3rd International Plant Phenotyping Symposium
Phenotyping for Agriculture Sustainability

Chennai, 17 February 2014

Plant Phenotyping for Meeting the Zero Hunger Challenge

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UNESCO Chair in Ecotechnology, MSSRF, Chennai
United Nations Secretary-General’s Vision (2012)

HUNGER CAN BE ELIMINATED IN OUR LIFETIME

Source: www.un.org
South Asian Enigma

- Extraordinary economic growth in South Asia
- Population largely dependent on agriculture
- Yet, 2 out of 5 children stunted

39% of children are stunted in South Asia

UNICEF 2013
South Asian Enigma

- Region with the largest number of children with stunted growth

- First 1000 days critical. Low Birth Weight Babies 1 in 4

- Under-nutrition reduces a nation’s economic advancement by 8% (Lancet 2013)

Top 6 countries with highest number of stunted children (millions)

- India: 61.7
- Nigeria: 11
- Pakistan: 9.6
- China: 8
- Indonesia: 7.5
- Bangladesh: 6

UNICEF 2013
2013 – A Significant Year in India’s Struggle Against Hunger

Some Milestones

1943 : Bengal Famine; 3 million children, women and men died of hunger
1963 : Beginning of intensive research on raising the ceiling to yield
1966 : Increasing PL 480 wheat imports, going upto 10 million tonnes
1968 : Issue of the stamp “Wheat Revolution”, depicting the role of science in agricultural transformation
2013 : Parliament approves the National Food Security Act, conferring the legal right to food on over 70% of India’s population

Thus, 2013 marks the transition from ‘ship to mouth’ to ‘right to food’ with home grown food
The Green Revolution And The Dwarf Phenotype

The effects of different Rht alleles on plant height in wheat (cv. April Bearded). The wild-type contains Rht-B1a and Rht-D1a, which are homoeologous (corresponding) genes on the B and D genomes. Rht-B1c is a more severe allele at the Rht-B1 locus.

Comparison of woo-gen (right) and dee-geo-woo-gen strains, the latter containing the sd1 mutation.

Source: http://5e.plantphys.net/
Genetic Containment of Wheat Rusts

Stem, Leaf and Stripe Rusts

1953: Composite Varieties – phenotypically similar but genotypically diverse

1960: Gene pyramiding

Genetic Shield – gene deployment strategy

March 2009: Check-mating UG-99, a virulent stem rust race in wheat
Deployment of leaf rust resistance genes over North India

Need for Genetic checkmating of new disease threats

PBW 343 (Lr26+34+)
HD2687 (Lr26+34+)
WH 542 (Lr26+34+)
UP 2338 (Lr26+34+)

HS 365 (Lr26+1+)
HS 295 (Lr23+34+)
HPW 42 (Lr26+1+34+)

Annapurna-1 (Lr26+)
Annapurna-2 (Lr1+13)
Annapurna-3 (Lr13+)
BL 1022 (Lr26)
Vinayak (Lr1+13)

K 9107 (Lr 34+)
LOK-1 (Lr 34+)
HP 1731 (Lr 34)
HUW 234 (Lr 14a)
Sonali (Lr 9)

Puccinia Path

Niez
NWPZ
NEPZ
NEPAL
The Plant Phenomic facility in Phytotron of IARI
Parameters measured for Plant Phenotyping in Wheat at IARI

- Leaf area
- Chlorophyll content
- Stem diameter
- Plant height / width
- Growth rate
- Stress pigment concentration
- Tip burn
- Biomass
- Internode length
- Color
- Leaf rolling
Phenotyping of abiotic stress through thermal imaging

Thermal images of durum wheat seedlings treated with salt – temperature differential of 1°C

Thermal image of a wheat trial
World Cereal Needs

2007 Data

<table>
<thead>
<tr>
<th>Crop</th>
<th>Area (x10^6 ha)</th>
<th>Production (x10^6 tons)</th>
<th>Yield (t/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maize</td>
<td>158</td>
<td>792</td>
<td>5.0</td>
</tr>
<tr>
<td>Rice</td>
<td>156</td>
<td>680</td>
<td>4.2</td>
</tr>
<tr>
<td>Wheat</td>
<td>214</td>
<td>606</td>
<td>2.8</td>
</tr>
</tbody>
</table>

Tester and Langridge – Science 327, 818 [2010]
Three major dimensions of hunger

- CALORIE DEPRIVATION
- PROTEIN DEFICIENCY
- MICRONUTRIENT DEFICIENCY
Rice: The advent of new plant type in the 1960s

Non-lodging habit together with a vigorous root system
Phenotypic Revolution

Pusa Basmati 1509: Released in 2013

- Reduced height
- Earliness
- Non-lodging
- Non-shattering
There is need for information on functional genomics of cooked kernel elongation and volume expansion in Basmati rice.
Evergreen Revolution is the Pathway

- World requires 50% more rice in 2030 than in 2004 with approximately 30% less arable land of today.
- Mainstreaming ecology in technology development and dissemination is the road to sustainable agriculture.
<table>
<thead>
<tr>
<th>Pathways</th>
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<tbody>
<tr>
<td><strong>Green Revolution</strong>: Commodity-centred increase in productivity</td>
</tr>
<tr>
<td>- Change in plant architecture, and harvest index</td>
</tr>
<tr>
<td>- Change in the physiological rhythm-insensitive to photoperiodism</td>
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<tr>
<td>- Lodging resistance</td>
</tr>
<tr>
<td><strong>Evergreen Revolution</strong>: increasing productivity in perpetuity without associated ecological harm</td>
</tr>
<tr>
<td>- Organic agriculture: cultivation without any use of chemical inputs like mineral fertilizers and chemical pesticides</td>
</tr>
<tr>
<td>- Green Agriculture: conservation farming with the help of integrated pest management, integrated nutrient supply and integrated natural resource management</td>
</tr>
</tbody>
</table>

If farm ecology and economics go wrong, nothing else will go right.
No Time to Relax: Major Challenges Ahead

- Food losses and Food Waste
- Climate change: scientific checkmating of adverse impact
- Shrinking per capita land and water resources
- Expanding biotic and abiotic stresses
- Adverse cost-risk-return structure of farming
- Market volatility
- Reluctance of youth to take to farming

The Monsoon and the Market are two of the major determinants of farmers’ well being
Climate Change: Temperature

- Global mean surface temperatures continue to rise. Eleven of the last 12 years rank among the 12 warmest years on record since 1850.
- It is extremely likely that human influence has been the dominant cause of the observed warming since the mid 20th century. The evidence for this has grown.
- Global surface temperature change for the end of the 21st century is projected to be likely to exceed 1.5°C relative to 1850 to 1900 in all but the lowest scenario considered, and likely to exceed 2°C for the two high scenarios.
- Warming will continue to exhibit inter-annual-to-decadal variability and will not be regionally uniform.

Source: SPM, IPCC AR-5
Sea Level Rise

- Global mean sea level has risen by 0.19 [0.17 to 0.21] m, estimated from a linear trend over the period 1901–2010.
- Between 1993 and 2010, the rate was very likely higher at 3.2 [2.8 to 3.6] mm yr⁻¹.
- Ocean thermal expansion and glacier mass loss are very likely the dominant contributors to global mean sea level rise during the 20th century.
- Global mean sea level will continue to rise during the 21st century. Under all RCP scenarios the rate of sea level rise will very likely exceed that observed during 1971–2010 due to increased ocean warming and increased loss of mass from glaciers and ice sheets.
- As the ocean warms, and glaciers and ice sheets reduce, global mean sea level will continue to rise, but at a faster rate than that have been experienced over the past 40 years.

Source: SPM, IPCC AR-5
Sea Water Farming
(Sea water constitutes 97% of the world’s water resource)
Innovations in below sea level farming in Kuttanad

**COCONUT - ONE RICE - ONE FISH**

*Punja season*
November - February
Low chemical input or Organic
Yield - 4.2 t/ha

April - October

**Monoculture** – Giant Prawn
(*Macrobrachium rosenbergii*)

**Polyculture***- Indian major carps or common carps or Silver carps and grass carps and Giant Prawn

Yield - Rice: 4.2 t/ha
Fish - Prawn: 480 kg;
Carp : 300 kg.

*Recommended practice*
**Genetic Garden of HALOPHYTES at Vedaranyam**

**Converting Sea Water into Fresh Water through Halophytes**

**Obligatory halophytes**
- Tolerate high concentration of sodium salts
- > 3 times of seawater salinity
- Even demand high NaCl for survival and reproduction
- 1560 species

**Facultative halophytes**
- Most of the species tolerate only moderate level of salinity
- Reproduction requires low saline condition
- Mangroves
- 60 species
Deepwater (floating) rice has three special adaptations:

i. ability to elongate with the rise of water levels;

ii. develop nodal tillers and roots from the upper nodes in the water

iii. the upward bending of the terminal part of the plant called 'kneeing' that keeps the reproductive parts above the water as flood water subsides
Genetic Shield against Sea Level Rise

Mangrove Forests
Mangrove Carbon Fixation at One Year

8.3 tC/ha from atmosphere

12.7 t/ha biomass (dry)
(5.0 tC/ha)

11.0 t/ha biomass (dry)
(3.3 tC/ha)
Salt tolerant Rice Plants with Mangrove Genes

10 days 1 month

C T CTRL Transgenic

Performance Evaluation

<table>
<thead>
<tr>
<th>Characters</th>
<th>White ponni with 150mM NaCl</th>
<th>Transgenic with 150mM NaCl</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plant height (cm)</td>
<td>95.10</td>
<td>104.95</td>
</tr>
<tr>
<td>No. of productive tillers</td>
<td>9.90</td>
<td>14.20</td>
</tr>
<tr>
<td>Panicle length (cm)</td>
<td>17.08</td>
<td>22.45</td>
</tr>
<tr>
<td>No. of grains per panicle</td>
<td>134.60</td>
<td>174.80</td>
</tr>
<tr>
<td>100 grain weight (g)</td>
<td>1.45</td>
<td>1.63</td>
</tr>
<tr>
<td>Yield per plant (g)</td>
<td>20.30</td>
<td>34.75</td>
</tr>
</tbody>
</table>

Rice plants with Mangrove Genes and Promoter
C4-re-engineering photosynthesis to develop physiologically efficient rice

C4 rice could:
- increase rice yield by 25-50%
- double water-use efficiency
- improve nitrogen-use efficiency

C4 photosynthesis is one of the few evolutionary mechanisms that could deliver these superior combination of benefits.

**Evolutionary Change**

Genetic alterations

C3 + Anatomy Change + Biochem Change + Fine Tuning = C4

*P. Quick & J. Sheehy, IRRI*
Some advantages of C4 photosynthetic systems over C3 include:

- Faster and more complete translocation of assimilates from leaves.
- Photorespiration is rarely greater than 5% of the rate of photosynthesis while in C3 it can exceed 30% of the rate of photosynthesis above 30°C.
- Almost twice the efficiency in dry matter production per unit of water transpired.
- In drought prone ecosystems, yield could be maintained or increased with less water and less fertilizers.
- Greater photosynthetic efficiency at high temperature.
Agro-forestry Remedy for Nutritional Malady

*Moringa Oleifera*

- 25 x iron in spinach
- 17 x calcium in milk
- 15 x potassium in bananas
- 10 x vitamin A in carrots
- 9 x protein in yogurt

*National Geographic, November 2012*
Breadfruit Can Be Manna

- The Breadfruit Institute has found that the perennial trees produce more food in dry weight per hectare than corn, rice, or wheat.

- A fruit rich in iron, potassium, and Vitamin A precursors.

Source: Science Vol 342 18 October 2013
Rich source of Vitamin C

Phyllanthus emblica
Orange-fleshed Sweet Potato Rich in Beta carotene
Biofortification: High-iron Pearl Millet

ICTP 8203
ICRISAT-bred OPV
(70-74 ppm Fe)
With 10% Higher Yield

Marketed by NIRMAL SEEDS

86M86
Pioneer hybrid (54-64 ppm Fe)
Mango – Wheat (Horti-agri farm)

Maximising benefit from cubic volumes of air and soil
Agro-forestry System involving Fertilizer Trees

Building Soil Carbon Banks
Carbon Sequestration Potential of Different Land Use and Management Options, (adapted from IPCC 2000)

In this area, we face challenges such as the establishment of robust protocols and screening methods, which integrate non-invasive, automated high throughput measurement of relevant plant traits both under controlled greenhouse and field scenarios. Plant phenotyping is fast developing as a scientific field that aims to quantify accurately phenotypic traits, and give valuable prognoses for plant environment interaction.