Rice

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Overview

• Introduction
  – History
  – Taxonomy
  – Production and Consumption

• Phenology

• Dissection of Physiological Processes
  Underlying Yield

• Future Prospects
History

- Origin on estimate since Chinese did not keep accurate records
- Cultivation of Rice began in China in approx. 10500 BC
- Oryza was first spices to be domesticated
- Cultivation then spread to India around 4530BC and eventually the rest of Asia
Taxonomy

• Domesticated species origin comes two strains of Oryza genus of Poaceae Family
  – Asian Rice Oryza Sativa
  – African Rice: Oryza Glaberriva

• Wild Rice comes from the genus Zizania which is related
  – Can be domesticated or grown in wild
Global Rice Production
Global Rice Yield

Global Rice Yield Increase

Years

Yeild (t/ha)
Global Production and Consumption

- Global Production in 2007: 650,193,000 t
  - 91% in Asia, mostly from China and India
- Global Production has increased over 3 times since 1961
- Land use to produce rice has only increased 35% since 1961, roughly 115,000,000 ha to 151,000,000 ha
- Global Average yield per acre has increased from 1.87t/ac to 4.15
Lowland/ Terracing
Upland Rice production
Mechanized upland
Green Revolution

- Crops which were genetically modified to increase food production by increasing yields
- Dwarfing genes to reduce lodging from heavy heads - increase yield by fertility and pest management
- IR8 - first rice variety - cross between Indonesian and Chinese variety
Green Revolution

- High Yielding Varieties (HYV) were bred conventionally by agronomists.
- Later, a rice semidwarf gene was identified. Stem growth is reduced—photosynthetic assimilates can be used for grain production.
- HYV outcompete older varieties when irrigated, fertilized, and pesticides are used.
- In absence of these, traditional varieties may outyield the HYV.
Wheat yields in developing countries, 1950-2004

Yield (kg/ha)

Source: FAO
Green Revolution

- New ‘Super Rice’ was released in 2000- 35% yield increase
- Fewer but stronger tillers carrying more grains per florescence
- IR8 plant, half of the plant's weight is grain and half is straw, whereas the new Super Rice plant is 60% grain and 40% straw.
- Genetic material from maize was inserted into the rice plant. This raised the efficiency of photosynthesis
New Rice for Africa (NERICA)

• Interspecific cultivars to improve African rice variety yields
• West Africa- rice is the primary source of energy in diet
• Majority is imported. Improving yields would increase food security
• African rice, Oryza glabberima has profuse vegetative growth, smothering weeds, and is drought resistant
• However, O. glabberima has low yields, lodges, and may shatter
NERICA

- NERICA varieties- O. glabberima x O. sativa
- Resulted in heterosis- progeny grow faster, yield more and resist stress better than parents

- New varieties
  - Head size 100→400 grains
  - Yield 1 →2.5 ton/ha
  - Tolerate drought and infertile soils
  - better than Asian varieties
  - Taller, easier to harvest
Nitrogen

- Nitrogen is the major limiting nutrient
- Excessive N causes lodging and diseases
- Applying too much N can reduce yields as much as too little N
- Managing N in rice fields can be difficult
- Plant growth and yields are significantly and proportionally increased with levels of N
- Measuring N requirements mid-season can be difficult for growers
Rice and Nitrogen
Rice and Nitrogen

• Rice farmers use split applications for N. The # and rate of application can be varied.

• Ability to adjust # and rate allow the synchronization to real time demand by the crop

• Leaf colour charts allow farmers to estimate nitrogen demand of the crop by comparing the leaf colour to a chart
Early rice
Yield target: 6–7 t ha⁻¹

*All rates are given in kg mu⁻¹ (1 mu = 667 m²); 3.4 kg N = 20 kg ammonium bicarbonate or 7.4 kg urea.
Growth Stages of Rice

- Vegetative
- Reproductive
- Germination (0 days) - heading (55 days) - maturity (120 days)
Vegetative Stage

• Germination

• Early seed growth

• Tillering
  – Gradual plant height and increase in tiller number
  – Leaf emergence at regular intervals
  – Duration of vegetative stage dependent on N
    • Critical N content >7% in culm (stem) to keep tillering
  – Vegetative lag phase- from max tiller to first panicle
    • Tiller # decreases- increase in height & straw weight starts to level off
Reproductive Stage

• Starts when culm elongation begins
  – Also decline in tiller #, emergence of the last leaf
• Panicle initiation 25 days pre heading
• Anthesis starts on same day as heading
  – Fertilization within 6 hrs of spikelet flowering
    • Self fertilize
  – Great variation in panicle emergence from different tillers (10-14 day variation)
  – Variation in spikelet flowering within the same panicle
  – Spikelets flower from mid morn- shortly after noon
Rice anthesis
Ripening

• Immediately following fertilization
  – Milky, dough, yellow-ripe, mature
• Length of ripening 15-40 days depending on variety
• Yield determined by:
  • # panicles/ m²
  • # grains/ panicle
  • % ripe kernels
  • 1000gm weight
Mature Field of Rice
Problems with Kernel Development

- Cold weather injury
- Low temp during flowering = poor fertilization
- Rainy, cloudy, windy during flowering
- Nutrient deficiency during kernel development
- High temp, then dry winds= sun checked kernels
- Diseases
- Birds & insects
Amount of growth

- Tiller number
- Plant height
- Panicle number
- Grain weight

Days after germination

Germination → Emergence → Seedling → Active tillering → End of effective tillering → Maximum tiller number → Panicle primordia → Booting → Heading/anthesis → Milky Dough → Yellow ripe → Maturity

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Vegetative - Reproductive - Ripening
Growth, Development and Dry Matter Accumulation
Fig. 1. The relation between the number of main-stem visible leaves (i.e. the number of leaf tips) and days from seedling emergence in plants of rice.
Light Interception

![Graph showing light interception over time after transplanting with different symbols representing different conditions.](image)
LAI and Stage of development

1- Transplanting stage

2- Critical stage for effective tillering

3- Elongation stage

4- Booting stage

5- Heading stage

6- 5 days after heading

7- 15 days after heading

8- 25 days after heading

9- 35 days after heading

10- Maturity stage

WU Wen-ge et al. 2007
Leaf angle

Thomas R. Sinclair
U.S. Department of Agriculture,
Dry matter Accumulation

- Maximum LAI can varies 7.4–8.4, and depends on the cultivar (CRITICAL FOR DRY MATTER PRODUCTION)

- Leaf area duration (LAD) \ Senescence
LAI and stage of development

Relationships between grain yield and leaf area index at the full-heading stage in Akita 63 and the reference cultivars, 7.4–8.4
LAI and Stage of development

1- Transplanting stage

2- Critical stage for effective tillering

3- Elongation stage

4- Booting stage

5- Heading stage

6- 5 days after heading

7- 15 days after heading

8- 25 days after heading

9- 35 days after heading

10- Maturity stage

WU Wen-ge et al. 2007
PGR and stages of development

1- Transplanting stage

2- Critical stage for effective tillering

3- Elongation stage

4- Booting stage

5- Heading stage

6- 5 days after heading

7- 15 days after heading

8- 25 days after heading

9- 35 days after heading

10- Maturity stage

Booting stage-heading Maximum LAI

WU Wen-ge et al. 2007
Net assimilation rate (g/m² · d)

Rice growth period

WU Wen-ge et al. 2007
Dry matter accumulation and Grain Yield

- *Rice potential yield* → *Biomass Yield*

- $HI \ (SOURCE \ \ SINK)$

- $HI \ 0.45 \ and \ 0.5 \ depending \ on \ the \ cultivar$

- *Non-structural carbohydrate stored in culms and sheaths before Heading*

- *Cultivar*
DMA from elongation to heading related with the accumulation during the grain filling stage and yield.
The relationship between rice-yield attributes (grain yield, above-ground total biomass, spikelet per square metre) and growing-season mean maximum temperature (A–C), minimum temperature (D–F), or radiation (G–I). Yield-attribute data were obtained from irrigated field experiments in which crop management practices were optimized to achieve the highest possible yields from rice cultivar IR72 at the IRRI Farm in the dry seasons from 1992 to 2003. *Data From Peng et al., 2004*
Dry Matter RUE

a) 1.29 g.Mj\(^{-1}\)

b) 1.55 g.Mj\(^{-1}\)
Late Season\ Senescence
LAI and Stage of development

1- Transplanting stage

2- Critical stage for effective tillering

3- Elongation stage

4- Booting stage

5- Heading stage

6- 5 days after heading

7- 15 days after heading

8- 25 days after heading

9- 35 days after heading

10- Maturity stage

WU Wen-ge et al. 2007
Zhang et al., 2003
Late Season\ Senescence

Fig. 3. Relationship between the decrease in leaf blade N and leaf area reduction during two weeks after anthesis. Symbols are the same in Table 1. $y = -218.4 + 11.7 \times x$, $r = 0.875^{**}$.

Fig. 1. Relationship between sink size and LAI reduction during two weeks after anthesis. Symbols are the same in Table 1. $y = -1.93 + 5.19 \times 10^{-3} \times x$, $r = 0.840^{**}$.

Wada and Wada, 1991
Mid-day Photosynthetic Depression

- Lemont (Le): developed in Texas
- Qi Gui Zao (Qi): developed in South China
- Plants were grown in Southeastern US and Southeastern China, both in the laboratory and the field

Mid-day Photosynthetic Depression

Xanthophyll Cycle

- Once PPFD exceeds photosynthetic capacity damage is done to cellular membranes and photosynthetic machinery
- Sun adapted plants have more xanthophyll and are able to continue photosynthesis even at high PPFDs.
- Rice shows a depression in photosynthesis because it lacks a very high capacity for PPFDs.

Xanthophylls protect the plant by converting from one form to another
Mid-day Photosynthetic Depression

Xanthophyll Cycle

• Xanthophyll increases as PPFD increases
• Le/Qi respond to change in PPFD faster and is higher
• Le responds slowest and has lowest maximum
• Qi responds similar to Le/Qi only slower
Mid-day Photosynthetic Depression

- Le/Qi had 22% higher yield over 5 years
- Qi had always outperformed Le
- Grain quality was higher for the Le/Qi hybrid
- Le/Qi has a quicker time to heading: 5 d faster than Qi and 10 d than Le
- The differences in yield can be attributed to achieving maximum canopy photosynthesis quicker and maintaining it until harvest time
Increasing Harvest Index

Looking at Nitrogen Use Efficiency

- New Atkita variety has a better NUE than old O. japonica or other rice cultivars
- This gives the plant an advantage in all physiological aspects pertaining to yield
- Important for:
  A) Reducing environmental impact of nitrogen pollution
  B) Increase Yield

Increasing Harvest Index

• Above shows allocation of DM: panicles, sheaths, culms (white); leaf blades (top black); spikelets 1° (bottom black); spikelets 2° (lattice)

• Right shows no significant difference in N treatments or cultivars

• Means that photosynthetic potential between the treatments were the same, yet the partitioning was very different

• So why is there a difference in yield?
Increasing Harvest Index

- Sink capacity is larger for Akita at same [N] means more yield potential
- Better fertilizer recovery means that less need to be applied

<table>
<thead>
<tr>
<th>Year</th>
<th>N-treatment cultivar</th>
<th>Agronomic NUE (g g-N⁻¹)</th>
<th>Fertilizer recovery efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>High level</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Akita 63</td>
<td>76*</td>
<td>59</td>
</tr>
<tr>
<td></td>
<td>Yukigesyou</td>
<td>60</td>
<td>57</td>
</tr>
<tr>
<td></td>
<td>Single application</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Akita 63</td>
<td>109*</td>
<td>63</td>
</tr>
<tr>
<td></td>
<td>Yukigesyou</td>
<td>80</td>
<td>46</td>
</tr>
<tr>
<td>2001</td>
<td>High level</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Akita 63</td>
<td>79*</td>
<td>78</td>
</tr>
<tr>
<td></td>
<td>Toyonishiki</td>
<td>64</td>
<td>57</td>
</tr>
<tr>
<td></td>
<td>Single application</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Akita 63</td>
<td>85*</td>
<td>96</td>
</tr>
<tr>
<td></td>
<td>Toyonishiki</td>
<td>68</td>
<td>53</td>
</tr>
<tr>
<td>2002</td>
<td>High level</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Akita 63</td>
<td>63*</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Akitakomachi</td>
<td>51</td>
<td></td>
</tr>
</tbody>
</table>

Asterisk (*) indicates significant difference between Akita 63 and the reference cultivar, i.e., Yukigesyou, Toyonishiki or Akitakomachi in the same treatment at the 5% level (t-test).
Increasing Harvest Index

- Moderate increase, but demonstrates huge potential when applied to large scale production
- Proves small changes to physiological processes can have impact on yield

<table>
<thead>
<tr>
<th>Year</th>
<th>Cultivar</th>
<th>Dry matter (g m⁻²)</th>
<th>Grain yield (g m⁻²)</th>
<th>HI</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>Akita 63</td>
<td>1912 ± 60</td>
<td>1225 ± 79**</td>
<td>0.55</td>
</tr>
<tr>
<td></td>
<td>Yukigesyou</td>
<td>2003 ± 135</td>
<td>954 ± 72</td>
<td>0.41</td>
</tr>
<tr>
<td>2001</td>
<td>Akita 63</td>
<td>2017 ± 119</td>
<td>1173 ± 39**</td>
<td>0.50</td>
</tr>
<tr>
<td></td>
<td>Toyonishiki</td>
<td>1792 ± 172</td>
<td>956 ± 48</td>
<td>0.46</td>
</tr>
<tr>
<td>2002</td>
<td>Akita 63</td>
<td>1646 ± 204</td>
<td>937 ± 44*</td>
<td>0.50</td>
</tr>
<tr>
<td></td>
<td>Akitakomachi</td>
<td>1419 ± 93</td>
<td>765 ± 53</td>
<td>0.47</td>
</tr>
</tbody>
</table>
Stress Tolerance

Cold Stress

• Atkita- E.g. of N stress tolerant
• Cold, particularly in Japan, limits yield through photoinhibition
• Maximum quantum efficiency of PSII shown by chlorophyll florescence Fv/Fm

Fv/Fm decreases in cold temperatures, which results in a decrease in CO₂ assimilation

Stress Tolerance

Cold Stress

- The decrease in the rate of the linear electron transport by photoinhibition led to a decrease in the capacity for RuBP degeneration which resulted in the decrease in CO₂ assimilation
- This photoinhibition, (shown on last slide) effects the regeneration of RuBP
Putting DM in perspective

• US Corn grain yield (150bu/ac) = 6800kg/ha (14%)

• US rice grain yield = 7300kg/ha (14%)
  – Same as 161 bu/ac corn at 14%

• Average rice yield Egypt = 10100kg/ha (14%)
  – Same as 222bu/ac corn at 14%
Putting ENERGY in perspective

• Rice (grain)- 1530kJ/100g
• Maize (grain)- 1620kJ/100g

• US corn energy yield (150bu)= 1.18x10^8kJ/ha
• US rice energy yield (161bu corn equivalent)= 1.12x10^8kJ/ha

• Egypt rice energy yield (222bu corn equivalent)= 1.54x10^8kJ/ha
Aerobic Rice Production

- Area’s of intense rice production also have heavy population density’s = high water demand
- Aerobic Rice uses less moisture in production
Figure 5. Global average annual precipitation. (From H. L. Penman, "The Water Cycle." Copyright © September 1970 by Scientific American, Inc. All rights reserved.)

Table 2. Biophysical and socio-economic performance indicators of aerobic rice and lowland rice produced by farmers at Guanzhuang and Hanjiachuan.

<table>
<thead>
<tr>
<th>Site</th>
<th>Guanzhuang</th>
<th>Hanjiachuan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rice type</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Farmer</td>
<td>1 2 3 Mean</td>
<td>1 2 3 Mean</td>
</tr>
<tr>
<td>Area (ha)</td>
<td>0.4 0.2 0.3</td>
<td>0.1 0.1 0.1</td>
</tr>
<tr>
<td>Yield (t ha(^{-1}))</td>
<td>4.7 6.1 6.6</td>
<td>7.7 7.9 8.3</td>
</tr>
<tr>
<td>Irrigation (mm)</td>
<td>550 538 539</td>
<td>1129 1355 1390</td>
</tr>
<tr>
<td>Total water (mm)</td>
<td>620 608 609</td>
<td>1199 1425 1460</td>
</tr>
<tr>
<td>Total water productivity (g kg(^{-1}))</td>
<td>0.75 1.01 1.08</td>
<td>0.95 0.64 0.55</td>
</tr>
<tr>
<td>Irrigation water productivity (g kg(^{-1}))</td>
<td>0.85 1.14 1.22</td>
<td>1.07 0.68 0.58</td>
</tr>
<tr>
<td>Paid-out costs ($ ha(^{-1}))</td>
<td>352 375 355</td>
<td>266 338 321</td>
</tr>
<tr>
<td>Own labor (h ha(^{-1}))</td>
<td>270 465 398</td>
<td>813 750 931</td>
</tr>
<tr>
<td>Price of labor ($ d(^{-1}))</td>
<td>1.9 1.9 1.9</td>
<td>1.9 1.9 1.9</td>
</tr>
<tr>
<td>Price of grain ($ kg(^{-1}))</td>
<td>0.15 0.15 0.15</td>
<td>0.15 0.15 0.12</td>
</tr>
<tr>
<td>Production value ($ ha(^{-1}))</td>
<td>698 920 988</td>
<td>899 1181 969</td>
</tr>
<tr>
<td>Gross returns ($ ha(^{-1}))</td>
<td>345 545 633</td>
<td>633 843 649</td>
</tr>
<tr>
<td>Net returns ($ ha(^{-1}))</td>
<td>282 437 539</td>
<td>419 443 667</td>
</tr>
</tbody>
</table>

Note: all costs and prices converted from Yuan into US dollar using \(1\text{Y} = 0.125\text{ }\).
Aerobic Rice Production

• Han Dao Variety
• Initial research has shown some varieties to of yield 4.7-5.3 t/ha
• Uses around a 1/3 of water grown in lowland environment
• Requires improved breeding and further development before becoming an economical replacement for lowland rice
Thank You