Current Challenges and Directions for Rice Cultivar Development

The following article is reprinted in large part from a presentation given in Beijing, China, on October 21, 2009, at the China-U.S. Relations Conference. As an aid in understanding the units that are used in this paper, a metric ton is equal to 2,200 lbs. To convert from metric tons per hectare to lbs per acre, divide by 1.1 and add three 0s. As an example, 8 metric tons/ha equals ca. 7,300 lbs/acre. To convert from $/ha to $/acre, divide by 2.5.

Worldwide Rice Production

Rice is a staple food for a large part of the world. As global population size increases, rice production must increase to avert wide spread shortages. Global rice production is increasing at a rate of nearly 10 million metric tons per year and total production is expected to reach 700 million metric tons by ca. 2012 (Fig. 1). China is the largest producer of rice, with ca. 200 million metric tons produced during each of the past 20 years. In contrast, Myanmar (Burma), which has the highest per capita rate of rice consumption (226 kg/year), produces ca. 2.4 million metric tons per year. As an interesting statistic, were the U.S. to export to China every single grain of rice it produced in 2008 (9.24 million metric tons), it would be sufficient to last China 16.9 days. While U.S. production is miniscule when compared with China’s production, the U.S. nevertheless is the third largest rice exporting country behind Thailand and Vietnam.

Regional Rice Exports and Imports

Regional exports and imports of rice tell an interesting story. Asia leads in exports and imports,
Welcome to the October issue of Texas Rice. This issue highlights an article that was developed from a presentation given this month in Beijing, China at the China-U.S Relations Conference. The article provides a broad overview of global rice production and current activities by scientists in Texas that focus on rice varietal development. The session that I spoke at focused largely on the current state of transgenic crop production in China and in the U.S. Although rice that has been genetically modified using genes from other organisms is not a commercial reality, the ever-burgeoning world population clearly conveys the message that we will need to use every production tool in our arsenal, including transgenics, to meet the growing demand for food. Transgenics can help us achieve a goal of global food security by reducing yield losses caused by biotic stresses, such as from insect injury, and potentially by improving the yield performance under currently suboptimal growth conditions, such as poor soil conditions or limited levels of fertilizers.

The following figure (Fig. 1) derived from global population statistics provided by the U.S. Census Bureau (http://www.census.gov/ipc/www/idb/) illustrates the change in population growth from the birth of Christ into the near future, highlighting the ever increasing pressure placed on world food supplies. As points of reference, world population size reached 1 billion around 1850, 2 billion by 1930, 3 billion by 1959, 4 billion by 1974, 5 billion by 1987, and 6 billion by 1999, with 6.77 billion on the earth today. By 2020, world population size is expected to reach 7.6 billion, with an additional 73 million people added to the global population each year. Looking at the data slightly differently, 80 years were required for the world population to increase from 1 to 2 billion, while only 13 years are expected to be required to increase from 6 billion to 7 billion. While good intentions aim at bringing about sensible population growth across the world, history suggests that at least for the short-term, the only way to insure adequate food supplies in the future will be by increasing the productivity on each unit area of land. With average per capita rice consumption currently averaging 143 lbs/person/year, 10.4 billion lbs of additional rice production will be needed each and every year to feed the 73 million additional

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Fig. 1. World population size.
Factors Affecting Global Rice Supplies

An examination of the global rice production and global population size shows that the rate of production has been greater than the rate of population growth. However, the change in amount of harvestable rice land is an ominous statistic, with the rate of increase obviously slowing. Rice is currently grown on ca. 158 million hectares, with further increases likely to be extremely small or possibly negative during each of the next 10 years. A number of factors place downward pressure on further increase in global rice production, not least of these being 1) limited arable land, particularly in parts of Asia where the need is the greatest, 2) increased competition for rural lands and fresh water across much of the world, 3) limited monetary purchasing power by countries that most need rice, particularly many developing countries in Asia, Africa and South/Central America, and 4) increasing constraints on world fertilizer production (Fig. 3). China appears to be experiencing the greatest decrease in arable land, having reached its peak harvested acreage in the mid-
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1970s. In contrast, Myanmar’s production oscillated from 1960 to ca. 1990, but has generally increased from 1990 until a couple of years ago. A number of factors place upward pressure on global rice supplies. Decreasing rice consumption by increasingly affluent Asian countries, such as China and Japan, is lessening per capita consumption. Opportunities for further yield increases through conventional and transgenic inbred and hybrid cultivar development holds tremendous potential for increasing supplies. Further improvements in agronomic management continue to push yields towards their potential, while improving insect, weed, and disease control continues to reduce losses. An unknown on the supply side are pending production programs proposed by China in West Africa. Depending on their success, this has the potential to greatly increase global rice production.

Grain Yield Improvements

Increases in rice yields have contributed greatly to addressing increasing global demand. From the end of the Second World War in 1945 to the present, rice yields in Texas have increased ca. 450% from about 1.8 to over 8 metric tons/ha, representing a 2.2% annual rate of increase (Fig. 4). Putting these numbers in perspective, Texas rice growers now produces as much rice on a hectare of land that it took to produce on 4.5 hectares in 1945. About 45% of the yield increase in Texas is attributed to increases in genotype yield potential with the remaining increase due to improvements in agronomic and pest management.

Globally, rice yields have increased as well. Yields have reached ca. 7.6, 6.6, and 2.6 metric tons/ha in
the U.S., China, and Myanmar, respectively (Fig. 5). From 1960 to 2008, yields have increased at an annual rate of 74, 98, and 32 kg/ha for these countries. In contrast, global rice yields averaged ca. 4.3 metric tons/ha in 2008, with an annual rate of increase of 52 kg/ha. The high variability in both yield and the rate of yield increase comparing different countries suggests there is considerable room for further improvement in global rice production, even with the looming threat of a decrease in arable land.

**Inbred Cultivar Improvement in Texas**

Historically, much of the increase in rice yields in Texas has been achieved using inbred cultivars (Fig. 6). While average yields are ca. 8 metric tons/ha, a significant number of producers consistently average nearly 14 metric tons/ha, with a record yield of ca. 17 metric tons/ha. Improved yielding inbred cultivars continuing to be developed, with data from the Texas rice cultivar development program suggesting the yield of future inbred rice can be increased by 20 to 30% over the currently best inbreds.

**Hybrid Rice Research in Texas**

During the past 6 years, hybrid cultivars have become a significant part of Texas and U.S. rice production, with ca. 25% of the acreage now planted to hybrids. Hybrids currently offer higher yields than currently achievable with inbred, and there is no doubt that hybrids will gain an increased share of the U.S. rice production market. With this said, hybrid production in the U.S.

Fig. 5. Global, China, Myanmar, and U.S. rice yields per hectare from 1960 to 2008.

Fig. 6. Pedigree inbred rice breeding.
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greater cost of hybrid seed in the U.S. (ca. US$230/ha), compared to the cost of conventional inbred seed (ca. US$50/ha).

Plant breeding in Texas on hybrid rice focuses on developing locally adapted cytoplasmic male sterile lines, which are key to establishing a 3-line hybrid breeding program, developing locally adapted temperature sensitive mutants, which are key to establishing what is referred to as a 2-line hybrid breeding program, and conducting research that focuses on improving our understanding of the physiological basis for why hybrids are superior yielding and whether the traits that afford improved yield performance in hybrids can be incorporated into inbred cultivars. Our research shows that hybrids possess a number of traits that provide them with an advantage (Fig. 7). To discuss but a few, the canopy structure of hybrids provides up to 30% greater light interception, adjusted for differences in leaf area. Hybrids have a greater ability to mine the soil for nitrogen, which supports a higher rate of photosynthesis. Hybrids also have higher tiller and leaf node production rates, and a greater demands for biomass by organs, which results in less photosynthesis feedback inhibition, allowing the crop canopy to grow more quickly and produce photosynthate at a 21% higher rate. In a recent experiment, our team documented a 37% average increase in biomass produced by hybrids compared to

Fig. 7. Three-line hybrid rice breeding and observed differences in light interception, photosynthesis, and biomass.

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the parental inbreds. However, we also documented considerable phenotypic variability within the inbreds, with a number of inbred lines appearing to perform on par with some of the best hybrids. The question is still out there as to whether inbreds can be developed having the yield advantages of hybrids.

**Herbicide Tolerance and Cold Tolerance**

A major component of the Texas inbred- and hybrid-breeding programs focuses on incorporating improved traits into breeding material. Mutation breeding is a method used to develop improved traits for a wide number of crop species. Mutation breeding has been used by rice plant breeders across the world to develop germplasm having superior cooking quality, disease resistance, herbicide resistance, cold tolerance seedling vigor, and reduced internode elongation (reduces lodging). Herbicide resistance and cold tolerance seedling vigor are currently the greatest focus of the Center’s rice mutation breeding efforts by Dr. Tabien and his team (Fig. 8). A number of promising herbicide resistant lines have been developed and efforts have begun to incorporate non-transgenic herbicide resistance into desirable inbred and hybrid cultivars. Cold tolerance, although not as far long in its development, is potentially even more valuable in that it offer the opportunity for the rice plants to out-compete early season weeds, thereby reducing the frequency of herbicide spraying, and increasing grower profits. Cold tolerance also offers the opportunity to expand rice production into areas previously outside of rice’s normal production range.

**Transgenic Breeding**

Transgenic breeding has played a relatively small role in the Texas cultivar development program. The relatively recent contamination of U.S. rice by Bayer’s Liberty-Linked gene caused major problems and suggests the need for extreme care when dealing with transgenic material. Historically, transgenic rice transformation has largely made use of either Agrobacterium or gene gun insertion methods (Fig. 9). Such methods have resulted in a number of successes across agriculture, the most noticeable being the development of insect resistant BT cotton and roundup resistant corn, cotton, rapeseed, and soybean. Two fairly recent events suggest that transgenic production will soon penetrate the world rice market. Firstly, China, India, and a number of other countries have developed herbicide tolerant rice cultivars and appear on the verge of making public releases. More importantly, at least in the long-term, transformation methodology is rapidly coming of age, as is indicated by the announcement that zinc-finger nucleases (ZFNs) allow site-specific insertion of transgenic material, avoiding many of the problems with random insertion methods such as found with Agrobacterium and gene gun methods. ZFNs have the additional advantage of providing transfer efficiencies that are much higher than can currently be achieved with other methods, providing for much greater speed of development.

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Model-Assisted Selection

All current forms of inbred and hybrid rice production, including conventional, mutation, and transgenic breeding share a common trait. It typically takes a large number of years from the initial screening to the selection and release of a new and improved cultivar. For every new cultivar that is commercially released, thousands of lines are rejected at various stages. This process takes ca. 7 to 12 years from an initial cross to the screening and release of a commercial cultivar. The difficulty is in determining which phenotypic traits a plant breeder should select when developing a superior yielding cultivar. This issue is made that much more difficult in rice by the extremely high phenotypic plasticity found in the rice genome. In other words, the genetics of rice allows a rice breeder to develop a near infinite number of rice plant types, most of which are unsuitable for commercial production. While traits that involve grain quality and disease resistance are “relatively” easy to select, traits involving crop growth, development, maturation, and yield are not.

Conceptually, two approaches can be taken to speed the rate of cultivar development. The first involves increasing the number of plant breeders, while the second focuses on developing improved criteria that provide a quantitative structure and direction to cultivar development so that undesirable traits can be eliminated and superior performing combinations of traits selected for more quickly.

Our approach has been to hire as assistant hybrid rice breeder and to integrate crop modeling into the cultivar selection process (Fig. 10). The physiologically based crop model synthesizes our current knowledge of rice and its response to physical and biotic stresses. The rice population simulation model (RicePSM) has been rigorously verified and validated for a wide range of rice phenotypes and played an integral role in our on-going efforts to develop a water efficient cultivar for the Upper Gulf Coast of Texas. RicePSM is currently being incorporated into a web-based interface, which we hope to release by next year, which will allow access by a wider number of scientists. RicePSM is build on physiological processes involving CO$_2$ and N uptake and allocation that are in turn controlled by atmospheric °C, photosynthetically active radiation (PAR), CO$_2$, and soil N. The web-based implementation automatically links RicePSM to geo-referenced climatic, soils, and cropland databases and accurately forecasts the collective impact of different combinations of primary phenotypic traits on rice maturity, yield, and yield stability. In essence, RicePSM allows the users to simulate numerous combinations of phenotypes and climatic conditions, and when combined with focused field experiments speeds the rate of cultivar development and improves our understanding of how traits interact to effect rice growth, development, and yield, and provides greater focus to cultivar development.

Our preliminary results suggest that model-assisted selection has the potential to increase the speed of cultivar development by ca. 30%. When
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combined with DNA marker-assisted selection, the rate of developing new cultivars is expected to be even greater. As our knowledge of gene sequencing and functional genomics improves, so will our ability to make greater use of quantitative approaches to rice cultivar development. *

*Article by L. T. Wilson, S. O. PB. Samonte, J. C. Medley, Y. Yang, and R. E. Tabien, Texas A&M University System, AgriLife Research and Extension Center Beaumont, Texas

From the Editor ...

people who will be added to the world every year. With the average yield of a rice field averaging 3,785 lbs/acre worldwide, we either need to increase the amount of arable land dedicated to rice production or increase rice yields. While there is room for further increases in per acre levels of rice production, this will require increased use of nitrogen fertilizers and petroleum bases pesticides, the first of which is in ever decreasing supply. In the case of arable, it has reached a peak in almost every country in the world and for rice it has begun to decrease globally. While China appears to be negotiating with African nations to develop large-scale modernized rice production efforts, the vote is still out on the likelihood of their endeavor succeeding. At present, global population size is increasing at a rate of 1.15% per year. In contrast, global rice production has increased at a rate of 1.41% from 1960 to 2008. These numbers are encouraging, but the difference between the rates of population growth and rice production are sufficient close that a natural disaster or a political disturbance could upset this fragile balance.

Recent forecasts of increasing rice prices in 2010 are a welcome sign for rice producers, and would spur a temporary increase in global production, but probably not to a level that would provide significant change in global supplies. Properly directed and monitored transgenic crop development would certainly offer greater food security and will help to buffer the global population from food shortages. While transgenics remains as a philosophical concern to many around the globe, it is undoubtedly one of the most promising means available to us to stay in front of the rapidly escalating population curve.

Sincerely,

L.T. Wilson
Professor & Center Director
Jack B. Wendt Endowed
Chair in Rice Research

Rice Crop Update

As of October 23, 2009, 99% of the main crop rice acreage in Texas had been harvested, while 6% of the ratoon crop had been harvested.

Weekly updates on the acreage and percentage of rice grown in Texas that are in the various growth stages are available at our website at http://beaumont.tamu.edu/CropSurvey/CropSurveyReport.aspx.

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L.T. Wilson
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Jack B. Wendt Endowed
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