

## SUMMARY: PAPERS PRESENTED AT INTERNATIONAL WORKSHOP ON INCREASING WHEAT YIELD POTENTIAL, CIMMYT, OBREGON, MEXICO, 20–24 MARCH 2006

### Challenges to international wheat improvement

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#### INTRODUCTION

Wheat is grown on 210 million ha throughout the world producing approximately 600 million tonnes of grain (10 year average; FAO 2005) and providing on average one fifth of the total calorific input of the world's population (FAO 2003). For some regions such as North Africa, Turkey and Central Asia, wheat provides half of total dietary energy intake. Of the cultivated wheat area, half is located in less developed countries where there have been steady increases in productivity since the green revolution, associated with genetic improvements in yield potential, resistance to diseases and adaptation to abiotic stresses (Reynolds & Borlaug 2006*a, b*) as well as better agronomic practices (Derpsch 2005). Nonetheless, challenges to wheat production are still considerable, especially in the developing world, not only because of increased demand but also because of the increased scarcity of water resources (Rosegrant 1997; WMO 1997), ever more unpredictable climates (Fischer *et al.* 2002), increased urbanization and loss of good quality land away from agriculture (Hobbs 2007), and decreased public sector investment in agriculture and rural affairs (Falcon & Naylor 2005). To meet demand in a sustainable way, more resources are required to breed a new generation of genetically improved cultivars as well as implement resource-conserving agronomic management practices.

A symposium was organized by the International Maize and Wheat Improvement Center's Global Wheat Programme (CIMMYT), with support from the Australian Centre for International Agricultural Research (ACIAR), in Obregon, NW Mexico in March 2006, with the view of bringing together wheat researchers worldwide to present and discuss their ideas on how to address some of these pressing

issues. The ideas are presented in the current and previous issues of the *Journal of Agricultural Science, Cambridge*, as well as in a special issue of *Euphytica* later in 2007. The present paper summarizes the papers published in vol. 145, issues 1, 2 and 3 of the *Journal of Agricultural Science, Cambridge*, that address issues relating to the physiological basis of yield potential and new technologies for increasing input use efficiency of wheat-based cropping systems.

#### PROGRESS IN UNDERSTANDING THE PHYSIOLOGICAL BASIS OF YIELD

Two papers review recent work on the physiological basis of genetic increase for yield potential in wheat (Fischer 2007; Foulkes *et al.* 2007), with the latter focusing more on winter wheat. Data from the last 10 years in NW Mexico indicate that yield potential progress in CIMMYT spring wheat has slowed to around 0.50% per year although physiological understanding has advanced. New research reinforces the importance of spike dry weight ( $\text{g/m}^2$ ) at anthesis in yield determination and so lengthening of the spike growth period through manipulation of sensitivity to photoperiod looks promising, a subject that is addressed in more depth in the paper by Miralles & Slafer (2007). Despite more kernels/ $\text{m}^2$  the latest wheat cultivars still appear to be largely sink-limited during grain filling, while evidence from wheat and other cereals indicates the importance of increased photosynthetic activity before and around flowering to achieve increases in yield potential (see also Reynolds *et al.* 2007). Fischer (2007) highlights the need to better define and utilize traits that confer lodging resistance. He also refers to recent advances in techniques for elucidating the physiological basis of genotype by year interactions. This is specifically addressed in the paper by Vargas *et al.* (2007): path analysis for genotype  $\times$  environment interactions

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using structural equation modelling enables a number of response variables to be modelled simultaneously while partitioning significance to interaction with specific weather parameters during the growth cycle.

Foulkes *et al.* (2007) point to the increasing number of reports of yield progress that is associated with biomass (in contrast to previous associations with partitioning alone). In winter wheat recent biomass progress was related to pre-anthesis radiation-use efficiency (RUE) and water-soluble carbohydrate (WSC) content of stems at anthesis. They also highlight the value of introductions of alien genes into wheat germplasm, e.g. the 1BL.1RS wheat-rye translocation and the 7DL.7Ag wheat-*Agropyron elongatum* translocation. Foulkes *et al.* (2007) provide a list of traits that their analysis has identified as high potential candidates to raise winter wheat yield potential in NW Europe including: optimized rooting traits, an extended stem-elongation phase, greater RUE, greater stem WSC storage and optimized ear morphology.

Miralles & Slafer (2007) and Reynolds *et al.* (2007) consider the issue of sink and source limitations in some detail. The former sketch out evidence, a considerable amount of which has been produced by Argentinean scientists, indicating that further increases in grain number/m<sup>2</sup> may be achieved through fine-tuning pre-anthesis developmental patterns to increase duration of the rapid spike growth period (RSGP) without altering flowering time. They report that there is genotypic variation in the relative duration of phenophases prior to anthesis and that theoretically photoperiod sensitivity could be manipulated to slow down and, therefore, prolong the floret primordial stage to achieve more fertile florets. However, genetic understanding is limited and quantitative trait loci (QTL) analysis is indicated to identify genetic markers for which they and their colleagues have already provided a substantial background of phenotypic data. The study by Reynolds *et al.* (2007) looks at both source and sink (SS) limitation in populations of random sister lines to establish a more definitive link of SS traits with productivity. The SS traits formed three main groups relating to (i) phenological pattern of the crop, (ii) assimilation capacity up until shortly after anthesis, and (iii) partitioning of assimilates to reproductive structures shortly after anthesis. The largest genetic gain in performance traits was associated with the second group; however, traits from the other groups were also identified as being genetically linked to improvement in yield and biomass. Principal component analysis indicated potential for additive gene action if complementary physiological traits are combined through breeding.

Parry *et al.* (2007) considered the issue of increasing assimilation capacity at the cellular level through overcoming the limitations of ribulose-1,5-bisphosphate carboxylase/oxygenase (Rubisco). Low activity

and the competing reactions catalysed by Rubisco are major limitations to photosynthetic carbon assimilation in C3 plants and they present the latest evidence that these subjects could be most effectively addressed by introducing Rubisco with a higher catalytic rate and/or better ability to discriminate between gaseous substrates. While enzymes with desirable traits have been identified, the technology is not available to incorporate them into crop species. They also suggest another approach via increasing the concentrations of substrates, CO<sub>2</sub> and ribulose biphosphate (RuBP) at the active site of Rubisco, much like in C4 plants.

Another issue addressed by the symposium was the use of physiological selection criteria for high yield environments. Although these data are reported elsewhere, they demonstrated the value of stomatal aperture-related traits (canopy temperature, leaf conductance and carbon isotope discrimination) in identifying high yielding genotypes among both random populations of inbred lines (Condon *et al.*, in press *a, b*) as well as breeder-selected material (Van Ginkel *et al.* 2004*a*, in press *b*). Parallel studies showed that a number of spectral reflectance indices also have considerable potential in selecting for yield (Babar *et al.* 2006*a*) and biomass (Babar *et al.* 2006*b*) in random inbred lines as well as advanced breeding lines. However, the aim of applying a physiological or molecular marker in breeding is to increase the efficiency of selection by reducing costs or increasing turnover. One of the papers presented an economic assessment of the use of physiological selection for stomatal aperture-related traits in CIMMYT's wheat breeding programme (Brennan *et al.* 2007). The analysis lent strong support for their potential value in reducing costs, for example by discarding physiologically substandard lines prior to extensive yield testing.

#### AGRONOMIC AND ENVIRONMENTAL STRATEGIES FOR RAISING AND SUSTAINING PRODUCTIVITY

While CIMMYT and other research groups within the Consultative Group for International Agricultural Research (CGIAR) have made major contributions to agricultural development, experts in geographical information systems (GIS) postulated that the continued ability to make far reaching contributions can only be facilitated by an increased ability to collect, analyse and assimilate large amounts of spatially orientated agronomic and climatic data (Hodson & White 2007). They state that understanding the geographic context of wheat production is crucial for priority setting, promoting collaboration, and targeting germplasm or management practices to specific environments. They described how modern GIS techniques can be used to help predict the effects of

climate change and classify production environments by combining biophysical and socioeconomic criteria. Regional-scale modelling of dynamic processes such as disease progression or crop water status provide, in combination with socioeconomic forecasting, a set of predictive tools that can be applied in determining priorities for genetic improvement. They are equally applicable for developing long-term cropping systems strategies aimed at maximizing the productivity of agro-ecosystems through the application of appropriate conservation type agricultural practices that incorporate local microeconomic factors (Dixon *et al.* 2007).

Conservation agriculture (CA) is a resource-conserving agronomic management practice that combines minimal soil disturbance (no-till) and permanent soil cover (mulch) with rotations. Hobbs (2007) describes what this practice is and why it is important for future food production. It is an improvement on conservation tillage which is best described as an intermediate step between normal tillage agriculture and CA, in which minimal tillage is combined with mulch to reduce wind and water erosion and increase water infiltration into the soil. This paper goes on to describe the physical, biological and chemical benefits of CA that is now practised (no-till acreage) on almost 100 million ha in the world, especially the South American countries of Brazil and Argentina. Additional benefits are economic (less cost and at least equal yield to traditional farming) and social (less time). The paper also explains the importance of suitable equipment development to enable farmers to adopt this green technology. Ransom *et al.* (2007) also describes a similar no-till, crop rotation system for dryer regions of North Dakota that results in significant yield increases and protects the productivity of the soil. That paper did not find similar results for wetter areas of North Dakota (again emphasizing the importance of local factors) but did show benefits of fungicide application for scab control. They conclude that identifying or developing crop management that exploits positive genotype by management interactions is needed.

CA is also becoming popular in South Asia in the rice-wheat systems of the Indo-Gangetic Plains (IGP). Gupta & Sayre (2007) use this case study as an example of improved resource conservation technologies (RCTs) that have led to improved profit, yields and impacted various environmental factors when zero-till was applied to wheat following rice harvest. Farmers were encouraged by the results and in 2005/06 season nearly 3 million ha of wheat were planted this way. The paper describes various RCTs that have been introduced in the past 10 years including laser levelling, crop diversification, and even promising results with no-till and direct seeded rice, the latter being important for 'double' no-till systems and better soil physical and biological properties.

Raised bed planting technologies are a further improvement on CA on the flat. Sayre *et al.* (in press) uses the data collected in the Yaqui Valley in NW Mexico as a case study of the findings of this technology in an irrigated wheat-maize system in a long-term trial managed over the past 15 years. Farmers have mostly shifted in the Yaqui valley to planting irrigated wheat (and most other crops) on beds rather than on the flat (with basin irrigation), however, still using conventional tillage. Bed planting was adopted because of the 30–40% savings in water use. Sayre *et al.* (in press) present convincing data that shows that it is feasible for permanent, raised bed, CA technologies to provide opportunities to reduce tillage dramatically, save water and costs, manage retained residues on the soil surface and diversify crop rotations resulting in the same physical, biological and chemical benefits outlined above in the Hobbs (2007) paper.

Reduced fertilizer use efficiency can result in unnecessary costs to farmers but also negative effects on the environment (pollution of groundwater). With a likely increase in nitrogen fertilizer costs to farmers anticipated in the next few years, largely due to rising fossil fuel prices, increased nitrogen use efficiency (NUE) is a crucial requirement for future food production. Two papers, Ortiz-Monasterio & Raun (2007) and Girma *et al.* (2007), looked at ways to improve NUE in wheat. The Ortiz-Monasterio & Raun paper was based on data collected from the Yaqui Valley in NW Mexico where NUE has been estimated to be only 0.31. They evaluated the use of N-rich strips together with the 'GreenSeeker™' sensor and a crop algorithm as a tool to improve NUE in spring wheat against conventional farmer use of nitrogen. The results showed, on average, farmers could save 69 kg N/ha without a yield penalty; this represents a saving of US\$ 62/ha. On larger (10 ha) fields farmers could improve farm income by US\$ 50/ha just using the GreenSeeker™ sensor technology. Girma *et al.* used the same GreenSeeker™ normalized difference vegetation index (NDVI) sensor, calibration stamp (CS), N-rich strips and ramped calibration strips (RCS) to improve top-dress nitrogen efficiency in winter wheat in Oklahoma, USA. They obtained similar benefits and conclude that the simplicity of these technologies means they can be readily applied by farmers in developed and developing countries. The RCS method is designed to include more pre-plant N and is more efficient at predicting top-dress N needs.

The adoption of new technologies by farmers is a prerequisite for equating technology advances to benefits that would contribute substantially to the Millennium development goals (MDG). Dixon *et al.* (2007) draws on a wide spectrum of recent literature for diagnosing the adoption of improved technology and measuring impact. The paper looks at input value

chains, farm household characteristics and the output value chain in a U-impact pathway to determine the rate and extent of adoption of improved varieties and practices, the magnitude of impacts and the potential for feedback loops leading to improved functioning of the input–output chains. The U-impact pathway proposed in the paper provides a framework to identify a set of beneficiaries which extend beyond producers and consumers to estimate the wider benefits to technology. They conclude that additional metrics may be needed to estimate the wider benefits of crop improvement, such as poverty, health and social capital. The implication of the results suggest that the benefits accruing to agricultural research may be greater, and more widely distributed across the economy, than previously recognized and strengthens the case for increased investment in agricultural science.

### CONCLUDING REMARKS

The slow though steady rate of yield potential increase in wheat is insufficient to meet predicted global demand. In the last two decades, however, research has made significant progress in a number of areas that if brought to a common platform have the potential to achieve substantial increases in productivity at the farm level. These areas include (i) improved understanding of the physiological and biochemical basis of yield and RUE in wheat, (ii) genetic tools that would permit markers for traits

associated with improved yield and RUE to be rapidly developed, (iii) a new generation of statistical tools which permit genotype by environment interaction to be dissected into its genetic and physiological components, and (iv) a rapidly increasing body of practical knowledge on how to implement CA practices that would both raise and stabilize the environmental threshold on which genetic yield potential is expressed. CIMMYT, with its expertise in germplasm development, phenotyping, strategic agronomy, use of statistical models and practical application of molecular markers in breeding in addition to its well-developed network of scientists in national programmes and advanced research laboratories around the world, is strategically positioned to provide a focal point for these disciplines.

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