Applicator maintenance and calibration



Theoretical Impact on the World Nitrogen Fertilizer Market

Nitrogen Fertilizer Use by Crop at the Global Level: 2006-2006/07



Source: IFA

No impact before 2020

Maize and rapeseed together account for <20% of world N fertilizer consumption → Probably little impact, between 2020 and 2025

Possible larger impact from 2025 if the trait is transferred to wheat and rice, and if its use is profitable to the farmers

Other Crop Traits with Potential Impact on Fertilizer Consumption

Examples of other traits with a potential impact on fertilizer consumption

Nutrient	Trait
Nitrogen	Improved protein content
Phosphorus	Higher bioavailable phosphorus content Phytase-excreting plants Improved phosphorus metabolism efficiency
Potassium	Enhanced potassium absorption
Sulphur	Improved content in essential amino acids
Micronutrients	Higher zinc content Higher iron content
All nutrients	Tolerance to drought Tolerance to salinity Aluminium tolerance

Other Biological Options

- **Harnessing the rhizoshpere**
  - Focus on "The Hidden Half"
    - root health critical to nutrient and water uptake
    - manipulation of this 'source sink' is critical
  - Plant growth-promoting rhizobacteria (PGPR)
  - Biological control agents (BCAs)
- **Improvement of microorganisms and symbiosis**
  - Phosphorus solubilization
  - Sulphur oxidization
  - Ability to develop symbiosis with nitrogen fixing bacteria
  - Improved nitrogen fixation in legumes

Courtesy of Monsanto

The Challenge to the Fertilizer Industry

- **Fertilizer uptake by plants is low**
  - low recovery rates in year of application: ~40% for nitrogen and <20% for phosphorus (but up to 90% over long periods)
- **Unwanted impacts due to fertilizer misuse**
  - hypoxia, algal blooms (not all caused by fertilizers)
  - … but also desertifcation if underuse
- **R&D and new product development not a fertilizer industry focus**
  - largely locked in a commodity mentality
- **Expected competition with 'non-traditional' actors**
  - seed & ag-chem companies
  - vertically-integrated through the ag value chain
  - global marketing reach
  - drawing on high-tech product development

Conclusions

- Several biotechnological inventions in the pipeline could have a potential impact on crop nutrition
- Impact on fertilizer demand is seen either positive or negative depending on the trait
- The main trait expected to have an impact on fertilizer consumption is nitrogen use efficiency, but no impact anticipated before 2020
- Main gains in nitrogen use efficiency in the short and medium term seen coming from improved agronomic practices
- In the long term, the fertilizer industry might have to compete with 'non-traditional' actors and should develop partnerships with them