International Symposium on Wheat Yield Potential:

Challenges to International Wheat Breeding

Days Inn, Ciudad Obregón, Sonora, Mexico
March 20-24th, 2006

EXTENDED ABSTRACTS

ACIAR

CIMMYT

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Sponsors:

- Australian Centre for International Agricultural Research (ACIAR)
- International Maize and Wheat Improvement Centre (CIMMYT)

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Matthew Reynolds (Chair: Scientific agenda & logistics coordination)
Diana Godinez (Administrative support)
David Poland, Miguel Mellado, Wenceslao Almazan (posters & abstracts)
Arnoldo Amaya (travel, and local logistics)
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CONTENTS

ORAL PRESENTATIONS

Borlaug, N.E.
International Collaborative Wheat Improvement: Future Challenges 1

Sears, R.G.
New Challenges in Wheat Breeding: Increasing Yields in Sub-optimal Environments 3

Rajaram, S. and Braun, H.-J.
Wheat Yield Potential in Sustainable Agriculture Model 4

Singh, R.P., Huerta-Espino, J. Sharma, R. and Joshi, A. K.
High Yielding Spring Bread Wheat Germplasm for Irrigated Agro-ecosystems 5

Chatrath, R., Mishra, B., Joshi, A.K. and Ortiz Ferrara, G.
Challenges to Wheat Production in South Asia 6

Scheeren, P.L., Caierão, E., e Silva, M.S., Nascimento Junior, A., Caetano, V.R., Bassoi, M.C., Brunetta, D., Albrecht, J.C., Trindade, M.G. and Sobrinho, J.S.
Challenges to Wheat Production in Brazil & Related Agro-ecosystems 7

Ortiz, R., Trethowan, R., Ortiz Ferrara, G., Iwanaga, M., Dodds, J.H., Crouch, J.H., Crossa, J. and Braun, H.-J.
Shuttle Breeding: Ways Forward 8

Ortiz Ferrara, G., Joshi, A.K., Chand, R., Bhatta, M.R., Mudwari, A., Thapa, D.B., Sufian, M.A., Witcombe, J.R. and Virk, D.S.
Partnering with Farmers to Speed up the Adoption of New Technologies in South Asia 9

Van Ginkel, M., Reynolds, M., Trethowan, R., Hernandez, E. and Condon, A.
Complimenting the Breeders Eye with Canopy Temperature Measurements 10

Ogbonnaya, F., Dreccer, F., Ye, G., Trethowan, R., Lush, D., Shepperd, J. and van Ginkel, M.
Yield of Synthetic Backcross-derived Lines 12

DePauw, R.M., Clarke, J.M., McCaig, T.N., Knox, R.E., Clarke, F.R., Fernandez, M.R. and Wang, H.
Breaking Negative Correlations 13

R.J. Peña
Preserving End-use Quality While Enhancing Grain Yield 14

Duveiller, E., Singh, R.P. and Nicol, J.
Challenges to Maintaining Wheat Productivity: Pests, Diseases and Potential Epidemics 15

Eagles, H.A., Cane, K., Moody, D.B., Eastwood, R.F., Hollamby, G.J., Kuchel, H. and Martin, P.J.
Using Plant Breeding Data to Move from Genotype-by-environmental interactions to gene-by-environmental interactions 16

Hede, A. and Braun, H.-J.
International Winter Wheat Trials: Adaptation and Trends 17

Trethowan, R. and Crossa, J.
Forty Years of International Bread Wheat Trials: What Have We Learned? 18

Ammar, K., Lage, J., Villegas, D., Crossa, J., Hernandez, E. and Alvarado, G.
Association among Durum Wheat International Testing Sites and Trends in Yield Progress over the Last Twenty Two Years 19

Chapman, S.C., Mathews, K.L., Trethowan, R., Singh, R.P., Crossa, J., Pfeiffer, W., van Ginkel, M., DeLacy, I.H.
Global Adaptation of Near-isogenic Spring Wheat Lines Contrasting for Major Reduced Height Genes 21

Morgounov, A.I. and Trethowan, R.
Avenues to Increase Yield of Short Season High Latitude Wheat in Northern Kazakhstan and Siberia 22

Zhou, Y. Sui, X.X., Xia, X.C., Zhang, X,K., He, Z.H. and Zhang, G.S.
Genetic Improvement of Yield Potential and Associated Traits in North China Winter Wheat Region from 1960 to 2000 23

Sharma, R.C., Ortiz-Ferrara, G., Crossa, J., Bhatta, M.R., Sufian, M.A., Shoran, J. and Ortiz, R.
Genetic Improvement and Stability of Wheat Grain Yield Assessed through Regional Trials in the Eastern Gangetic Plains of South Asia 24

Fischer, R.A.
Understanding the Physiological Basis of Yield Potential in Wheat 25

Parry, M.A.J., Andralojc, P.J., Keys, A.J., Madgwick, P.J.
Increasing Photosynthesis by Overcoming the Limitations of Rubisco 26

Miralles, D.J. and Slafer, G.A.
Sink Limitations to Yield in Wheat: How Could it be further Reduced? 27

Condon, A.G., Reynolds, M.P., Rebetzke, G.J., Van Ginkel, M., Trethowan, R., Brennan, J., Bonnett, D.G., Richards, R.A., Farquhar, G.D.
Stomatal Aperture Related Traits and Yield Potential in Bread Wheat 28

Reynolds, M.P., Condon, A.G., van Ginkel, M., Rebetzke, G. Crossa, J, Fischer, R.A.
Strategies for Raising Yield Potential in Wheat 29

Foulkes, M.J., Snape, J.W., Shearman, V. J. and Sylvester-Bradley, R.
Factors Determining Yield in Winter Wheat 31

Pardey, P.G.
Global Investments in Agricultural R&D and Spillover Implications 32

Brennan, J.
Returns to Investment in New Breeding Technologies 33

Dixon, J., Hellin, J., Erenstein, O., Kosina, P.[1] and Lanier Nalley, L.
Wheat Adoption, Impact Pathways and Innovation Systems 34

Hobbs, P.R.
Conservation Agriculture: What is it and Why is it Important for Future Sustainable Food Production 35

Gupta, R. and Sayre, K.D.
Conservation Agriculture in South Asia 36

Sayre, K.D., Limon-Ortega, A. and Gupta, R.
Raised Bed Planting Technologies for Improved Efficiency, Sustainability
and Profitability 38

Girma, K., Raun. W., Mack, C. and Ortiz-Monasterio, I.
Managing Temporal Variability in Nitrogen Recommendation Using
Nitrogen Rich and Ramped Nitrogen Reference Strips in Developing Countries 39

Ransom, J., Endres, G. and Schatz, G.
Management to Increase Yield and Quality While Enhancing the Natural Resources 40

Sorrells, M.
Application of New Knowledge, Technologies, and Strategies to Wheat Improvement 41

William, H.M.
Wheat Molecular Breeding - Does it Offer any Hope? 42

Kishii, M.
Exploitation of Genetic Resources through Wide Crosses 43

Vargas, M., Crossa, J., Dhungana, P., Reynolds, M. and Eskridge, K.
Structural Equation Modeling for Studying Genotype x Environment Interaction
of physiological traits affecting yield in wheat 44

Varela, M., Crossa, J., Rane, J., Joshi, A.K. and Trethowan, R.
Analysis of Three-way Interaction Including Multi-attributes 45

Hodson, D. and White, J.
Use of GIS to Define Agro-ecosystems & Climate Change 46

POSTER PRESENTATIONS

Nisi, J. and Abbate, P.E.
Issues of wheat production in Argentina 47

Akparov, Z.I., Jafarova, R.G., Sheykhzamanova, F.A. and Rzayeva, S.P.
Study of Local Wheat Genetic Resources in Azerbaijan 48

Barma, N.C.D., Malaker, P.K., Baksh, M.E., Hossain, I., Samad, M.A., Saifuzzaman, M., Sufian, M.A. and Hossain, A.B.S.
Wheat Production in Bangladesh - An Overview 49

Scheeren, P.L., Caierão, E., e Silva, M.S., Nascimento Junior, A., Caetano, V.R., Bassoi, M.C., Brunetta, D., Albrecht, J.C., Trindade, M.G., Mori, C.D. and Sobrinho, J.S.
The Brazil Country Survey 50

He, Z. and Yu, Z.
Priority and Challenge of Wheat Production in China 51

Zemede Lemma, A. and Kelemework, F.
Challenges of Wheat Production in Ethiopia 52

Chatrath, R. Mishra, B. and Shoran, J.
Yield Potential Survey – India 53

Jalal Kamali, M.R. and Duveiller, E.
Wheat Production and Research in Iran: A Success Story 54

Limon Ortega, A., Villaseñor Mir, E. and Huerta-Espino, J.
Wheat Production in Mexico 55

Dahan, R., Jlibene, M. and Nasralah, N.
Challenges to Wheat Production in Morocco 56

Bhatta, M.R., Sharma, R.C. and Ortiz-Ferrara, G.
Challenges to Wheat Production in Nepal 57

Kisana, N.S., Hussain, I., Mujahid, M.Y. and Mustafa, S.Z.
Increasing Wheat Productivity in Pakistan 58

Izzat S.A. Tahir
Wheat Yield Potential in Sudan 59

Muminjanov, H.A., Eshonova, Z. and Morgounov, A.I.
Wheat Yield Potential Improvement in Tajikistan 60

Küçüközdemir, Ü., Yildirim, T., Taner, S., Yilmaz, A., Ünsal, R., Bolat, N., Kalayci, M., Dönmez, E., Yazar, S., Zencirci, N., Özseven, I., Öztürk, I., Avçin, A.K., Dinçer, N., Kün, E., Akin, B., Karahan, S., Kiliç, H., Ilkhan, A.
Wheat in Turkey 61

Ziyadullaev, Z.F. and Nurbekov, A.I.
An overview of Agriculture in Uzbekistan 62

Havazvidi, E.K.
Wheat Production Constraints in Zimbabwe 63

ADDITIONAL ABSTRACTS

Christensen, L.K. and Skovmand, B.
A Vision for Fast and Non-destructive Clustering of Plant Genetic Variation 64

Joshi, A, K., Chatrath, R., Mishra, B., Ortiz Ferrara, G. and Singh, R.P. 65
Wheat Improvement in India: Emerging Challenges

PROGRAM

SUNDAY 19th March

6:30-8:00 PM: Registration and Welcome Reception, Days Inn, Cd Obregon

MONDAY 20th March

8:30 Opening Ceremony to Welcome Participants (Chair John Dodds)
- Alejandro Elias-Calles – Secretary of Agriculture for Sonora
- Erasmo Valenzuela Cornejo – Regional Director for NW Mexico, INIFAP
- Jorge Artee Elias-Calles – President of Patronato
- Norman Borlaug – 1970 Nobel Peace Laureate, SG2000
- John Dodds- DDG Research, CIMMYT

9:00 Opening address by Dr. Norman E. Borlaug
International Collaborative Wheat Improvement: Future Challenges

10:00 COFFEE

New Challenges in Wheat Breeding (Chair Art Klatt)
- 10:30 Keynote: New Challenges in Wheat Breeding: Increasing Yields in Sub-optimal Environments (R.G. Sears, Agripro Int, USA)
- 11:15 Wheat Yield Potential in Sustainable Agriculture Model (S. Rajaram and H.-J. Braun, ICARDA-Syria and CIMMYT, Turkey)
- 11:40 High Yielding Spring Bread Wheat Germplasm for Irrigated Agro-ecosystems (R. Singh et .al., CIMMYT, Mexico)
- 12:05 Challenges to Wheat Production in South Asia (R. Chatrath, DWR, India)

LUNCH 12:30-1:30 (free to chose local restaurants)

- 1:30 Challenges to Wheat Production in Brazil & Related Agro-ecosystems (P.L. Schereen, EMBRAPA, Brazil)
- 1:55 Shuttle Breeding: Ways Forward (R. Ortiz, et. al., CIMMYT, Mexico)
- 2:20 Partnering with Farmers to Speed up the Adoption of New Technologies in South Asia (G. Ortiz-Ferrara et. al., CIMMYT, Nepal)
- 2:45 Complimenting the Breeders Eye with Canopy Temperature Measurements (M. van Ginkel et al, PIRVic, Australia)
- 3:10 Yield of Synthetic Backcross-derived Lines (F. Ogbonnaya, et. al., PIRVic Australia)
  3:35 COFFEE
- 4:05 Breaking Negative Correlations (R.H. DePauw, et. al., Agriculture and Agri-Food Canada)
- 4:30 Preserving End-Use Quality While Enhancing Grain Yield (R.J. Peña, CIMMYT, Mexico)
- 4:55 Challenges to Maintaining Wheat Productivity: Pests, Diseases and Potential Epidemics (E. Duveiller, et. al., CIMMYT, Iran)
- 5:20 Brainstorming on Increasing Yield - General Discussion
- 6:00 Close

TUESDAY 21st March

Understanding the Basis of Genotype by Environment Interaction Globally (Chair Sanjaya Rajaram)
- 8:15 Keynote: Using Plant Breeding Data to Move from Genotype-by-environmental Interactions to Gene-by-environmental Interactions (H. Eagles et. al., ACPFG, Australia)
- 9:00 International Winter Wheat Trials: Adaptation and Trends (A. Hede and H.-J. Braun, CIMMYT, Turkey)
- 9:25 Forty Years of International Bread Wheat Trials: What Have We Learned? (R. Trethowan and J. Crossa, CIMMYT, Mexico)
- 9:50 Association among Durum Wheat International Testing Sites and Trends in Yield Progress over the Last Twenty Two Years (K. Ammar, et. al. CIMMYT, Mexico)
  10:15 COFFEE
- 10:45 Global Adaptation of Near-isogenic Spring Wheat Lines Contrasting for Major Reduced Height Genes (S. Chapman, et. al., CSIRO, Australia)
- 11:10 Avenues to Increase Yield of Short Season High Latitude Wheat in Northern Kazakhstan and Siberia.(A. Morgounov and R. Trethowan, CIMMYT, Kazakhstan and Mexico)
- 11:35 Genetic Improvement of Yield Potential and Associated Traits in North China Winter Wheat Region from 1960 to 2000 (Z. He et. al., CIMMYT, China)
- 12:00 Genetic Improvement and Stability of Wheat Grain Yield Assessed through Regional Trials in the Eastern Gangetic Plains of South Asia (R.C. Sharma, et. al., IAAS, Nepal & CIMMYT)

LUNCH 12:25-1:45

Understanding the Physiological Basis of Yield (Chair: Conxita Royo)

- 1:45 Keynote: Understanding the Physiological Basis of Yield Potential in Wheat (R.A. Fischer, ACIAR, Australia)
- 2:30 Increasing Photosynthesis by Overcoming the Limitations of Rubisco (M. Parry, et. al., Rothamsted, UK)
- 3:00 Sink Limitations to Yield in Wheat: How Could it be further Reduced? (D.J. Miralles and G. Slafer, Univ Buenos Aires, Argentina)
- 3:30 COFFEE
- 4:00 Stomatal Aperture Related Traits and Yield Potential in Bread Wheat (A. Condon, et. al., CSIRO, Australia)
- 4:30 Strategies for Raising Yield Potential in Wheat (M. Reynolds and A. Condon, CIMMYT, Mexico and CSIRO, Australia)
- 5:00 Factors Determining Yield in Winter Wheat (M.J. Foulkes, et. al., Univ. Nottingham, UK)
- 5:30 Brainstorming on Increasing Yield - General Discussion
- 6:00 Close

WEDNESDAY 22nd March

Full day field trip to CIMMYT experiment station, Cd Obregon

"Regional and CIMMYT-Mexico Collaborations" 8:30-3:00 pm (Prepared Lunch 12:00:1:30)

- Quality and Fusarium (Zhonghu He, Javier Peña, et. al.)
- High Latitude Wheat (Alex Morgounov, Richard Trethowan, et. al.)
- Heat and HLB tolerance (Guillermo Ortiz-Ferrara, Arun K. Joshi, et. al.)
- Yield Potential (Etienne Duveiller, Ravi Singh, et. al.)
- Drought (Arne Hede, Jacob Lage, Osman Abdalla, et. al.)
- Conservation Agriculture (Raj Gupta, Ken Sayre, et. al.)
- Durum Wheat (Karim Ammar, et. al.)
- Linkages between CIMMYT and the Mexican National Program (Ivan Ortiz Monasterio, Julio Huerta-Espino, et. al.
- ICARDA/CIMMYT barley breeding (Flavio Capettini)
- Wheat Physiology (Matthew Reynolds)

- 3:00 Open for informal field visits

Symposium Carne Asada and Musical Entertainment (MC: Ivan Ortiz Monasterio)

- 5:00 Refreshments
- 6:00 Musical Event (Mariachis)
- 7:00 Carne Asada
- 9:00 Return to Hotel

THURSDAY 23rd March

Socio-Economics Challenges for Wheat Improvement (Chair Ravish Chatrath)

- 8:15 *Keynote:* Global Investments in Agricultural R&D and Spillover Implications (P.G. Pardey, InSTePP, USA)
- 8:55 Returns to Investment in New Breeding Technologies (J. Brennan presented by P. Martin)
- 9:20: Wheat Adoption, Impact Pathways and Innovations Systems (J. Dixon et. al.)

Poster Session "*Challenges to International Wheat Improvement*"

- 9:45 Formal introduction to posters by John Dixon (displayed all week).
- (Coffee will be served from 10:15 am onwards during the poster session)

- J. Nisi & P.E. Abbate, **Argentina**
- Z.I. Akparov, R.G Jafarova, F.A. Sheykhzamanova & S.P. Rzayeva, **Azerbaijan**
- N.C.D. Barma, P.K. Malaker, M.E. Baksh, I. Hossain, M.A. Samad, M. Saifuzzaman, M.A. Sufian & A.B.S. Hossain, **Bangladesh**
- Pedro Scheeren, **Brazil**
- Zhonghu. He & Zhenwen. Yu, **China**
- Mosaad Mohamed M. Abdel Aleem, **Egypt**
- Zemede Lemma & F. Kelemework, **Ethiopia**
- R. Chatrath, B. Mishra & J. Shoran, **India**
- M.R. Jalal Kamali & E. Duveiller, **Iran**
- M Karabayev, B Alimgazinova, A Morgounov, **Kazakhstan**
- Limon-Ortega, E. Villaseñor-Mir & J. Huerta-Espino, **Mexico**
- R. Dahan, M. Jlibene & N. Nasralah, **Morocco**
- M.R. Bhatta, R.C. Sharma & G. Ortiz-Ferrara, **Nepal**
- N.S. Kisana, I. Hussain, M.Y. Mujahid & S.Z. Mustafa, **Pakistan**
- Izzat S.A. Tahir, **Sudan**
- H.A.Muminjanov, Z.Eshonova & A.I.Morgounov, **Tajikistan**
- Ü. Küçüközdemir, T. Yildirim, S. Taner, A. Yilmaz, R. Ünsal, N. Bolat, M. Kalayci, E. Dönmez, S. Yazar, N. Zencirci, I. Özseven, I. Öztürk, A.K. Avçin, N. Dinçer, E. Kün, B. Akin, S. Karahan, H. Kiliç, A. Ilkhan, **Turkey**
- Z.F.Ziyadullaev & A.I.Nurbekov, **Uzbekistan**
- E.K. Havazvidi, **Zimbabwe**

Enhancing the Natural Resource Foundation (Chair Tony Fischer)

- *10:45 Keynote*: Conservation Agriculture: What is it and Why is it Important for Future Sustainable Food Production (P. Hobbs, Cornell University, USA)
- 11:25 Conservation Agriculture in South Asia (R. Gupta and K. Sayre, CIMMYT, India and Mexico)
- 11:50 Raised Bed Planting Technologies for Improved Efficiency, Sustainability and Profitability (K. Sayre, et. al., CIMMYT, Mexico)
- 12:15 Managing Temporal Variability in Nitrogen Recommendation Using Nitrogen Rich and Ramped Nitrogen Reference Strips in Developing Countries (K. Girma et. al., Oklahoma State Univ. & CIMMYT, Mexico)
- 12:40 Management to Increase Yield and Quality While Enhancing the Natural Resources (J. Ransom, N. Dakota State Univ, USA)

- LUNCH 1:00-2:00

Cutting Edge Technologies with Application in Wheat Breeding (Chair John Snape)

- *2:00 Keynote*: Application of New Knowledge, Technologies, and Strategies to Wheat Improvement (M. Sorrells, Cornell University, USA)
- 2:45 Wheat Molecular Breeding - Does it Offer any Hope? (H.M. William, CIMMYT, Mexico)
- 3:15 Exploitation of Genetic Resources through Wide Crosses (M. Kishii, CIMMYT, Mexico)
- 3:45 COFFEE
- 4:15 Structural Equation Modeling for Studying Genotype x Environment Interaction of Physiological Traits Affecting Yield in Wheat (J. Crossa et. al., CIMMYT, Mexico)
- 4:45 Use of GIS to Define Agro-ecosystems & Climate Change (D. Hodson and J. White, CIMMYT, Mexico USDA)
- 5:15 Brainstorming on Increasing Yield - General Discussion
- 6:00 Close

FRIDAY 24th March

Workshop: Challenges to Wheat Production Internationally (Chair: John Dixon with assistants)

08:15 – 17:30 hrs (prepared lunch 12:20-1:30)

A one-day interactive workshop involving all national program participants and CIMMYT scientists. Participants will evaluate, extend and analyze the information provided in the standardized survey of national wheat programs, focusing on the following topics:

- Cultivars grown and released over the last 50 years
- Changes in agronomic practices over the last 10 years
- Environmental constraints to wheat production
- Socio-economic, institutional and policy constraints to wheat production
- Constraints to wheat improvement research activities
- Evaluation of partnerships and capacity associated with wheat improvement and production
- Identification of future requirements from CIMMYT during the coming 20 years
  - Priority traits in lines and cultivars
  - Priority crop management technologies
  - Priority socio-economic research
  - Priority capacity building, knowledge sharing and partnership strengthening

Participation will involve representatives from the following national wheat programs and CIMMYT staff

South & East Asia: Bangladesh, China, India, Nepal, Pakistan
Africa: Egypt, Ethiopia, Morocco, Sudan, Tunisia, Zimbabwe
Central and West Asia: Iran, Kazakhstan, Uzbekistan, Turkey, Azerbaijan, and Tajikistan
Latin America: Argentina, Brazil, Mexico

X

ORAL

PRESENTATIONS

International Collaborative Wheat Improvement: Future Challenges

N.E. Borlaug
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n.borlaug@cgiar.org

My career in international agriculture began in 1944, when I joined the recently established Rockefeller Foundation agricultural program in Mexico, the first systematic attempt to help a food-deficit country increase food production. The Mexican Government-Rockefeller wheat improvement program was the forerunner—and in many respects the model—for the network of 15 international agricultural research centers that emerged two decades later, and which today are funded through the Consultative Group for International Agricultural Research (CGIAR). The Farmers' Association of Sonora (*Patronato*) played an important supporting role in wheat research in Mexico, and in the Green Revolution.

The first two centers—the International Rice Research Institute (IRRI) in the Philippines established in 1960 and the International Maize and Wheat Improvement Center (CIMMYT) in Mexico, first established in 1963 and later reorganized in 1966—became the international agricultural research and development leaders in Asia, whose varieties and crop management information launched the so-called "Green Revolution."

Between 1965 and 2000, the area in developing Asian countries planted to new high-yielding wheat and rice varieties increased from zero to 170 million ha. The new seeds were the catalyst for a doubling in irrigated area, a 35-fold increase in fertilizer use, and a 20-fold increase in the use of agricultural machinery, and more than a three-fold increase in cereal production—from 309 to 962 million tonnes.

Science and technology has had its greatest impact on the lands best suited to agriculture. Between 1950 and 2000 the world's farmers have been able to triple world cereal production—from 650 million metric tons to 1,900 million with only a 10 percent increase in total cultivated cereal area. If we had tried to produce the world cereal harvest of 2000 using the agricultural technology of 1950, we would have needed an additional 1.1 billion hectares of land, of the same quality, over and above the 660 million hectares that were actually used. Too often, the environmental critics of modern agriculture fail to see these very beneficial aspects to producing more food, feed and fiber on the lands best suited for these uses, so that other lands can be spared for other uses.

Despite the successes of the Green Revolution, the battle to ensure food security for hundreds of millions miserably poor people is far from won. Mushrooming populations, changing demographics, failed rural development programs, including those designed to take farmers off the land into other jobs, and environmental abuses have all taken their toll. Enormous challenges lie ahead to ensure that the projected world population in 2025 of around 8 billion people is adequately and equitably fed, and in environmentally sustainable ways.

Over the next 20 years, world cereal demand will likely increase by 50 percent, driven strongly by rapidly growing animal feed use and meat consumption. With the exception of acid-soil areas in South America and Africa, the potential for expanding the global land area is limited. Future expansions in food production must come largely from land already in use.

The productivity of these agricultural lands must be sustained and improved. Central to achieving these productivity gains will be a "Blue Revolution," one in which water-use productivity is much more closely wedded to land-use productivity. Significant improvements in water-use efficiency can be achieved through conservation tillage, planting on beds, and drip irrigation. Much more work is also needed in soil fertility management, especially in intensive production systems if high-yield agriculture is to be sustained. Secondary and micronutrient deficiencies are on the rise and must be corrected and soil organic matter and structure must be managed more effectively.

Roughly 50 percent of the world's 800 million hungry people live in marginal lands and depend upon agriculture for their livelihoods. These food-insecure households face frequent droughts, degraded lands, remoteness from markets, and poor market institutions. Investments in science, infrastructure and resource conservation are needed to increase productivity and lower their production risks. Although significant improvements should be possible, we must also recognize that some of the problems of marginal lands will be too formidable for science to overcome.

Biotechnology will play a major role in developing new crop varieties with greater tolerance to pests and diseases, drought, and with higher nutritional content. Exciting progress is being achieved in wheat improvement for increased tolerance to a range of biotic and abiotic stresses. The greater tolerance to drought and other abiotic stresses of the new wheat synthetic varieties is especially exciting. We must also push forward research efforts to increase maximum genetic yield potential in future years, if we are to meet future demand projections, without significant area expansions.

Over the last 20 years, biotechnology based upon recombinant DNA has developed invaluable new scientific methodologies and products for food and agriculture. So far, agricultural biotechnology has mainly conferred producer-oriented benefits, such as resistance to pests, diseases, and herbicides. But many consumer-oriented benefits, such as improved nutritional and other health-related characteristics, are likely to be realized over the next 10 to 20 years.

Today, the world's wheat farmers face a dangerous situation. For the last 53 years we've had no major change in stem rust organism any place in the world. But in 1999, first reported in Uganda, then in Kenya and now in Ethiopia, a new race of stem rust has evolved that is capable of severely damaging perhaps half of the world's bread wheat.

The publicly funded international disease screening and testing system we had for the 25 years ago has broken down, partly a victim of the malaise that has led to steady declines in public sector research real funding.

International germplasm sharing and testing ushered in a golden age in wheat improvement. Enormous quantities of new genetic diversity were introduced into wheat breeding programs worldwide. Multi-location testing helped to develop disease-resistant, broadly adapted cultivars.

The international wheat fraternity developed during the past 50 years is still alive, although not as vibrant as it once was. International collaboration is central to sustaining progress in individual wheat improvement programs and also to ensure that international surveillance and control systems are in place to protect against pandemic disease attacks.

New Challenges in Wheat Breeding: Increasing Yields in Sub-optimal Environments

R.G. Sears
AgriPro-Coker, 12115 Tully Hill Road, Junction City, KS 66441, USA.
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Global average wheat yields hover near 2.5 t/ha today and an estimated production of 4.0 t/ha necessary to sustain a hungry world in 2020. Theoretical wheat yields have been guessed at 20 t/ha and yield reports as high as 18 t/ha have been reported in southern Chile. Clearly under optimum conditions wheat has very high yield potential, but wheat is a crop that is grown in sub-optimal environments that are plagued by both abiotic and biotic stress. Increasing yields in these environments is more about solving specific production problems and less about increasing maximum genetic yield potential. Average genetic gain for yield during the past 30 years has been approximately 1.5%/y in stressful environments. We will need to increase genetic gain to over 2.0%/y to reach the 4.0 t/ha goal. These are gains generally reported in higher yielding, non-stress environments. A continued merging of traditional wheat breeding techniques based on field evaluation and new technologies will allow us to reach these lofty goals, but wheat improvement programs must continue to be supported at high levels for these goals to be realistic.

Wheat Yield Potential in Sustainable Agriculture Model

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There is general indication that the farm level productivity is stagnated in many parts of the world. The yield data available indicate that there has been continuous but slow rise in potential yield in many studies. We were fortunate to hold the 7th International Wheat Conference in Mar Del Plata, Argentina inDecember 2005 . Many papers presented there highlighted the yield potential which clearly established that a few genetic traits and physiological parameters contributed to yield advancement in last 15 years of 20th Century. These were 1BL/1RS, 7DL/7AG, and 4BL/2R translocations.The staygreen trait was also linked to yield and biomass. The Carbon Isotope discrimination and canopy temperature dipression (CTD) were suggested as usefull methods to inhance yield potential. The arquitectural change in morphology and hopefully internal anotomy resulting into robust stem, broad leaf and long spike woth unusual fertility could be a research topic worth considering at CIMMYT and ICARDA.

Our overall valuation of these genetic traits and physiological methodology is only worth when we also consider changing agronomic practices such as no till, water use efficiency and efficient nutrient uptake. In most circumstances in developing countries the water and nutrients are not only lacking but these are also polluted and contaiminated. We suggest that the genetically influencing traits on yields must be tageted under the condition of proper agronomy influencing the farmers situation and circumstances.

High Yielding Spring Bread Wheat Germplasm for Irrigated Agro-Ecosystems

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Global wheat production must continue to increase 2% annually until year 2020 to meet future demands imposed by population and prosperity growth. Moreover, this must be achieved under reduced water availability, global warming scenario, stricter end-use quality characteristics and evolving pathogen and pest populations. Breeding wheat cultivars with increased grain yield potential, enhanced water use efficiency, heat tolerance, end use quality and durable resistance to important diseases and pests can contribute to meet at least half of the desired production increases. The remaining half must come through better agronomic and soil management practices and incentive policies. Analyses of the recent International Yield Trials (ESWYT and SAWYT) indicate that grain yields of the best new entries were usually 10% higher than the local checks globally as well as within a country across sites. A great deal of variation in yield across sites within a country/region underlines the role of genotype × environment interaction and provides opportunity to select for stable genotypes, which is not often done. This could undermine proper utilization of germplasm with high yield potential and stability in the national wheat breeding programs. Some of the best performers in irrigated areas were amongst the best in semiarid environments reinforcing the fact that high yield potential and drought tolerance can be improved simultaneously. The best performing lines often had genotypic base of widely adapted genotypes 'Kauz', 'Attila', 'Baviacora' and 'Pastor' with genetic contributions from other parents including synthetic wheat. We recommend and encourage within country multi-location analysis of trial performance at the end of the crop season to identify lines suiting to a particular or different locations of a country. The immediate feedback on genotype x environment interaction will also help in breeding lines for countries having substantial variation across locations.

Considering that the yield potential is quantitative and based on minor genes with additive effects, a breeding approach that builds on the past achievements by retaining most of the desired gene combinations and allowing selection for additional additive genes offers a promise to continue increasing the yield potential. A 'single-backcross, selected-bulk breeding scheme' was used recently to transfer additive, minor genes based resistance to leaf and yellow rusts and was found to promote a simultaneous selection for increased grain yield in conjunction with high levels of resistance. As several of CIMMYT's globally adapted genotypes now have adequate durable type of quantitative adult plant resistance to leaf and yellow rusts, it may now be easier to enhance yield potential and incorporate genes for other traits into them as a higher frequency of single-backcross derived progenies will be resistant thus increasing the chances of selecting desired transgressive segregates for higher yield potential. Selection of F4-F5 selected-bulk populations for certain diseases and stresses such as heat at key hot-spot sites should assist incorporating resistance/tolerance into widely adapted high-yielding germplasm. Another approach being practiced to enhance grain yield potential of CIMMYT wheats is to incorporate widely the white floured 7DL.7Ag segment with genes *Lr19/Sr25* into a range of genotypes. Our studies have shown that this translocation increases yield potential by 10-15%.

Recent resurgence of stem (or black) rust, caused by *Puccinia graminis tritici*, in East Africa and presence of unique combination of virulence factors for a number of resistance genes in race Ug99 poses a major threat to wheat production as majority of popular cultivars and breeding materials are susceptible to this race. Identification and breeding of adapted wheat cultivars with diverse resistance, including durable type, and replacement of current susceptible cultivars is a high priority to avoid likely epidemics when Ug99 migrates to North Africa, Middle East and Asia. Such migration of a *P. striiformis* race from East Africa is known to have caused yellow rust epidemics in many countries in its path during 1990s. Sources of resistance to race Ug99, both race-specific and adult plant, were identified and are being used in breeding adapted wheat germplasm with diverse and durable resistance. Some resistant lines have shown relatively high grain yield potential and can be deployed directly.

Challenges to Wheat Production in South Asia

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Wheat is the second major staple crop, after rice, in India and Pakistan and is also gaining similar importance in Nepal and Bangladesh. The total wheat production in South Asia has increased from 15 mt in 1960s to 95.5 mt during 2004-05. In this region, area under wheat, total production and productivity are highest for India, followed by Pakistan, Bangladesh and Nepal. To meet the ever growing needs of a burgeoning population, in the region, there is a need to produce wheat at a sustained growth rate of 2-2.5% annually until the middle of 21st century. However, for India, recent estimations have shown a reduced growth requirement of about 1.1%. The green revolution gave a big push to wheat production mainly due to the introduction of newer genotypes that were photo-insensitive, dwarf and fertilizer responsive. The wheat improvement programme in these countries, with the active collaboration of CIMMYT and ICARDA made significant progress due to the utilization of the vast wheat biodiversity in breeding programmes to evolve agronomically superior and disease resistant genotypes. It is a matter of concern however, that for last several years the region is witnessing a plateau in wheat productivity. There is a very little scope for further increasing the area under wheat cultivation, so the major challenge is to break the yield barriers by developing hybrids in wheat, winter wheat x spring wheat hybridization, pre-breeding for yield components and achieving disease resistance through use of synthetics, buitre and Chinese materials. Biotechnological approaches like marker aided breeding, structural and functional genomics, gene pyramiding and transgenics are set to play an important role in breaking these barriers.

The other most serious constraints to wheat production in this region are a host of biotic and abiotic stresses. Among the major biotic stresses, control of rust diseases and foliar blight are more critical for achieving higher yields. However, India in particular has not faced any rust epidemic since last three decades because of proper deployment of rust resistance genes in wheat breeding programmes. However, this is no time to be complacent, especially as the threat of a new black rust (Ug99) looms large; fortunately timely steps have been initiated through the `Global Rust Initiatives' to combat this impending problem. Directorate of Wheat Research, Karnal has already initiated the breeding programme for incorporation of resistance to stem rust by utilizing the resistant genetic stocks. The problem of leaf blight is being taken care of in a complementary mode by India, Nepal and Bangladesh and CIMMYT (South Asia, Nepal). Other problems like Karnal bunt, powdery mildew, weed infestation and pests (aphids, termites, etc) are also receiving due attention in the wheat improvement programme. Among the abiotic stresses, unusual warming trends during grain filling period are imposing heat stress and playing an important role in causing yield declines, especially in eastern and central India. Besides, it is very important to tackle stresses like salinity/alkalinity, waterlogging and unusual weather trends causing droughts, hailstorms etc. which are increasingly leading to unsustainable trends in crop productivity in all crops and regions, in general.

Besides the above, there are other important challenges that are specific to the highly productive rice-wheat cropping system predominant in the Indo-Gangetic plains. The total factor productivity of this system is declining due to intensive tillage leading to the depletion of soil organic carbon status. The declined soil organic carbon is directly responsible for the decreased water and nutrient holding capacity of the soil thereby adversely affecting the native soil fertility. The problem is further aggravated by burning of rice and wheat crop residues by farmers especially that of rice under rice-wheat system in north western parts. Nutrient mining, imbalanced fertilisation and over-exploitation of water resources are the other factors responsible for decline in total factor productivity. Addition of organic matter to soil through green manuring and crop residue recycling, balanced fertilisation, integrated nutrient management, diversification/ intensification of rice-wheat system by including pulses, oilseeds and vegetables crops are some of the remedial measures to counter this decline.

For achieving the targets of wheat production in the south Asian region, the international linkages with CIMMYT requires strengthening for developing more highly productive wheat genotypes through enhanced germplasm exchange and human resource development.

Challenges to Wheat Production in Brazil & Related Agro-ecosystems

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The wheat production in Brazil and related agro-ecosystems is limited by several factors in the four different environments for wheat breeding. Acid soils (with aluminum and manganese toxicity to the wheat plans), pre-harvest sprouting, frost at flowering in the south and dry conditions in the Savana region and diseases caused by fungus, bacteria and virus limited the yield of the varieties cultivated under these conditions. Inferior or low bread making wheat quality of the grain produced in the South of Brazil also is a constrain to increase the production

In Region I - Temperate & Humid, with high rainfall and mean altitude around 700 m.
The main constrains are: *Leaf rust (Puccinia triticina); Scab (Fusarium graminearum); Mildew (Blumeria graminis); Glume blotch (Stagonospora nodorum); Tan spot (Drecshlera tritici repentis); Virus Diseases (Barley Yellow Dwarf Virus and Soil borne Mosaic Virus); Pre-harvest Sprouting and soil acidity.*

In Region II - Warm & Humid, with high rainfall and mean altitude around 500 m,
the main constrains are: *Leaf rust (Puccinia triticina); Scab (Fusarium graminearum); Mildew (Blumeria graminis); Glume blotch (Stagonospora nodorum); Tan spot (Drecshlera tritici repentis);* Spot blotch *(Bipolares s)(H. sativum); Blast (Magnaporthe grisea); Virus Diseases (Barley Yellow Dwarf Virus and Soil borne Mosaic Virus); Pre-harvest Sprouting and Acid Soils.*

In Region III - Warm & low rainfall and mean altitude around 400 m,
the main constrains are: *Leaf rust (Puccinia triticina); Mildew (Blumeria graminis); Tan spot (Drecshlera tritici repentis);* Spot blotch *(Bipolares s)(H. sativum); Wheat Blast (Magnaporthe grisea); Virus (Barley Yellow Dwarf Virus); Pre-harvest Sprouting and Acid Soils in part of the area.*

In Region IV - Warm & Dry Season or Warm & Irrigated = Savanas/Cerrado Region.
Main constrains are: *Leaf rust (Puccinia triticina); Mildew (Blumeria graminis); Tan spot (Drecshlera tritici repentis);* Spot blotch *(Bipolares s)(H. sativum); Wheat Blast (Magnaporthe grisea); Virus (Barley Yellow Dwarf Virus); Pre-harvest Sprouting and Acid Soils.*

Since 1922, Brasilian breeding programs releazed 429 wheat cultivars for the different wheat production regions. During the last 30 years, Embrapa is working hard to select new genetic materials with better resistance to adverse environmental conditions and more resistant to prevalent diseases. As a result of this, the 115 new cultivars were relezead and the recent cultivars are caracterized by: new genes dwarfing genes, confering better lodging resistance; new genes for disease and abiotic stresses (pre-harvest sprouting and acid soils) tolerance; less responsive to vernalization and on photoperiod durationand better end use quality.
The research in crop rotation, no till systems and the development and use of new fungicides, associated with the new short varieties, with better harvest index and better resistance to biotic and abiotic stresses permit to elevate the yield potential from 1,500 to 5,000 kg ha^{-1}.

Shuttle Breeding: Ways Forward

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The main elements of the international wheat improvement program of the Centro Internacional de Mejoramiento de Maíz y Trigo (CIMMYT) have been shuttle breeding at two contrasting locations in Mexico, wide adaptation, durable rust and *Septoria* resistances, international multi-site testing, and the appropriate use of genetic variation to enhance yield gains of subsequently produced lines. Such an approach yielded successes known collectively as the Green Revolution. However, at the beginning of this 21st century, this "cultivar assembly line" approach needs fine tuning to address crop needs under increasingly adopted resource conserving practices as well as those related to nutritional requirements of the end-users. International wheat improvement will therefore focus on the targeting of traits in respective mega-environments, and the use of participatory methods, especially in marginal environments. The main features of this wheat improvement strategy include the introduction of new and novel sources of genetic variation through wild species, landraces and, potentially, the use of transgenes for intractable traits. This variation will be combined using international shuttle breeding and increased breeding efficiency will be achieved through marker-aided methods, more targeted use of crop physiology, plant genetics, bio-statistics and bioinformatics. Likewise, CIMMYT will increase focus on the needs of end-users by emphasizing regional efforts in participatory research and client-oriented plant breeding.

Partnering with Farmers to Speed up the Adoption of New Technologies in South Asia

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South Asia is considered a challenging region due to the high level of poverty, its high population growth rate, and the many biotic, abiotic and policy constraints that affect the production of wheat and other cereals. Three quarters of the world's poorest people live on <$1 a day of which 37% live in South Asia. There is an extreme poverty, malnutrition, and food insecurity particularly in the eastern part of the sub-continent including Bangladesh, eastern India, and Nepal. The population growth rate in these areas is significantly higher than the growth in agriculture productivity. Hunger is inextricably linked to poverty and vulnerability. The millennium development goal of the reduction of extreme poverty and hunger can only be met by increases in agricultural productivity, particularly by resource-poor farmers, which is fundamental to growth and poverty reduction in the region. Wheat production is one of the economic mainstays in South Asia, but the productivity of wheat cropping systems lags far behind its potential. The yield gap between farmer's fields and experimental yields is wide across all South Asian countries. Foliar diseases such as leaf and yellow rust, as well as Helminthosporium leaf blight, are important biotic constraints. Heat stress, low fertilizer dose, delayed seeding, and the lack of, or improper irrigation, play an important role as well. However, one of the main causes of low yields in the region is farmer's continued cultivation of old wheat varieties. These varieties are genetically inferior to more recently developed materials, and are more susceptible to diseases. Two factors, in turn, seem to be holding back the dissemination of newer varieties: (a) inadequate extension (poor linkages with farmers) and (b) poor seed production systems. Genetic vulnerability to diseases is another important issue in South Asia where large areas are occupied by one single variety in each of these countries. The potential threat of new races of rust such as Ug-99 of stem rust and others, call for the urgent need to diversify the area with varieties with broad spectrum of disease resistance. For the last three years, CIMMYT and CAZS-NRM have been collaborating with farmers, NARS and other partners of South Asia in promoting the improved wheat varieties and new resource conservation techniques (RCTs) in farmers' fields. The collaboration has been participatory, and significant progress has been made in promoting those technologies. Participation between farmers, scientists, extension specialists, NGOs and the private sector is fostered including participatory plant variety selection (PVS), and participatory agronomic practice assessment. Socioeconomic baseline studies conducted in the region have allowed project cooperators to better understand the target environments, constraints, and the people with whom we are focusing our efforts. Through PVS, several farmer-friendly and farmer-preferred technologies have been identified including wheat varieties for adverse conditions, e.g. for high pH soils in the eastern UP of India and for boron deficiency in Nepal. There has been considerable improvement in the access of farmers to new varieties and technologies in the rural areas. High yield increases (15-70%) have been achieved by resource-poor farmers over the existing varieties through the adoption of new varieties, and they have made substantial cost savings and achieved higher yields through resource-conserving agronomic techniques such as zero-till. Genotype by tillage by disease interaction studies conducted in farmer's fields have allowed collaborating scientists to have a better understanding of the response of wheat varieties to the new RCTs. The effect of diseases on these varieties and tillage systems is also better understood. Machinery manufacturers have been identified to assist farmers having access to these implements. Seed of the new farmers-selected cultivars has been multiplied and delivered to and by groups of collaborating farmers. Thousands of farming households have rapidly adopted farmers-preferred varieties and technologies and have benefited from them.

Complimenting the Breeders Eye with Canopy Temperature Measurements

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Introduction

Canopy Temperature Depression (CTD) has been widely studied on a range of wheat genotypes under various types of stress, such as excess drought (Blum, 1988) and heat (Reynolds et al., 1994; Amani et al., 1996), with impressive correlations with yield recorded. The underlying philosophy is that cooler canopies (an expression of a higher level of integration) reflect a relatively less stressed crop under the circumstances, that is expected to produce more biomass and hence yield (in most cases), than a stressed crop. When leaves are able to regulate stomatal conductance such that canopies are sufficiently cooled relative to elevated ambient conditions it indicates that a plant is well adapted to that environment enabling it, for example, to access sufficient water from the soil via its vascular system, fix adequate CO^2 from the environments and secure optimum temperatures for enzyme activities. The case for CTD being useful under stressed conditions, in particular those involving increased ambient temperatures (both a signature of most drought and heat stressed conditions), while indirect in terms of cause-effect seems logical. Indirect in the sense that the cool canopy is not the cause for the better functioning of the plant, but a result of physiological processes working near optimum despite outside stresses due to other protective measures. Hence the case for CTD being able to distinguish genotypes and predict their relative yield under 'optimum' conditions of 'full' water availability and temperatures within the preferred range for wheat (Pfeiffer et al., 2004) seems at least questionable.
This study aims to determine the potential of CTD as adding value to the breeder's eye.

Materials and Methods

In this study we compared five crosses among CIMMYT spring bread wheats. CTD measurements were first recorded in the F4 generation, earlier and later generations being selected by the breeder in accordance with ongoing breeding practices. In addition an unselected bulk of each cross was separately multiplied in bulk alongside the selected generations. This approach resulted in three germplasm flows: 'Breeder', 'Breeder+CTD' and 'Bulk'.

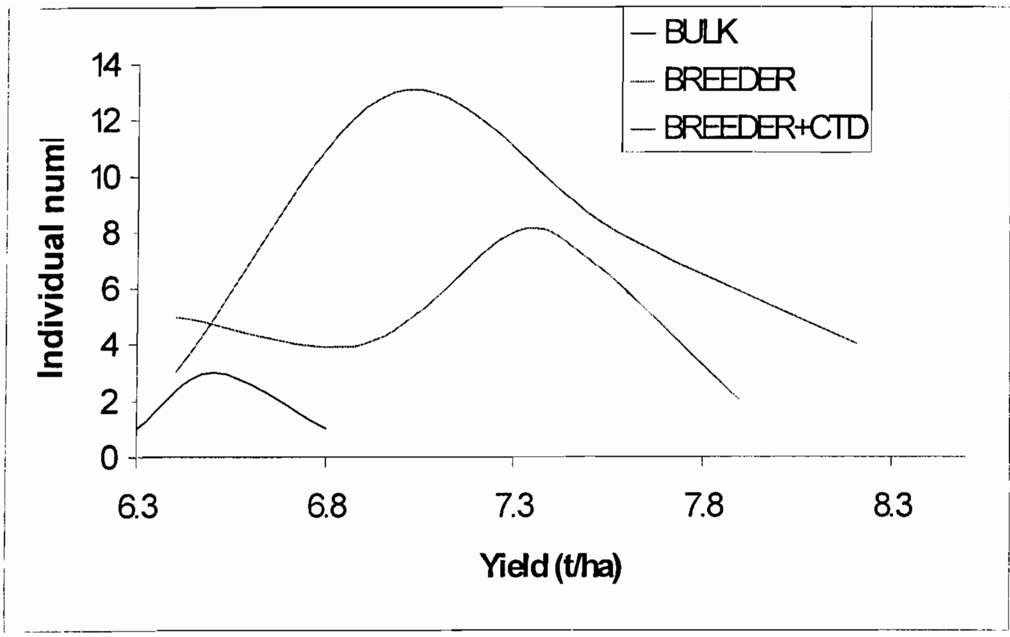
Yield trials of the resulting homozygous lines from all three flows were carried out at Cd. Obregon in north-eastern Mexico under fully irrigated and optimally fertilized conditions during three crop cycles (November – April; 1999-2000, 2000-2001, and 2003-2004). Trial design was a latinized alpha-lattice design with two replications. The number of lines for each cross and for each germplasm flow varied depending on whether the breeder promoted desirable phenotypes or not, fully reflective of an ongoing breeding program. However, relevant contrasts between crosses and flows could be determined.

Results and Discussion

Some data was already presented in late 2004 (van Ginkel et al.).

50% of the variation in yield under these 'optimum' conditions was explained by cooler canopies ($r = 0.74$ ($P = 0.001$)), when analyzed across all crosses and germplasm flows.
Overall 'Breeder+CTD' was superior to 'Bulk' in identifying high yielding lines. While not superior in all crosses to 'Breeder' alone, 'Breeder+CTD' did identify more high-yielding lines based on the 1999-2000 and 2000-2001 crop cycles, which could reflect a wider genetic diversity being sampled. See Figure 1 (modified from van Ginkel et al. 2004).

Figure 1. Number of lines identified and yield by three selection methods of germplasm flows: 'Breeder', 'Breeder+CTD' and 'Bulk' (modified from van Ginkel et al. 2004).



In particular the last 2003-2004 cycle highlighted a second positive contribution by CTD. It confirmed that 'Breeder+CTD' allows very high yielding lines to be identified, statistically similar to 'Breeder' (as expected since the breeder is involved in both). But the outstanding difference was that use of CTD by the breeder in 'Breeder+CTD' permitted lower yielding lines to be noted and discarded, that would otherwise have entered into expensive yield trails.

Conclusions

This study has resulted in the following conclusions:

1. CTD is relatively highly correlated to yield under optimum production conditions.
2. The breeder alone or complemented with CTD information is equally able to identify high yielding lines.
3. Use of CTD information allows lines to be identified and eliminated that otherwise look agronomically sufficiently promising to breeders to be promoted to yield trials, while in fact their yield level is sub-optimal.
4. CTD appears promising in augmenting breeders' selection skills.

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Yield of Synthetic Backcross-derived Lines

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Wheat is one of the major food crops in the world. It is Australia's largest crop and most important agricultural commodity. In Australia the crop is grown under rainfed conditions with inherently important regional environmental differences in the wheat growing areas. The Western Australia, South Australia, Victoria and southern New South Wales regions are characterised by winter dominant rainfall; Queensland and northern New South Wales regions rely primarily upon summer rainfall. Maximizing yield potential across these diverse regions is dependent upon managing, either genetically or agronomically, those factors in the environment that limit yield. One of the primary limitations to yield across the Australian wheat belt is drought. There is limited genetic diversity for tolerance to moisture stress in the current generation of bread wheat varieties, either in Australia or around the world. Consequently, we have explored the potential benefit of synthetic hexaploid wheat (SHW) 'recreated' by artificial hybridisation of its progenitor species, *Triticum turgidum* spp. *durum* (AABB, 2n=28) and *Aegilops tauschii* (syn *Ae. squarrosa*, *Triticum tauschii*; DD, 2n=14) as a means of increasing novel genetic diversity for bread wheat including yield improvement.

Research in breeding for 'drought tolerance' in wheat using SHW in a collaboration between CIMMYT Mexico and Australia commenced in the late 1990's. Results showed that selection for increased yield at CIMMYT under controlled drought was possible. Selected SHWs were backcrossed into adapted Australian cultivars and the progenies of the backcrosses termed synthetic backcross-derived lines (SBL) evaluated under limited moisture at CIMMYT. SBLs with more than 10% yield increase under drought stress conditions in Mexico were sent to Australia and evaluated in various regions. Enhanced yield was demonstrated in these synthetic backcrossed-derived lines across diverse environments. Significant yield advantages were found for many of the SBLs. Depending on the environment yield of the SBLs ranged from 10 to 50% higher than 'Janz', one of the most widely adapted cultivars in Australia. SBLs were also identified with significantly superior yield performance compared with locally adapted check varieties in both northern and southern Australia. Apart from adaptation to semi-arid water stressed conditions, in addition some SBLs were found to be significantly higher yielding also under more optimal (irrigated) conditions.

An elite group of SBLs was identified that exhibited broad adaptation across all diverse Australian environments included in this study. Other SBLs showed specific adaptation to either northern or southern Australia. In addition, evidence is building from CIMMYT's global wheat yield trials that synthetic derivatives can also contribute to yield potential in well watered, highly productive environments.

This study showed that SBLs are likely to provide breeders with the opportunity to significantly improve wheat yield beyond what was previously possible in a number of diverse production environments. Further studies are under way to determine the underlying genetic diversity of this broad adaptation, and molecular markers are being identified to facilitate introgression into modern wheat germplasm.

Breaking Negative Correlations

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Wheat functions as a complex well integrated organism with adaptation to many environments. Traits of wheat may be correlated in a positive or a negative manner. The direction of the correlation is independent of breeding objectives and may change from one production environment to another. The relationship of grain yield and grain protein concentration exemplifies an undesirable negative correlation in a wheat quality type where protein content is positively correlated with loaf volume. However, this same correlation has an advantage to those end-products which are favoured by low protein concentration such as confectionary products. To shift the negative correlation between grain yield and protein concentration requires assembling in combination or separately a more photo-synthetically efficient, nitrogen-use efficient and\or water-use efficient genotype. Correlations and breeding strategies including marker assisted selection can be employed to shift undesirable correlations.

Preserving End-use Quality while Enhancing Grain Yield

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Increasing grain production based on improved grain productivity is the main goal of wheat breeding. However, the world urban population is continuously increasing and so is the demand for industrially processed foods; a farmer would obtain a better income if the wheat crop is both, highly productive and posses the quality attributes demanded by the market. Breeders' interest in quality is greatly stimulated by the changing situation in many developing countries; in some wheat production has become a significant component of the domestic economy while in others farmers have started to sell their wheat grain on the world market, where good quality brings in premium prices. To keep up with the demands of both domestic and international markets, farmers must produce high-yielding, quality-acceptable wheat grain. Main wheat-based food types include leavened-, flat- steamed breads, noodles, biscuits, alimentary pasta (spaghetti, etc.), and regional wheat-based dishes (cous-cous, burghul). Not all wheat varieties possess the same type of quality attributes, therefore a wheat cultivars suitable for one kind of wheat-based food type is not necessarily suitable for a different one. These quality differences result mainly from genetically-controlled grain traits such as endosperm hardness, grain protein, and gluten protein composition. These grain quality traits can be improved through breeding. However, there are non grain factors (biotic, abiotic constraints) affecting the expression of quality as much as they affect grain yield. In addition, the availability of nitrogen during grain filling and maturation is determinant of the amount of protein accumulated in the grain, and consequently, of the expression of the inherent quality traits of the genotype. Wheat quality improvement by the CIMMYT Wheat Program is a team effort; breeders, agronomist, physiologist, and cereal chemists work together to achieve high yield and high quality. The problem is tackled by combining 'good quality' genes/alleles and other previously identified quality-enhancing factors, by crossing the right wheat parents. At the end of every crop cycle, several quality tests are used to screen early advanced lines in Cd. Obregon, while intermediate and elite lines are quality-screened at headquarters. There is an inherent problem in attempting to improve both grain yield and grain quality at the same time, since there is an inverse relationship between high yield and high protein content. Consequently, breeders must find a way to increase one without affecting the other. Nitrogen Use and Nitrogen Translocation efficiencies are important plant traits required to accumulate desirable levels of protein in the grain. One additional strategy to increase grain protein content could be introducing protein-enhancing genes from *Triticum dicoccoides* into improved wheat germplasm. These two aspects are being examined by an interdisciplinary team at CIMMYT. Agronomists are also working on developing appropriate farming practices (based mainly on nitrogen use efficiency, including nitrogen fertilization rates and timing) which can impact positively both grain yield and grain protein content. Further advances in combining high yield and high quality are expected to come as more 'good quality' genes are identified and as Marker Assisted Selection is applied.

Challenges to Maintaining Wheat Productivity: Pests, Diseases and Potential Epidemics

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Increasing wheat yield potential in high production zones will not occur in a vacuum: pests and diseases are ready to take advantage of the situation. Knowing pests and diseases that may cause injuries and are likely to affect the plant health and quality is critical to minimize the gap between attainable yield and actual yield. We highlight concepts and strategies towards controlling major biotic constraints affecting wheat in intensive systems and present emerging challenges with a special attention to the developing world.

In environments characterized by dense stands and high density of tillers, foliar diseases are the most important constraints due to their effect on grain-fill after anthesis and direct impact on reduction of light interception and radiation use efficiency. Pathogen populations with a high evolutionary potential such as causing rusts and powdery mildew are more likely to overcome genetic resistance than pathogen populations with a low evolutionary potential. Since rust spores can travel over long distance, international collaboration involving field monitoring, use of trap nurseries, enhanced information on the genetic basis of resistance and the accumulation of non-race specific resistance genes are key aspects of a successful resistance breeding strategy. Shift toward breeding and deploying cultivars with durable resistance is essential to protect yield against rusts. The occurrence of yellow rust with virulence to *Yr27* in parts of South Asia and an overdependence on cultivars grown on millions ha illustrate the continuing challenge of maintaining genetic gains and the risk of facing new epidemics. The outbreak of stem rust race UG99 in Africa for which most current commercial cultivars are susceptible is another serious concern because all wheat growing areas may soon be at risk if the new pathotype spreads or is introduced accidentally to other areas.

Disease epidemics always result from the combination of inoculum, favorable environment and host susceptibility. Changes in cropping systems as a result of adoption of conservation agriculture may have serious implications in some areas. Necrotrophic pathogens such as causing tan spot or Septorias are likely to emerge, and Fusarium head scab may increase. However, resistance breeding combined with rotations, timely sowing and irrigation or even fungicide utilization if affordable, are part of integrated crop management practices minimizing losses. In South Asia, the effect of spot blotch, a devastating foliar disease caused by *C. sativus* in warmer growing areas can be minimized by reducing physiological stress through timely sowing and adequate use of fertilizers which shows the complex relationship between crop physiology, disease resistance and yield. Although foot rots inducing lodging may often occur in cooler high yielding humid environments, root rots should not completely be ignored at lower latitudes. However, common root rot caused by *C. sativus* and crown rot due to *Fusarium* are more severe in dry lands. Similarly, yield losses due to nematodes or viruses may be overlooked, but with cyst and lesion nematodes are less likely to be important as they are problematic under drier sub-optimal growing systems. Lastly climate change is likely to modify the wheat disease spectrum in some regions and pathogens or pests considered unimportant today may turn out to be potential new threats in future. One example is the spread of blast disease on wheat in warmer areas of Brazil and Bolivia.

Using Plant Breeding Data to Move from Genotype-by-environmental Interactions to Gene-by-environmental Interactions

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Genotype-by-environmental interactions, especially of the cross-over type for quantitative traits, impede the development of cultivars in plant breeding programs. Progress has been made with self-pollinated cereals to identify and quantify these interactions, usually where the genotypes are cultivars or breeding lines. However, genes influencing traits of interest, such as grain yield or grain quality, are much more long-lasting than cultivars, with allele frequencies changing as the breeding program progresses.

Molecular technologies provide the means of identifying allelic variation for genes influencing quantitative traits. Statistical software and computing power can now make unbiased predictions of effects and values of identifiable genes from large, unbalanced data-sets for combinations of alleles across many loci. We have used these technologies to identify gene-by-environmental interactions with cross-over points for the glutenin and puroindoline genes that influence key grain quality traits in wheat (*Triticum aestivum* L.) and made predictions across 7 glutenin and puroindoline loci for 5184 combinations of alleles at different flour protein levels. These predictions include both gene-by-environmental interactions and gene-by-gene epistatic interactions.

Similar methods have been used to identify the effect of the *sdw1* gene in barley (*Hordeum vulgare* L.) on grain yield. We suggest that the same molecular and statistical technologies that we have used for polygenic inheritance of grain quality can be used for polygenic inheritance of grain yield in wheat, but that relationship matrices will be more important to minimise bias. Large data-sets, of the type generated by plant breeding programs, will be necessary, and can now be used with these technologies.

The Cross Prediction software used by collaborating wheat breeders will be demonstrated.

International Winter Wheat Trials: Adaptation and Trends

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In 1986 the Turkish Ministry of Agriculture, CIMMYT and ICARDA joined forces to conduct research on winter wheat through the International Winter Wheat Improvement Program (IWWIP). The two main objectives of the program is to develop broadly adapted, disease resistant, high yielding winter wheat germplasm for the winter and facultative wheat growing areas in Central and West Asia and North Africa (CWANA), and to help facilitating germplasm exchange among the winter wheat breeding programs around the world. About 31 million hectares of the 103 million hectares of wheat in low-income countries is facultative or winter wheat, of which 16.5 million hectares are grown in Central and West Asia and North Africa, 13 million hectares in China, and 1 million hectares in South America, North Africa and North Korea. Germplasm exchange and evaluation is facilitated through the yearly shipment of various international nurseries, to a number of collaborators around the world. Among these, three yield trials are distributed; WWEERYT (Winter Wheat East European Yield Trial) and EYT-IR and EYT-RF (Elite Yield Trial for Irrigated and Rainfed Areas, respectively) which for this presentation were used to study the effects of genotype x environment interaction, and the progress in grain yield for breeding material originating from the IWWIP program. Multiplicative models for multi-site cultivar trials have been used for studying genotype x environment interaction (GEI) and for developing methods for clustering sites or cultivars into groups with statistically negligible crossover interaction (COI). SREG biplots were developed for each year to investigate the relationship among sites for grain yield and to cluster location and genotypes in order to minimize the crossover interaction (COI) within a cluster, and to identify the highest and lowest yielding entries across locations within a cluster. In order to study the progress in grain yield of germplasm originating from the IWWIP program (1EYT-IR to 6EYT-IR, and 1EYT-RF to 6EYT-RF), grain yield of the five highest yielding entries from each location was expressed as percent of the trial mean and grain yield of locally adapted check cultivar and regressed over years. Mean grain yield of the five highest yielding entries were utilized, as the diversity among entries in the nurseries is quite high, and only a small proportion of the entries is expected to be adapted at any given region.

Forty Years of International Bread Wheat Trials: What Have We Learned?

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Yield potential is the maximum attainable yield within the limits imposed by the production environment. Better understanding of these constraints and the underlying causes of genotype x environment (GxE) interaction will improve productivity both regionally and globally. For forty years the International Maize and Wheat Improvement Center (CIMMYT) has coordinated the global distribution of wheat yield trials, and collaborators from across the world have provided yield, disease and agronomic data. Various analyzes of these data have been conducted over the years with the aim of assessing the effectiveness of CIMMYT's Mexican based breeding program, identifying key selection environments and genotypes with broader adaptation.

The International Spring Wheat Yield Nursery (ISWYN) was distributed world wide between 1964 and 1994. After 1992, the world's wheat production environments were divided into mega-environments, or zones with similar climatic and production constraints, in order to better target the wheat breeding effort in Mexico and reduce GxE. As a result the ISWYN was discontinued and four new international trials introduced that spanned the irrigated (ESWYT), high rainfall (HRWYT), semi-arid (SAWYT) and hot (HTWYT) wheat mega-environments. Analysis of these data confirmed the value of shuttle breeding in Mexico and the value of Ciudad Obregon, CIMMYT's primary yield testing environment, as a key selection environment. Lines entering the ESWYT (and prior to 1994 the ISWYN) are optimally sown and selected under well watered conditions at Ciudad Obregon, whereas those entering the HTWYT are late sown to generate terminal heat stress. Both these Mexican environments correlate well with their global target areas. Germplasm entering the SAWYT is selected and screened in Cd. Obregon for response to drought stress using limited irrigation. This type of screening correlated well with environments in south Asia, but less so with sites in west Asia and South America. On the basis of these findings drought screening in Mexico has been modified to better reflect a wider array of drier environments. In contrast, CIMMYT's high rainfall environment at Toluca, the other arm of the Mexico based shuttle, was found to be a poor predictor of global high rainfall areas. Yield testing has been discontinued at this site although its importance for disease screening is undiminished.

In the process of analyzing these data, key locations in countries outside Mexico have been identified. Integrating information from these sites with that obtained in Mexico has helped improve the efficiency of CIMMYT's global wheat breeding effort. The analysis of global cultivar performance has helped identify superior genotypes from within clusters; and has also allowed breeders to target crosses among clusters to broaden adaptation.

Association among Durum Wheat International Testing Sites and Trends in Yield Progress over the Last Twenty Two Years

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Durum wheat currently represents 8-10% of the wheat grown and produced worldwide. It is however concentrated in relatively small geographical areas where it often plays a major role in the food security of urban populations and in the livelihood and nutrition of urban communities.

More than 80% of the spring durum cultivars released in the developing world, covering more than 50% of the area planted in this crop, are semi-dwarf types either from CIMMYT crosses or from crosses that involve at least one CIMMYT parent. This global impact and the widespread sowing of relatively few, widely adapted cultivars, such as the YAVAROS lines, across large geographical areas underscore CIMMYT's global responsibility to keep providing National Programs with germplasm that can replace advantageously the current cultivars and provide an opportunity for a viable diversification of the cultivar basis in developing countries. To do that, CIMMYT distributes each year a set of durum wheat nurseries, including a replicated yield trial, the International Durum Yield Nursery or IDYN, to more than 100 collaborators worldwide.

In order to ascertain continued global relevance of our breeding activities based on the shuttle-breeding approach in Mexico, it is important to regularly analyze historical data available to us to monitor the global trends in yield progress over many years in different environments/regions. It is also important to explore the association among international testing sites based on genotype by environment interactions over years. The results from such analyses of the IDYN historical data are presented herein for a total of 827 environments (or location/year combinations) representing 145 locations reporting data from 1983 (14th IDYN) to 2003 (35th IDYN). Only those durum wheat genotypes from crosses made at CIMMYT and produced through at least one round of shuttle-breeding in Mexico were included in the study. Only those locations that have reported results as complete datasets from at least two years were considered. With very few exceptions, all years/nurseries included 3 common, widely adapted checks, namely, MEXICALI 75, YAVAROS 79 and ALTAR C84.

Whereas the best yielding check varied over years and locations, YAVAROS 79 had the highest overall mean yield over years and locations. Whereas the difference between YAVAROS 79 and MEXICALI 75 was not statistically significant, both out-yielded significantly ALTAR 84. Most importantly, stability analysis of the checks results using regression (slope and deviation from regression) and the Wricke ecovalence parameter clearly indicated that YAVAROS 79 was the most stable check, supporting its well documented wide adaptation and its status of the most widely grown cultivar in developing countries to date. Consequently, yield trends over years are reported here relatively to this check cultivar.

Regression analysis indicated that, from 1983 to 2003, the yield nursery means (in t/ha) averaged over reporting locations (23-45 depending on year) increased by 1.15% per year and the means of the 5 best yielding genotypes (in t/ha) at each site, averaged over the same reporting sites increased by 3.75% per year. However, progress in yield over years is best indicated in relation to a common check, the widely adapted, widely grown and remarkably stable genotype YAVAROS 79. During the same time period, the means of the 5 best yielding genotypes at each site expressed as % of the yield of YAVAROS 79, averaged over all reporting sites, increased by 1.43% per year. In order to explore trends in yield progress in environments characterized by different yield potentials, we have subdivided the environments (regardless of geographical location) in 3 classes based on their average nursery yield (ANY) in a given year, in unfavorable environments (ANY<2.5 t/ha), intermediate environments (2.5<ANY<5.0 t/ha) and favorable (ANY>5.0 t/ha). The means of the 5 best yielding genotypes at each site in the same class expressed as % of the yield of YAVAROS 79, averaged over all reporting sites in the same class, increased by 2.08% per year in unfavorable environments, by 1.36% per year in intermediate environments and by 1.39% per year in favorable environments. In the locations corresponding to the Central, West Asia and North Africa (CWANA) region, where durum wheat is most important and the YAVAROS 79 sister lines play a dominating role, the yield progress expressed as above was 1.2% per year when all yield levels were considered.

Although these annual yield progress values (1 to 2%) are common in many national or local breeding programs with local or regional scopes, they can be considered rather remarkable when obtained by a breeding effort centralized in a single country and tested for impact globally, practically wherever spring durum is grown in the world. As for bread wheat, these durum wheat results indicate that the concept of a centralized breeding effort in Mexico based on the "shuttle-breeding" approach and relying on a global network of NARs cooperators has been successful, not only in providing widely adapted, high yielding semi-dwarf cultivars to replace landraces in most durum growing countries in the developing world, but also in maintaining a steady flow of new genotypes representing an improvement in yield potential over years (under experimental stations conditions) for NARs to select from; And, interestingly, this success is apparently more pronounced in low yielding environments. On this last point, a preliminary exploration of the low environment sites leads to those rainfed locations in years of low rainfall, however a formal analysis of actual rainfall at those sites during the low yielding years needs to be conducted before we can reliably conclude that the most substantial annual progress rate of our breeding effort over the last 22 years occurred in drought-prone environments. However, it is important to emphasize that this positive assessment is based on general trends calculated by averaging results of many, often very different locations. Analyses for some individual locations reveal that yield progress over years has not been as positive and sometime negative overall. Detailed exploration of environmental conditions and disease pressure at those sites is needed to understand failure to show yield progress over time.

Associations between international testing sites over years were determined based on how sites differentiated genotypes for yield, using both classification and ordination approaches of pattern analysis. The former yielded a dendrogram dividing 44 of the 145 locations into 4 clusters (at the third fusion level) consisting of locations that differentiated genotypes similarly for yield. The first group included 14 sites while the other 3 consisted of 10 locations each. The first group included, high yielding, either irrigated locations of North Africa-Middle East and South Asia (2 in Egypt, one in Iraq, 4 in Northern India and 1 in Pakistan) or high-rainfall locations of Europe (Central Italy, France, Bulgaria, Serbia), West Africa (Kenya) and CIMMYT's Toluca station, one of the two locations of the shuttle breeding program. The second group included mostly irrigated sites characterized as warm environments (5 sites in West/South India, 1 site in Southern Egypt, 1 site in Ethiopia) as well as the heat testing sites established by CIMMYT in Obregon using late planting. However, it also includes a Canadian and a German site where photoperiod sensitivity can be an advantage. Group 3 represents primarily the high yielding irrigated sites of Northern Egypt (2 sites), 1 site in India, 1 in Pakistan and 1 in Zimbabwe and CIMMYT's irrigated location of Obregon, the other location involved in the shuttle breeding program. As for bread wheat (ESWYT), the high yielding testing site of ICARDA in Tel Hadya co-clustered with CIMMYT's fully-irrigated Obregon site. Finally, the drought environment simulated by CIMMYT at the same Obregon site through withholding of irrigation co-clustered with the full irrigation favorable environment at the same site. The last group included all rainfed sites with variable rainfall, mostly in the Northern Mediterranean shore (Spain, Portugal, Central Italy, Southern Turkey and Cyprus), or Algeria and finally 2 Chilean sites.

The ordination analysis yielded a biplot that supported overall the grouping obtained from the dendrogram except that some possible overlaps between groups were suggested. For example, both full irrigation and drought environments of the Obregon Station were at the limit of quadrants corresponding primarily to locations from group 1 and that corresponding to locations primarily from group 3. Similarly, the Egyptian, Ethiopian and the 2 Indian locations clustering in group 2, could very well be included in the quadrant corresponding to sites clustering to group 1. A more in depth analysis for each individual year and a study of how environmental variables may affect yield at certain locations is needed to better interpret the classification of durum wheat testing environments. However, the preliminary results presented here suggest that information obtained at CIMMYT stations (Obregon, full-irrigation, drought and heat and Toluca high rainfall) is highly relevant to 3 of the 4 groups identified with pattern analysis, which represent 34 of the 44 locations, including all irrigated sites, high yielding rainfed sites and some sites with warm environments.

Global Adaptation of Near-isogenic Spring Wheat Lines Contrasting for Major Reduced Height Genes

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The wide adoption and success of spring wheat cultivars containing the height reducing alleles, *Rht-B1b* and *Rht-D1b* (also known as *Rht1* and *Rht2*, respectively), continues 40 years after their first introduction, and subsequent contribution to the Green Revolution. Semi-dwarf cultivars allowed significant yield increases due to an increase in harvest index in irrigated, fertile environments where tall wheats tend to lodge (Athwal, 1971). However, the adoption of semi-dwarf wheats was not confined to the high input high yielding wheat production regions. Despite reports that semi-dwarf cultivars may have a yield penalty in less favourable environments where trial mean yields are generally below 2Mg ha-1 (Keyes and Sorrells, 1986; Richards, 1992), Heisey et al. (1999) reported that 95% of all cultivars released in developing countries, including both favourable and unfavourable environments, contain one of these height reducing (Rht) alleles. Since most spring wheat programs utilize semi-dwarf backgrounds, it is rare for tall lines to be released. Consequently, tall lines developed prior to the widespread adoption of semi-dwarfs are generally susceptible to diseases that have arisen since their release and comparison with more recently developed, disease resistant semi-dwarf lines is misleading. Hence, a comparison of modern semi-dwarf lines and their 'tall modern' counterparts is instructive about the current value of the reduced height genes.

The effect of major dwarfing genes varies with environment. Six reduced-height near-isogenic spring wheat lines, included in the International Adaptation Trial (IAT), were grown in 81 trials around the world during 2001 to 2004. Of the 56 IAT trials yielding > 3 t ha^{-1}, the mean yield of semi-dwarfs was significantly greater than talls in 54% of trials; in the 27 trials yielding < 3 t ha^{-1} semi-dwarfs were superior in only 24% of trials. Sixteen pairs of semi-dwarf:tall near-isolines were grown in six managed drought environment trials at CIMMYT in northwestern Mexico. In these trials, semi-dwarfs outyielded talls in all but the most droughted environment (2.5 t ha^{-1}). The effect of the height alleles varied with genetic background and environment. For both yield and height, variance components for allele and environment by allele interaction were larger than those for genetic background and genetic background by environment. Pattern analysis showed that tall and semi-dwarf lines had similar adaptation to stressed environments (< 2.8 t ha^{-1}, low rainfall) while semi-dwarfs yielded more in less stressed environments (> 4.3 t ha^{-1}, high rainfall). The best adapted near-isogenic pair had a Kauz background, where the tall was only 16% taller than the semi-dwarf. In the Kauz-derived pair, the semi-dwarf outyielded the tall in only 13% of trials with no differences in low yielding trials. This supports the idea that 'short talls' may be useful in marginal environments (yield < 3 t ha^{-1}).

Avenues to Increase Yield of Short Season High Latitude Wheat in Northern Kazakhstan and Siberia

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High latitude spring wheat production in northern Kazakhstan and western Siberia covers an area of close to 20 million ha. The wheat production environment is a dryland fallow-wheat system with precipitation ranging from 250 to 450 mm. Crops are planted in the second part of May and harvested in late August and September. Spring bread wheat remains the dominat crop in the region with an average yield of 1.0-1.5 t/ha. This region has a relatively limited cultivation history: The whole region of virgin lands was brought to cultivation 50 years ago to satisfy the growing demand in grain. On-farm yield varies from 0.5 t/ha in very dry years to 3.0 t/ha in favorable years. An agronomic approach to enhance yield potential is to increase the share of fallow in the rotation which provides more nitrogen and improves soil moisture. Each consecutive wheat crop after fallow reduces the yield by 10-20%. However, the adoption of conservation agriculture is increasing across the region and the practice of fallowing is diminishing and may be abolished. In this scenario crop diversification and nitrogen management will play a major role. The currently grown varieties are characterized by tall straw, high sensitivity to day length and susceptibility to diseases; leaf rust specifically. Comparison of wheat varieties from the USA, Canada and Kazakhstan/Siberia at several sites demonstrated a yield advantage for the local germplasm, suggesting that height and day-length sensitivity are important elements of adaptation in the region. Multilocational testing of the Kazakhstan-Siberian Spring Wheat Nursery across years showed the importance of leaf rust resistance in maintaining yield potential in years with average to high precipitation. The analysis of yield components identified grains per unit area and thousand kernel weight as key characters influencing yield potential. Efforts are underway to combine these traits from different gene pools using shuttle breeding methodology.

Genetic Improvement of Yield Potential and Associated Traits in North China Winter Wheat Region from 1960 to 2000

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Knowledge of changes with grain yield and associated traits of historical cultivars is essential for understanding yield limiting factors and developing strategies for future cultivar improvement. Four trials, including a total of 47 leading bread wheat (*Triticum aestivum* L.) cultivars from the North China Winter Wheat Regions from1960 to 2000, were conducted during 2001-2003 seasons with a randomised complete block design of three replicates under controlled field environments. Results showed that averaged annual genetic gain in grain yield was 48.88 kg $ha^{-1}year^{-1}$ or 0.78%, ranging from 32.1 kg $ha^{-1}year^{-1}$ to 67.1 kg $ha^{-1}year^{-1}$ or from 0.48% to 1.23% annually in different Provinces. The significant increase of grain yield was mainly occurred in the early 1980s, largely due to the successful utilization of dwarfing genes and 1B/1R translocation. There was no common trend across trials in terms of changes in spikes m^{-2}, kernels per spike, thousand kernel weight (TKW), and biomass. The genetic improvement of grain yield was primarily attributed to the increased kernel weight per spike, reduced plant height , and increased harvest index (HI). The dwarfing genes *Rht-D1b* took a predominant position (68.0%), followed by *Rht 8* (42.0%) and *Rht –B1b*(16.0%). The frequency of 1B/1R translocation cultivars released since 1980 was 42.6%. The future challenge is to maintain the genetic gain in grain yield and to improve grain quality, without increasing the inputs for the maize-wheat rotation system.

Genetic Improvement and Stability of Wheat Grain Yield Assessed through Regional Trials in the Eastern Gangetic Plains of South Asia

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Improving the level and stability of grain yield is the primary objective of wheat breeding programs in the Eastern Gangetic Plains (EGP) of South Asia. A regional wheat trial, the Eastern Gangetic Plains Yield Trial (EGPYT), was initiated by CIMMYT in collaboration with national wheat research programs in Bangladesh, Nepal and India in 1999-2000 to identify wheat genotypes with high and stable grain yield, disease resistance and superior agronomic traits for the EGP region. A set of 21 wheat experimental genotypes selected from a regional wheat screening nursery in South Asia, three improved checks, one each from Bangladesh ('Kanchan'), India ('PBW343') and Nepal ('Bhrikuti'), and one long-term check ('Sonalika') were tested at 9 to 11 sites in six wheat growing seasons (2000 to 2005) in the EGP region. The 21 experimental genotypes changed every year whereas the four check cultivars remained unchanged. In each year, one or more of the experimental genotypes showed higher and more stable grain yield, higher thousand-kernel weight, similar maturity and plant height, and lower foliar blight severity compared to the check cultivars. However, analysis across six years showed that biotic and abiotic stresses have caused a declining trend in grain yield in the region as shown by the yield of the check cultivars. Identification of wheat genotypes with high grain yield in individual sites and high and stable yield across EGP region undermines their value for regional wheat breeding programs attempting to improve grain yield and agronomic desirability. A few high yielding lines identified through the EGPYT have been released or are in the varietal release pipeline. The results demonstrate the important role the EGPYT has been playing in continuous introduction and exchange of valuable wheat germplasm thereby complementing breeding efforts to increase wheat yields in the region. The findings also present a broader picture of the biotic and abiotic constraints to wheat production on the warm Eastern Gangetic Plains of South Asia where livelihood of millions of resource poor farmers depends on the successful wheat cultivation.

Understanding the Physiological Basis of Yield Potential in Wheat

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This paper focuses on the last 10 years. Lately the physiology of wheat yield has come under pressure from two new imperatives, perceived slowing genetic progress and ambitious functional genomics. Analysis of trials between 1996 and 2005 at CIANO suggests that yield potential progress in CIMMYT spring wheats has slowed to less than 0.50% pa, but has not ceased. Meanwhile in the last 10 years or so, physiological understanding has advanced somewhat, although we know little as to why spring wheat harvest index at around 45% still lags behind other crops. Kernel number/m2 remains the key to higher yield, and new research reinforces the importance of spike dry weight (g/m2) at anthesis in its determination; lengthening the spike growth through manipulation of sensitivity to photoperiod looks promising, but more attention to kernels per unit of spike weight is also urged. With respect to plant height, an optimum somewhere between 70 and 100 cm is accepted and we are moving away from infatuation with the Norin 10 dwarfing genes as way of reaching that. What we haven't achieved is good lodging resistance in all short spring wheats, nor a complete understanding of its physiological basis. New information is coming to light on the possible role of stored stem reserves at anthesis, for these reserves appear to have increased as yield potential has increased, a counterintuitive observation when the importance of spike dry weight is considered. Part of the benefit may be related to our increased understanding of the importance of assimilate supply per kernel around anthesis for maximum potential kernel weight. Nonetheless most results suggest that despite more kernels/m2, the most modern wheats are still largely sink limited during grain filling. Growing evidence from spring and winter wheat (and from rice and maize) now points to the importance of increased photosynthetic activity before and around flowering for recent genetic increases in yield potential. This opens up obvious possibilities for selection in field plots. Finally, attention is given to effects of weather on yield potential and recent advances in techniques for elucidating the physiological basis G x Y effects.

From physiological understanding such as described, traits are suggested as possible selection criteria for yield potential. However, apart from the ACIAR CIMMYT project looking at stomatal aperture-related traits to be described elsewhere in this meeting, there appear to have been few recent attempts to validate physiological (or morphological) selection criteria for wheat yield potential. This contrasts with efforts to improve the performance of wheat (and maize) under water limited conditions, and with the new plant type and super rice approaches of IRRI and China, respectively. Such research could be mapped out for wheat yield potential improvement but it needs a multidisciplinary team, including nowdays molecular biologists, as well as suitable controlled and field environments, and long term support: all this may no longer be available in the public sector, at least at a single location.

Increasing Photosynthesis by Overcoming the Limitations of Rubisco

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Since the molecular machines of nature are built around a central scaffolding of organic carbon, the assimilation of CO_2 into biomass is central to life on this planet. In C_3 plants, including wheat and rice, the initial assimilation of CO_2 requires the enzyme Rubisco. However, catalysis by Rubisco is inefficient and its slow turnover of substrate is a major limitation to photosynthesis at light saturation and at current CO_2 concentrations. Rubisco also catalyses a competing and wasteful reaction with O_2 that leads to the loss of assimilated carbon as CO_2. Considerable progress has been made in identifying the extent of natural variation in the catalytic properties of Rubisco from different species. Even amongst terrestrial C_3 species there is some modest variation in the catalytic properties of Rubisco. Even so, if the best characteristics of Rubisco from C_3 species could be introduced into crops then significant improvements on photosynthetic rate would ensue. It may be possible to bring about further improvements in crop photosynthesis through genetic modification to increase the availability of CO_2 at the catalytic site or by increasing the catalytic rate and/or specificity of Rubisco for CO_2 relative to O_2. Our understanding of the catalytic mechanism of Rubisco has been greatly enhanced by the characterisation of site-directed mutants coupled with availability of high resolution 3-dimensional structures. Considerable progress has been made in developing the tools for introducing improved Rubisco genes into plants. But major challenges remain, such as overcoming the complexities of protein folding and subunit assembly, which are prerequisite for a functional holoenzyme *in vivo,* and also ensuring effective regulation and preservation of catalytic activity. Success in these areas will confer great agronomic benefit although the need to remedy other downstream limitations which impact on assimilation will also be essential.

Sink Limitations to Yield in Wheat: How Could it be further Reduced?

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Variations in yield are mostly explained by changes in grains per unit land area, suggesting that wheat yield is mainly limited by sink strength during grain filling. Although the different yield components are defined throughout the whole crop cycle not all phases of development have the same importance in terms of yield formation. In fact, the phase of stem elongation (SE) comprising the period from terminal spikelet initiation (TSI) to anthesis (An) has been identified by many authors as the most important phase for grain number, and yield, determination (i.e the critical period for yield determination in wheat). Since this critical phase is probably the only period of the crop cycle when yield is largely limited by source strength, any trait allowing more assimilates available to the growing spikes during that period would result in increased spike dry weight at anthesis, which in turn concomitantly increases spike fertility. An alternative avenue to keep increasing spike dry weight and thereby number of grains is lengthening the duration of stem elongation phase avoiding major changes in flowering time. Previous evidences carried out under controlled and field conditions, manipulating the photoperiod during the stem elongation phase, support the hypothesis that the longer the phase from terminal spikelet initiation to anthesis, the higher the number of fertile florets and grains established by the crop. The critical experiments to elucidate the possible interaction between photoperiod and assimilates availability, modifying incident radiation during the stem elongation phase in combination with different stem elongation duration strongly supported the idea that most photoperiod effects on the number of fertile florets, and grains, were mediated by assimilates supply to the growing spike. When stem elongation phase was modified the survival of florets positioned in the middle of the spike (mostly florets from the 3rd to 5th position within central spikelets) may be improved. Genetic manipulation of photoperiod sensitivity during the late reproductive phase would likely help keep increasing yield potential. Photoperiod response in wheat is determined by a series of homoeologous loci *Ppd-D1 (Ppd1), Ppd-B1 (Ppd2)* and *Ppd-A1 (Ppd 3)*, located on the group 2 chromosomes: 2D, 2B and 2A, respectively. Unfortunately only few experiments were carried out to analyse the effect of particular Ppd genes on duration of stem elongation. In a recent work Gonzalez et al. (2006) using Mercia isogenic and Cappelle Deprez recombinant lines, and manipulating photoperiod in the field, analysed the effects of Ppd genes on (i) development of pre-anthesis phases and (ii) the number of fertile florets at anthesis. They found that Ppd-D1 was insensitive to photoperiod during the pre-anthesis phase, while PpD-B1 was insensitive only during the early reproductive phase. Whenever ppd-D1 was present a direct response to photoperiod during the LRP was observed independently of the presence of ppd-B1 or Ppd-B1. As this approach did not offer clear conclusions, chances are that the control of photoperiod sensitivity during stem elongation would be less simple than we thought initially, and probably the identification of its likely genetic bases would require the use of molecular biology tools.

Stomatal Aperture Related Traits and Yield Potential in Bread Wheat

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It is predicted that over the coming decades demand for wheat will continue to grow by over 1% per year world-wide and by about 1.8% per year in developing countries. On the other hand, the area sown to wheat is expected to change very little and inputs such as irrigation are expected to decline significantly. This scenario indicates an urgent need for accelerating the breeding and release of wheats with increasingly higher yield potential. Are there tools available that could help wheat breeders achieve this?

Research during the 1990's at CIMMYT revealed a consistent correlation between the historic increase in yield potential among CIMMYT semi-dwarf bread wheats and changes in stomatal-aperture related traits (SATs). These traits included stomatal conductance, canopy temperature and carbon isotope discrimination. The original detailed work was done on a relatively small number of entries. This paper reports results of more-recent studies with larger populations of breeding lines assessing the utility of SATs as indirect selection criteria in breeding for high yield potential.

Canopy temperature, leaf porosity (a rapid surrogate of stomatal conductance) and carbon isotope discrimination ($\Delta^{13}C$) were measured on 5 populations of random lines grown in small observation plots (1.6m^2) simulating early-generation sowings. These measurements on small plots were compared with yields of the same lines grown in larger 'yield-trial' plots (6.4m^2). Plots of both sizes were sown 2001-02, 2002-03 and 2003-04 at Obregon and managed under high-input conditions

All three SATs showed reasonable utility as tools for use in breeding for high yield potential. Genetic correlations (r_g) between SATs and yield were mostly statistically significant and moderate-strong (r_g = 0.3-0.9). On average, correlations were of a similar magnitude for all SATs. Correlated response to selection was calculated based on SATs measured in small plots (selection intensity 25%) and yield measured on large plots. In the majority of cases, the results indicated significant genetic gains in the range 40-60 g/m^2 (at ca. 600g/m^2 mean yield level).

Canopy temperature, leaf porosity and $\Delta^{13}C$ can all be measured relatively easily in breeding populations. Leaf porosity and canopy temperature are considerably cheaper, but successful collection of full data sets of both measurements is dependent on stable, sunny weather conditions. Analysis of plant material for $\Delta^{13}C$ avoids this problem, but isotopic analyses are expensive and so are less likely to be used in a routine fashion.

Strategies for Raising Yield Potential in Wheat

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Since the international workshop "Increasing the Yield Potential of Wheat: Breaking the Barriers" in 1996 (Reynolds et al., 2006), CIMMYT wheat scientists in collaboration mainly with Australian colleagues have combined physiological, genetic-resource, and breeding strategies to implement the proposed research agenda. This has been divided into three broad areas (funded by ACIAR Australia): (i) Identifying traits that limit yield and radiation use efficiency (RUE) in high potential environments, (ii) Pre-breeding using genetic resources expressing those traits identified as yield-limiting in elite cultivars, (iii) developing early generation selection (EGS) techniques to increase the efficiency of breeding and therefore the probability of identifying higher yielding material.

Early generation selection will be addressed by others in this symposium (Condon et al., 2006; van Ginkel et al., 2006) as will the issue of economic returns on investment in this strategy (Brennan et al., 2006). In summary, canopy temperature (CT) and leaf porometry (POR) have been shown to have value in EGS and are complimentary to visual selection by increasing the chances of identifying genotypes with the best yield potential. Parallel studies using spectral reflectance (SR) indices such as the *Water Index* (carried out in collaboration with Oklahoma State University and Colegio de Postgraduados, Mexico) have also indicated their value in EGS in selecting for yield potential (Gutiérrez-Rodríguez et al., 2004; Alibabar et al., 2006).

Limitations to yield and RUE were studied initially on wheat lines containing the alien translocation *7DL.7Ag*. These showed increases in the following traits averaged over six high yield backgrounds: grains m^{-2} (15%), yield (12%), and biomass (9%) compared with recurrent parents. The translocation was also associated with a larger investment in spike-mass at anthesis (15%), more grains/spike (10%), and increased flag-leaf photosynthetic rate during grain-filling (20%). The data suggest that increased biomass in *7DL.7Ag* lines was due to significantly increased RUE post-anthesis, as a result of a larger kernel number (sink) that increased the demand for photosynthesis during grain-filling (Reynolds et al., 2001;2005). The hypothesis that photosynthesis and RUE may respond directly to a larger number of grains/spike was tested experimentally by imposing a light treatment during boot stage. The treatment was associated with a small increase (5%) in the proportion of biomass invested in spike mass at anthesis, reflected by an average of 3 extra grains per spike at maturity. The treatment was associated with 25% more yield and 22% more biomass than checks, while carbon assimilation rate measured on flag-leaves during grain-filling was 10% higher than checks (Reynolds et al., 2005). The results suggest that RUE can be increased indirectly by increasing sink strength and that the current yield limiting process in spring wheat is the determination of kernel number, and not photosynthetic rate, which appears to have excess capacity The role of sink limitation in determining yield is supported by a large body of work that will be reviewed at this symposium by Miralles and Slafer (2006).

Pre-breeding with genetic resources was tackled by identifying germplasm that showed high expression of traits for which experimental evidence and/or conceptual models suggested a limitation in current high yield cultivars. The emphasis was on spike fertility traits. Crosses were made between lines that showed relatively high and low expression of the following characteristics: (i) growth rate during the spike-growth phase (boot stage), (ii) relative duration of the spike growth and grainfilling duration phases, (iii) total above ground biomass at anthesis, (iv) absolute spike-mass and relative spike-mass (spike index) at anthesis. Results from three populations of random inbred lines (RILs) over three cycles suggested that most of these traits contributed to yield. When 2-4 traits were combined using multiple regression analysis they could account for over 50% of the total variation in final yield and biomass. These results were later confirmed by path analysis (see paper by Crossa et al., 2006). Other pre-breeding work -currently in yield trial phase- has focused on balancing source and sink through the following types of crosses: (i) *Gigas*-spike spring wheat crossed to high biomass winter wheat Rialto (in collaboration with J. Foulkes, Univ Nottingham), (ii) multi-ovary lines from China (Chen et al., 1998) crossed to high biomass lines and extended rachis lines, (iii) large-spike (Baviacora type) crossed to erectophile canopy architecture (iv) high spike density lines (from spring x winter crosses) crossed to high yield/biomass lines.

Conclusions

- Indirect selection traits POR, CT and SR can improve the probability of selecting high yield potential lines. Being quick, cheap and easy to measure they can be readily used in combination with visual criteria, thus increasing the efficiency of early generation.
- Yield and RUE are predominantly limited by spike fertility (sink strength) in spring wheat, not by photosynthetic capacity. Even the best spring wheat lines show excess photosynthetic capacity; this is probably a legacy of natural selection in non- agronomically managed environments.
- Spike-fertility traits were associated with yield potential in populations of RILs, especially biomass at anthesis and spike-mass at anthesis. These traits can be measured readily in candidate parents, so that complementary crosses with elite cultivars can be designed.
- Pre-breeding efforts must focus on increasing spike fertility which may be co-limited by photosynthetic capacity during the pre-anthesis phase, although post-anthesis assimilation rate appears not to be limited in current elite germplasm, at least when grown under optimal agronomic conditions.

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Factors Determining Yield in Winter Wheat

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Knowledge of the changes in physiological traits associated with genetic gains in yield potential is essential to improve understanding of yield-limiting factors and to inform future breeding strategies. The growth and development of eight representative UK winter wheat (*Triticum aestivum* L.) cultivars introduced from 1972 to 1995 was examined in field experiments in 1997 - 1999. Significant genetic changes over time and positive correlations with grain yield were found for pre-anthesis radiation-use efficiency (0.012 g MJ^{-1} yr^{-1}; RUE) and water soluble carbohydrate (WSC) content of stems and leaf sheaths at anthesis (4.6 g m^{-2} yr^{-1}). Higher RUE of modern cultivars was correlated with changes in flag-leaf traits, specifically smaller leaves of greater specific leaf weight. Results suggested that yield of modern UK cultivars although still sink limited might be closer to source-limitation than their predecessors. Therefore, breeders may eventually need to take further steps to increase source size post-anthesis alongside improvements in grain sink size. In this respect, greater accumulation of stem carbohydrate reserves may be beneficial, providing this is not competitive with ear growth. Results suggested that the 1BL.1RS wheat-rye translocation may be associated with greater harvest biomass in modern cultivars. The relationship between the amount of stem WSC measured shortly after flowering and grain yield was further tested in two doubled haploid (DH) populations, Rialto x Spark and Beaver x Soissons in 2001 and 2002. There was a positive linear relationship between stem WSC and grain yield in both populations. The effects of 1BL.1RS were further examined in two DH populations, Beaver (1BL.1RS) x Soissons (1B) and Drake-sib (1BL.1RS) x Welton (1B), in 1998-2002. 1BL.1RS increased harvest biomass in both populations, although grain yield was only increased in the Beaver x Soissons population. In the Drake-sib x Welton population, the physiological basis of the increased harvest biomass was investigated, and found to be associated with greater pre-anthesis biomass. There was no change in green area index or light extinction coefficient in the pre-anthesis period indicating 1BL.1RS may have conferred an increase in RUE. The prospects for further raising yield potential through manipulating physiological traits were reviewed with reference to benchmark values for traits established for the modern UK cultivar Consort. It was concluded that scope exists to further increase yield potential through: i) redistributing roots with soil depth to access extra sub-soil resources, ii) increasing the proportion of time to flowering accounted for by the stem-elongation period, to increase ear biomass and stem soluble carbohydrate reserves at flowering and iii) introgression of novel ear-architecture traits to improve ear fertility.

Global Investments in Agricultural R&D and Spillover Implications

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Since 1980 many countries have changed the ways they invest in and organize public agricultural research and development (R&D). Support for public R&D has diminished, especially for near market, applied, productivity-enhancing research, with funds being diverted to new agendas with environmental and food quality and safety objectives. These changes have important implications for sustaining crop productivity in developing countries, which in the past have relied on agricultural R&D spillovers from other countries.

The balance of global agricultural R&D investments is shifting in ways that will have important long-term consequences, especially for the world's least affluent countries. The primary reason is changes in supply and demand for agricultural technologies in developed countries, which have been the main producers of agricultural technologies. These countries seem unlikely to provide the quantities of productivity-enhancing technologies, suitable for adaptation and adoption in food deficit countries, that they did in the past. This trend has been compounded by a scaling back of developed country support for the international agricultural R&D system, which has already diverted its own attention away from finished productivity enhancing technologies, especially for staple food crops.

A shift in R&D agendas is forcing a rethinking of some national and multinational policies. National Governments can take some initiatives in national agricultural R&D policy, such as: enhancing IP and tailoring the institutional and policy details of IPRs to best fit local circumstances; increasing the total amount of government funding for their national agricultural R&D systems; introducing institutional arrangements and incentives for private and joint public-private funding; and improving the processes by which agricultural R&D resources are administered and allocated. While some developing countries are becoming more self-reliant and developing their own R&D programs, a business as usual strategy will mean the more disadvantaged countries will struggle to maintain productivity growth in the face of declining applicable spillovers.

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Returns to Investment in New Breeding Technologies

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Wheat breeding is an economic activity that has provided high returns in the past. Recent developments include technologies that can lead to improved genetic resources, improved selection methods, more rapid fixed lines, improved statistical analysis and improved targeting of production environments. They have the potential to allow for the development of new varieties more rapidly, and/or varieties with enhanced productivity in targeted environments, and varieties with novel characteristics. To ensure that future breeding investments also have high returns, breeding programs need to assess these new technologies to determine whether or not to incorporate them into the program. Clearly, given the extent of their uptake by breeders, there are significant perceived gains from incorporating some of the new technologies. However, not all programs will want to invest in all the new technologies, and the criteria that they need to assess in determining which of the technologies are identified in this paper. In some cases, the technologies allow for a reduction in the cost of a given operations. In other cases, they allow the selection program to be re-structured by providing additional information at an earlier stage of the program or by targeting specific traits. However, several of the new technologies require significant investment, either in the infrastructure itself if the operations are to be carried out within the breeding organisation, or funding for contracting the operations to outside organisations. Access to these facilities and the size of the necessary investment can be important issues for breeders considering incorporating the new technologies in their programs. Where some significant gains can be achieved at relatively low cost, all programs can adopt the new technology. Where the investment is large, only select breeding programs will be able to afford to incorporate the new technology into their programs. Analysis of marker-assisted selection shows that some markers can enable some operations to be carried out at a fraction of the cost of phenotypic evaluation. Similarly, analysis of the Stomatal Aperture-related Traits of leaf porosity and canopy temperature depression shows that both are low-cost options that can lead to significant cost savings in selecting for yield. If the resources saved with such technologies are reinvested in the program, the restructured programs are likely to produce markedly higher rates of gain from breeding, and consequently higher rates of return on the investment in wheat breeding.

Wheat Adoption, Impact Pathways and Innovations Systems

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Wheat is produced in a wide range of agro-ecologies and farming systems. Bread wheat, which accounts for 90 % of total wheat production, is grown on a substantial scale in 69 countries on 5 continents. In developing regions, wheat is harvested on about 100 million ha of crop land, which represents approximately 22 % of the total area of cereal crops. As a result, wheat underpins food security developing countries, providing 40 % of food crop energy. About one-third of global wheat area is found in poor countries where farm household incomes average less than US $ 1 per capita per day.

Wheat improvement, therefore, has the potential to contribute to the first MDG of halving hunger and poverty reduction by 2015, and to several other MDGs. Wheat productivity increased significantly during the past 40 years through, *inter alia,* the availability of better varieties, more effective pest and disease control, better production practices and improved farm management. Annual yield growth rates peaked at 2.75 % p.a. in the 1980s, but have slowed since. However, increased physical productivity has been offset, to varying degrees depending on location, by a substantial increase in input prices and a substantial decline in grain prices.

Building on the rapid adoption of modern wheat varieties in South Asia and Mexico in the 1960s and 1970s, successive generations of modern varieties spread now dominate the wheat area of the world. In developing countries modern varieties were sown on 83% of irrigated and high rainfall wheat land by the late 1970s and on practically all high crop potential land world wide by 1990. Empirical evidence points to a number of factors which influence the adoption of modern varieties, including (a) characteristics of the released varieties; (b) features related to local institutions, such as the availability of seed, finance and grain markets; and (c) farm and household characteristics, such as land quality, irrigation, farm size, competing and complementary enterprises and farmers' education.

It is generally recognized that the first step in the adoption of productivity-enhancing packages is the adoption of an improved variety. The process by which the germplasm is improved, seed is multiplied, complementary inputs "attached" and the improved germplasm reaches farmers' fields can de termed the *germplasm delivery pathway.* This also corresponds to the first part of the *impact pathway.* The impact pathway continues with the on-farm effects of adoption, notably the increase in yield and profit, the improvement of household food security and livelihoods, the changes in crop and livestock production patterns (often diversification) and practices (often better management and greater use of inputs). Further indirect impacts of the adoption of improved crop germplasm are generally evident in the local non-farm economy as a result of production linkages, such as increased business activity and employment, growth of input supply and service providers, and expansion of traders and processors. The transformation and transportation of wheat products from the producer to the consumer can be envisaged as a *value chain*, often characterized by competitive cooperation among actors along the chain. Additional indirect effects occur in the non-agricultural sectors as a consequence of consumption linkages, again taking the form of increased commercial activity, employment and economics growth. Thus, the adoption of improved cultivars is influenced by two important sets of non-farm factors -- the germplasm delivery pathways to the farm, and the product-related value chains from the farm to the consumer – which can be visualized as the "U". In the early stages of development, impact pathways and value chains can be relatively well defined single channels. However, they often take the forms of webs of interacting agencies and businesses in modernizing economies.

In practice, the impact pathway is embedded in an *innovation system* comprising a web of dynamic interactions among researchers, extension agents, equipment manufacturers, input suppliers, farmers, traders and processors. One good example of innovation systems at work agricultural R&D is conservation agriculture, where public agricultural research is but one source of technology. In such cases participatory methods can be very effective to facilitate interactions among multiple stakeholders for germplasm and technology generation and adoption. One common aspect of successful development is an effective enabling environment for public-private-farmer partnerships for technology adaptation, knowledge exchange and entrepreneurship.

Conservation Agriculture: What is it and Why is it Important for Future Sustainable Food Production?

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The paper focuses on conservation agriculture (CA), defined as minimal soil disturbance (no-till) and permanent soil cover (mulch) combined with rotations, as a more sustainable cultivation system for the future. The paper first introduces the reasons for tillage in agriculture and discusses how this age old agricultural practice is responsible for natural resource and soil degradation. The paper goes on to introduce conservation tillage (CT), a practice that was borne out of the American dust bowl of the 1930s, before comparing CT with CA, a suggested improvement on CT, where no-till, mulch and rotations significantly improve soil properties (physical, biological and chemical), other biotic factors and enables more efficient use of natural resources. Recent data is presented showing how CA can improve agriculture through improvement in water infiltration and reduction in erosion, improving soil surface aggregates, reducing compaction through promotion of biological tillage, increasing surface soil organic matter and carbon content, moderating soil temperatures and suppressing weeds. CA also helps with reducing costs of production, saving time, increasing yield through timelier planting, reducing diseases and pests through stimulation of biological diversity, and reducing greenhouse gas emissions. Availability of suitable equipment is a major constraint to successful CA but advances in design and manufacture of seed drills by local manufacturers is enabling farmers to experiment and accept this technology in many parts of the world. Estimates of farmer adoption of CA are close to 100 million hectares in 2005 indicating that farmers are convinced of the benefits of this technology. The paper concludes that agriculture in the next decade will have to sustainably produce more food from less land through more efficient use of natural resources and with minimal impact on the environment in order to meet growing population demands. This will be a tall order for agricultural scientists, extension personnel and farmers. Promoting and adopting CA management systems can help meet this complex goal.

Conservation Agriculture in South Asia

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The rice-wheat consortium of the Indo-Gangetic Plains is an eco-regional program of the CGIAR convened by CIMMYT. Its goal is to maintain food security and improve the livelihoods of farmers dependent on the rice-wheat systems in a sustainable way and through deployment of natural resource efficient 'Resource Conserving Technologies (RCTs)' and Conservation Agriculture (CA) expertise. The RWC has been promoting various RCTs for tillage and crop establishment of rice, wheat and other crops grown in rice-wheat systems. The rice-wheat system occupies nearly 13.5 million hectares in Indo-Gangetic plains (IGP), spread over nearly one-fourth of the total geographic area of the Indian subcontinent in South Asia. RCTs that occupy more than 3 million hectares in IGP are able to produce more food at less cost, significantly raise farmer profits, improve efficiency of natural resource use and also provide significant environmental benefits.

RCTs being promoted include, no-till establishment of rice and wheat, reduced tillage systems, bed planting systems, surface seeding of wheat and other crops and direct dry seeding or transplanting of rice in unpuddled conditions. Additionally, laser land leveling is promoted to improve water productivity and use efficiency of fertilizer nutrients (especially N fertilizers) using techniques such as leaf color charts (LCC), GreenSeeker crop sensor technology, and single deep placement of fertilizer N in rice and wheat. In order to promote crop diversification and intensification, efforts are being made to promote inter-cropping systems such as (sugarcane+wheat); (wheat+mint); substitute long-duration pigeonpea with extra-short duration cultivar to increase cropping intensity of wheat-pigeon pea/rice system.

Practices such as co-planting of *Sesbania* with direct seeded rice and growing short duration legumes such as mungbean and cowpea in sugarcane-wheat system are being promoted to provide surface cover for soils. Crop residues are retained on the surface rather than incorporated into the soils by tillage. These practices result in water savings at the field and farm levels in the irrigation commands.

To maximize farm profits and productivity, efforts are being made to integrate crop with livestock production. Dual purpose wheat for both fresh fodder and grain production (eg. VLW 616, VLW 829 with or without intercropping with Indian-mustard), is being introduced in northwest parts of the IGP. This strategy has the potential to reduce the diversion of land resources to only fodder production. Dual purpose wheat can provide green biomass varying from 6-10 $Mgha^{-1}$, valued from $US 150 to200, with little penalty on the wheat grain yield. Green fodder helps meet fodder shortages and improves livestock productivity and thus, the farm level benefit.

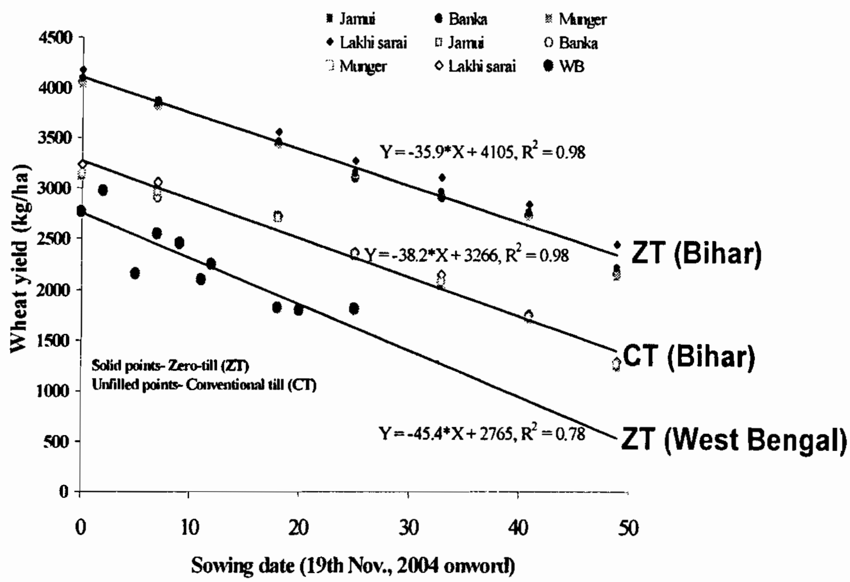
This paper presents the data collected by the RWC partners on the role of RCT's in improving crop and water productivity. It is the endeavor of the consortium to move forward in the direction of 'double no-till' system with crop residues retained on the surface to reach a more complete manifestation of the tenets that define a CA production system.
Through farmer participatory research approaches, we are trying to develop double no-till systems for flat and raised-bed planting of rice and wheat crops, having contrasting edaphic requirements. One of our major challenges is to grow no-till direct dry seeded rice with agronomic practices developed for wheat and other crops. The paper considers a set of innovations that enhance farmers' income while achieving the goals of conservation agriculture (CA).

In order to promote CA in the region , second generation multi-crop seed drills (double disk drills, Happy seeder Turbo-seeder, rotary disk drills and punch planters) have been developed which can place seed and fertilizers at appropriate line-spacing and soil depths in presence of loose and anchored crop residues.

It has been observed that raised bed planting system in precisely leveled fields promote diversification with high value crops. Zero-till and raised-bed planting systems significantly improve wheat productivity as compared with conventional tillage practices. Climates changes in the region appear to be associated with decreased wheat productivity since 2000-01. The yield declines have been associated with a rise in the minimal temperature (by 3-4C) during the wheat grain filling period. Raised bed planting (narrow and wider beds) seems to offer more advantages in terms of adapting nutrient management and irrigation practices to climate changes Results from farmer participatory trials indicate that productivity of zero-till wheat is always more than conventional tilled wheat (See the figure below).

However for adapting to climate changes, it may be more prudent to replace wheat planted in the winter cycle with maize or boro rice in the eastern Gangetic Plains of India and Bangladesh to continue to improve the food availability and security in the region. Substitution of wheat with winter maize or *boro* rice in the winter crop cycle is supported by the fact that productivity of winter wheat is 2.5 -3.5 Mgha^{-1} whereas yield of winter maize in eastern Gangetic plains is above 6.5Mgha^{-1}. Similar arguments can be advanced supporting crop substitution/diversification away from summer rice as a result of its high water requirement with the current, conventional production practices in the north western Gangetic Plains of India.

Need for substituting wheat with Winter maize or *Boro* rice



- **Replace wheat with winter maize in east to have more biomass (for food, feed and fodder).**

Raised Bed Planting Technologies for Improved Efficiency, Sustainability and Profitability

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The increase in average yield of irrigated spring wheat in farmer fields in the Yaqui Valley, from the early 1950s, when new rust resistant, non-semi-dwarf wheat cultivars were initially extended to farmers, through the development and release of the new, input responsive, high-yielding semi-dwarf cultivars up to the present, has been impressive (2.36% increase per year). However, this rate of yield improvement has gradually been decreasing to the point that there has been only a rather small yield increase in farmer fields since the 1980s. The declining yield trend, combined with both the very minimal farmer adoption of newly released cultivars in the Yaqui Valley over the past 10 to 15 year and the apparent meagre increase in bread wheat genetic yield potential since 1992, as estimated in optimally managed yield potential trials, is troubling. This situation has led to concerns that a possible genetic yield potential "ceiling" has been reached for irrigated spring bread wheat.

An important portion of the wheat yield increase that has occurred in Yaqui Valley farmer fields over the past 55 years can also be attributed to improved, crop management practices that farmers have adopted together with the new, higher-yielding cultivars. If speculation that a genetic yield potential ceiling proves correct or if continued genetic gains are going to be more difficult and expensive to realize, then one fact that is patently clear – farmers now need, perhaps more than ever before, new and appropriate crop management alternatives that can maintain superior yields, reduce production costs, improve input responsiveness and offer farmers long-term, sustainable production opportunities that both protect as well as enhance the natural resource base.

Since the 1970s, most Yaqui Valley farmers have switched from planting wheat (and most other crops) on the flat with flood/basin irrigation to raised bed planting systems with furrow irrigation between the beds (both using conventional tillage and frequent crop residue burning). INIFAP and CIMMYT scientists in Mexico, as well as scientists in other countries, have documented the clear advantages that irrigated raised bed planting can offer and this paper outlines some of these observed in northwest Mexico. CIMMYT scientists have also been using the raised bed planting system as a "platform" to develop feasible permanent, raised bed Conservation Agriculture technologies that provide opportunities to dramatically reduce tillage, manage retained crop residues on the soil surface and diversify crop rotations while offering farmers obvious and immediate production benefits and long term sustainability. This system is also described in this paper.

Managing Temporal Variability in Nitrogen Recommendation Using Nitrogen Rich and Ramped Nitrogen Reference Strips in Developing Countries

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Field average based recommendations have been a common practice for recommending the major crop nutrient Nitrogen (N). The problem is yield will not be the same from year to year with application of the same amount of recommended rate of N fertilizer. This reduced fertilizer use efficiency can incur unnecessary costs to producers especially with a likely $1.1 per kilogram of actual N price anticipated within the next few years, largely due to rising oil and natural gas prices. It has been estimated that by the year 2025 the consumption of nitrogen fertiliser will increase 60-90%, with two thirds of this being applied in the developing world. In this light, methods that increase nitrogen use efficiency, farmer profitability and reduced environmental impact are no longer simply commendable, but required in developing countries. This review assesses the temporal variability in winter wheat with respect to N nutrition and presents some approaches, including calibration stamp, N-rich and ramped N-reference strips and sensor based N rate calculator to over come this variability. These methods have been mainly conceptualized and tested in developed countries. However, the type of technology used suggests that they can be readily applied by many farmers in developing countries. The N-rich strip Program has been validated in several farmers' field across Oklahoma in US since 2004. The N-rich strip program contains a few simple steps. Farmers need to set up 4-5 strips in the field each receiving different N rate applied pre-plant or soon after planting. Then, the farmer waits until the winter wheat crop reaches Feekes growth stage 5-6 or some time between Feb. and March and subsequently evaluates either visually or using GreenSeeker Hand-Held Sensor if any of those strips are different from the entire field in greenness. In the former case just apply the lowest rate where the difference was apparent. In the latter, the N recommendation is based on in-season predicted yield potential obtained from Normalized Difference Vegetative Index (NDVI),Growing Degree Days (GDD), and Response Index of NDVI (RI_{NDVI}), the responsiveness to N of the field. In 2005 alone, 10 N-rich strip trials were conducted and the results suggested an improvement in both NUE and profit of $25 per hectare to farmers. The method is applicable to N fertilizer input responsive environments in developing countries since the method can be used either as visual tool or using the handheld sensor. The Hand-Held GreenSeeker Sensor has been evaluated in Mexico, China, Turkey, Argentina, Pakistan and India. The cost of the sensor will have an impact as to which farmers will have access to this technology. The sensor has been evaluated mostly by large farmers in the developing world. The Ramped N-reference strip gives farmers the opportunity to include more rates in the strip so that it could be possible for them to determine the actual N rate required to top-dress in the field. Like the N-rich Strip, this method can also be used either as a visual tool or along with the GeenSeeker Hand-Held Sensor. Alike the N-rich strip the option of using this technology as a visual tool will allow the application of the technology by small or large farmers any where in the world to manage temporal variability and improve NUE. These simple temporal variability based N recommendation tools avoid the need to run soil analysis and accounts for any in-season N available from rainfall, mineralization, legume rotation, and manure application.

Management to Increase Yield and Quality While Enhancing the Natural Resources

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North Dakota produces more hard red spring and durum wheat than any other state in USA. Increases in wheat yield over the last few decades in North Dakota have been modest when compared to yield increases in other wheat growing regions of the world. In the western part of the state, yield is frequently constrained by drought, while foliar diseases and scab constrain yield in the well-watered regions of the state. Grain quality requirements (protein in excess of 14%) have slowed the rate of genetic gain in yield potential in new genotypes. In drier regions of the state, conservation tillage significantly increases wheat yield by reducing soil moisture loss. This practice has greatly reduced soil erosion by wind and water. New developments in no-till systems include equipment that reduces soil disturbance and enhances the efficiency of applied fertilizers. Rotating wheat with certain non-cereal crops significantly enhance yield over continuous wheat even in no-till systems. In the eastern part of the state, research has focused on identifying management practice and positive interactions between management practices and genotypes in order to improve productivity. Early planting enables the development higher yield potential most years. Seeding rates in excess of 2.5 million seeds ha^{-2} increase the proportion of spikes arising on main heads, but do not reduce unproductive tiller numbers and rarely improve yield. Delaying N applications to the four-leaf stage can regulate tillering, but have little impact on yield or protein. Streamer bars allow the application of liquid N without leaf burn to an established crop and enable more accurate matching of N application to crop need. This practice can help reduce losses of N in the environment and improve overall fertilizer use efficiency. Fungicides applied at heading to control foliar diseases and reduce scab damage are profitable in most years. Genotype selection is key to achieving high yields. In experiments in 2005, management by genotype interactions were found to be significant. Positive interactions were primarily due to the genotypes with the most disease resistance producing relatively more yield when treated with fungicides than disease susceptible counterparts. These data demonstrate the need for disease resistance even in systems where fungicide is routinely applied. Among the modern genotypes tested, there was a negative correlation between yield and protein. The yield component most consistently correlated with yield was seed weight.

Application of New Knowledge, Technologies, and Strategies to Wheat Improvement

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Advances in technologies contribute to crop improvement by increasing the efficiency of generating accurate and unique phenotypes and genotypes in well characterized environments. There have been many technological advances since the last wheat yield symposium held in 1996. Cost of development and implementation has limited the routine use of some technologies to breeding programs in commercial companies. However the most dramatic changes have been a revolution in our knowledge of genetic phenomena that potentially impact breeding strategies. The rice genome sequence, over 600,00 wheat ESTs, RNAi, epigenetic mechanisms, novel transposable elements, conserved non-coding genome regions, and intraspecific genome heterogeneity are just a few examples of new knowledge that are changing the way we think about genetic variation and crop improvement. Also, there has been progress in dealing with GxE using improved statistical methods, detailed geographic information systems, and refined mega environments. These discoveries are good news for plant breeders with the realization that genes and genomes are not static, relatively slow changing entities but dynamic, rapidly evolving, complex systems. Association analysis can be used to integrate molecular tools and information into conventional breeding programs in a way that matches the dynamic nature of the genomes. Core germplasm collections, synthetic populations, and elite lines have complementary roles in mapping loci and quantifying allelic value for traits of interest that can feed back into parental selection and marker-assisted selection. Association mapping is a promising technique that it is within the reach of most plant breeding programs with reasonable genotyping capacity.

Wheat Molecular Breeding – Does it Offer any Hope?

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Due to their usefulness in managing and manipulating genetic factors responsible for qualitative as well as quantitative traits, molecular markers are considered valuable tools for crop improvement. Although wheat offers considerable challenges due to its ploidy level and general lack of molecular polymorphisms, considerable progress is being made in tagging alleles associated with important traits with molecular markers. Although genetically modified wheat has yet to enter the global wheat market, considerable land area is under cultivation with a limited number of crops engineered with a few specific gene constructs. Do these approaches offer any hope to complement the efforts of 'traditional' wheat breeders?

Molecular markers enable breeders to combine desirable alleles at single or multiple loci earlier in the breeding cycles as well as reduce the size of the segregating populations. In practical wheat breeding efforts, strategies have to be developed to maintain allelic diversity for other key traits that are targeted by traditional phenotypic screening methods. In its shuttle breeding efforts at CIMMYT, a set of markers is being used that target root health (cereal cyst, root lesion nematode, crown rot resistance and boron tolerance), foliar diseases (slow rusting, fusarium, barley yellow dwarf), agronomic (dwarfing genes such as *Rht1, Rht2* and *Rht8*), and quality parameters (GBSS- Null, Glu1BX- over expression and grain hardness), that are at various stages of implementation. Characterization of parental material enable making targeted crosses in order to either combine desirable alleles for multiple traits in specific crosses or to generate crosses with desirable alleles for a particular target trait fixed. Segregating progeny in early generations are selected for desired phenotype, which are further screened with markers in order to identify the entries carrying the desired allele/s, which are selectively advanced. In order to keep control of the number of marker assays, advanced progeny is again screened with markers to confirm the presence of the gene/s targeted. The total number of assays performed increases annually with the current figure in the range of approximately 15000. Acquiring new markers, validation and optimization are also integral components of molecular breeding efforts.

Future challenges include developing strategies for reducing the cost per assay, acquire more desirable markers to further complement the efforts of wheat breeders as well as evaluating emerging technologies to increase throughput with reduced cost. Integrating molecular breeding efforts in a few target national program partners also is considered an important challenge.

CIMMYT's efforts in genetic engineering has resulted in the identification of procedures for mass production of fertile transgenic plants which have been used to introduce gene constructs with putative effects on disease resistance and abiotic stresses. Although green house experiments have shown some positive effects, field experimentation with the transgenic wheat have yet to take place.

Exploitation of Genetic Resources through Wide Crosses

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Wild relatives of wheat are much more diverse genetically than bread wheat and contain genes that can possibly increase wheat's yield potential. Through two decades of wide-cross and breeding research, CIMMYT scientists have captured a significant portion of the diversity in wheat's D-genome ancestor, *Aegilops tauschii,* creating synthetic wheats using one-third to one-half of all *Ae. tauschii* accessions from major gene banks worldwide. The evaluation of the synthetics has demonstrated the potential of wild relatives as sources of resistance/tolerance to biotic and abiotic stresses, and there may also be genes that help boost yield potential. Work is now turning to more use of the A- and B-genome ancestors, as well as wild tetraploid (AB genome). In past efforts, wild relative accessions were chosen randomly. I propose more systematic selection, covering most areas of geographic distribution as well as targeting specific traits and drawing on molecular techniques. In addition to ancestral species, alien species of wheat can also contribute to yield as translocation lines. The collection and use of existing translocations offers one avenue. But we also need to produce new translocations to explore new sources of diversity.

Structural Equation Modeling for Studying Genotype × Environment Interaction of Physiological Traits Affecting Yield in Wheat

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Additive Main effects and Multiplicative Interaction, (AMMI) has been used for determining relevant environmental and genotypic variables that explain genotype × environment interaction (GEI). Structural Equation Modeling (SEM) approach is similar to multiple regression which simultaneously analyzes a system of equations where each equation describes a causal relationship among the variables considered in the system. SEM may be used to model intermediate endogenous traits (i.e., yield components) and their interrelationships with other exogenous variables, as well as with grain yield. The initial definition of the SEM comprises a path diagram where the mathematical representation of the hypothesized relationships between the various kinds of variables are displayed in a graphical representation. This path diagram reflects the theoretical model and it outlines the various levels of observed (or latent) independent or dependent variables as well as the directions of causal relationships among variables. The functional relationships between the variables are represented by arrows or paths (one-way or two-way) that express the association (covariance) between the connected variables.

SEM can be used for studying GEI of grain yield and its components and to account for the importance of intermediate traits associated with yield components. SEM can be used with latent variables derived from the first components of AMMI. This research was undertaken to assess SEM procedures together with AMMI multiplicative interaction components (as latent variables) and observed cross-products between genotypic and environmental exogenous covariates for studying the causes of GEI of grain yield and its yield components and other interrelated variables acting at five different developmental plant stages in wheat trials.
SEM was performed on GEI matrices of several variables but the most important were yield (YLD), thousand kernel weight (TKW), grains per square meter (GM2), spikes per square meter (SM2), grains per spike (GSP), biomass at the vegetative stage (BMV), relative duration of spike growth (RSG), and crop growth rate during the spike growth (dBMd).The structural equation model explained 96% of the total yield GEI variability. The most important latent variables that contributed to explaining GEI of yield were GEI of GM2 followed by TKW, GSP, and SM2. The GEI of variables RSG, BMV, and dBMd had low contribution to the yield GEI. Latent variable GEI of GM2, TKW, and GSP explained 93%, 43%, and 44% of the total variability.

The model indicated that the latent variables for the GEI of GM2 and TKW had the largest positive direct effect on the latent variable for yield GEI (1.10 and 0.63, respectively), while the latent variables for GSP and SM2 GEI had the largest indirect effects for yield GEI (0.64 and 0.53, respectively) and had a low negative direct effect (GSP = -0.05) or did not have any direct effect (SM2 = 0.0) on GEI of yield. The above results seems reasonable because the variables GM2 and TKW are directly related to yield in late developmental stages while the variables GSP and SM2 are earlier developing components to yield and thus can have impact on later developing components and not directly on yield.

Analysis of Three-way Interaction Including Multi-attributes

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The Additive Main Effects and Multiplicative Interaction (AMMI) model has been used to describe the mean response of genotypes over environments and for studying and interpreting genotype × environment interaction (GE) in agricultural multi environment trials (MET). We consider the situation in which MET is performed across several years giving rise to genotype × site × year interaction (GEY). The GEY is a three-mode (three-way) data array, where the modes refer to genotypes, environments, and years. The three-way array can be constructed for other conditions or factors artificially created by the researcher, such as different sowing dates or plant densities, etc.

An approach for gaining insight into the three-mode GEY array is to define a low dimensional structure for environments, years, and genotypes expressed in principal components and then study the relationships among these components. This approach is more useful than condensing the three-mode data array into two-mode data and using all the two-way models previously described. Another less useful approach would be to explicitly exclude one mode (for example years) and analyze the two-way array of genotypes × environments in each year; in this case the problem is finding an overall interpretation for the years.

Although three-way interaction data is common in agriculture experiments, the three-way AMMI has not been widely applied in plant breeding and agronomy trials. In this study two data sets were used to compare three-way AMMI with two-way AMMI analysis. Data set 1 represented wheat genotype × location × sowing date interaction; eight traits were measured. The three-way AMMI model was used simultaneously for all attributes such that interactions between genotypes and environments could be studied for several traits simultaneously. Data set 2 comprised a three-way interaction of wheat genotypes × irrigation methods × years.

Results show that the analysis of the two-way interactions obtained by combining levels of factors is less effective in interpreting GE than the analysis of the three-mode interaction. The simultaneous use of AMMI analysis with several attributes is useful for assessing the performance of genotypes across several traits as well as examining the association among traits.

Use of GIS to Define Agro-ecosystems & Climate Change

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Bread wheat and durum wheat occupy an estimated 200 million ha globally, are grown from sea-level to over 3500 masl, and from the equator to above 60N latitude in Canada, Europe & Asia. For an organization like CIMMYT, charged with improving wheat for the entire developing world, an understanding of wheat production environments is crucial for international priority setting, collaboration, and targeting germplasm to specific environments. Increasingly important is information on how those environments and associated biotic and abiotic stress patterns, and hence required traits or management, may shift with changing climate patterns. There is also an increasing need to classify production environments, not just solely in biophysical terms but also in respect to socio-economic factors. Geospatial technologies, especially GIS, are playing a role in each of these areas. Use of GIS is described using illustrative examples based on CIMMYT experiences. Since the 1980's, the CIMMYT wheat program has classified production regions into mega-environments based on climatic, edaphic and biotic constraints. Advances in spatially disaggregated datasets and GIS tools provide an opportunity for characterizing and mapping mega-environments in a much more quantitative manner – current progress is outlined. In parallel, advances are also being made in describing the spatial distribution of major crops, including wheat. The combination of improved crop distribution data and key biophysical data at high spatial resolutions also permit the exploration of scenario models for disease epidemics – the example of a stem rust is given. Availability of GIS data describing future climate scenarios may provide insights into potential changes in wheat production environments in the coming decades – selected examples are given. Despite progress in characterizing wheat environments, there is a pressing need to advance beyond static definitions of environments and incorporate temporal aspects to define locations or regions in terms of probability or frequency of occurrence of different environment types. Progress in this aspect is being made for other crops, and increased availability of nearly real-time daily weather data derived from remote sensing offers opportunities to further improve environment characterization as well as to produce regional-scale models of dynamic processes such as disease progression or crop water balance.

POSTER

PRESENTATIONS

Issues of Wheat Production in Argentina

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Wheat is the most important winter crop in Argentina, grown during the period 1995-2005 in 5.5 million hectares average, yielding about 2.6 tn/ha and representing an approximate production of 14 million tons per year. From them, 5.5 million tons/year are destined to local use and the rest is exported to Latin America (especially Brazil), to Africa and to Middle East. Argentina is heading towards a better system of classification of its production, to offer a wider range of specific grain features both to internal and external markets to satisfy the increasingly demanding industrial needs.

The amount and quality of Argentina wheat production are affected every year by different limiting factors, abiotic and biotic. Among the former, hydric and nutritional stress and high temperatures during anthesis are the most important. Among biotic factors, fungus diseases stand out by their incidence in humid years, being leaf rust (*Puccinia recondita*), head blight (*Fusarium graminearum*) and leaf spot (*Septoria tritici*) the most frequent diseases.

From 1990 to 2000 the economic environment favored technology: fertilization (N, P and S), watering and fungicides usage increased, accompanying the increase in cultivar availability and their potential yield, and in no-tillage management. During that period, yield increased by 49 kg/ha/yr, but from 2001 on the economic situation was less favorable to technology acquisition. As a consequence of the changes in cultural practices, the quality of the production was diminished and the incidence of certain diseases as yellow spot (*Drechslera tritici repentis*), leaf spot and head blight increased. Due to the fact that exists partial resistance to such pathogens and only a low level of tolerance is available; the control strategy is the integrated management, including the usage of resistant cultivars, fungicides and cultural practices. It is to be noticed the frequent changes in virulence of some pathogens as the leaf rust, endemic in the northern and central regions. In such cases, the development of resistant cultivars is the priority, as there is wide genetic availability to control such pathogens.

Genetic improvement is a low cost, nonpolluting technology, highly efficient to improve productivity, yield stability, and grain quality. The diversity of productive circumstances and consumer markets requires the development of genotypes adapted to diverse situations. To achieve so, it is necessary to complement traditional breeding programs with physiological bases and biotechnological tools. Among the latter, the use of molecular markers to assist selection of health and quality traits controlled by main genes, is more effective and faster than conventional breeding, allowing the immediate incorporation of those traits in well-adapted, high-yielding germplasm.

Study of Local Wheat Genetic Resources in Azerbaijan

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Cereal production is one of the key areas of Azeri agriculture and wheat contributes significantly to cereal production. In this regard the development of high yielding and high quality wheat varieties resistant to biotic and abiotic environmental factors is very important. Durum and bread wheat collections from various regions of Azerbaijan are considered as rich botanical-geographical and valuable genetic resource for study. The study of these material allows to identify valuable forms useful for breeding activities. Our study focused on agronomic traits and of 154 durum wheat entries and 242 bread wheat entries. Early maturing durum wheat entries were found to make up to 9,6% of total germplasm studied. In the case of bread wheat it was 17,3%. All three types of spike density were found in durum wheat samples studied. About 55,2% of total durum wheat samples studied were found to have moderate ear density, 10,3% with dens ear and 34,5% with friable ear. But in bread wheat it made up 49,6%; 1,6%; and 47,8%, respectively. By plant height 6,7% of durum wheat samples studied was found short-stalked, 23% middle-stalked and 70,3% high-stalked, but in bread wheat it made up 9,5%, 40,6% and 44,5% respectively. For the percentage of kernels in the ear there was also substantial difference. In durum wheat the number of grain per spile ranged from 38 to 66 grains, but in bread wheat from 38 to 72 grains respectively. The ear kernel weight in durum wheat germplasm varied from 1,2 to 3,6 gr. and from 1,0 to 2,9 gr. in bread wheat. The 1000 kernel weight varied significantly both among varieties and within varieties. Thus, 1000 kernel weight in durum wheat fluctuated between 37,0-67,8 gram and in bread wheat samples 30,0-67,8 grams, respectively. Durum wheat yielded 415-640 gram/m^2, and bread wheat - 490-720 gram/m^2. The protein content varied 18,2-20,6% in durum wheat and 13,7-17,1% in bread wheat germplasm. As a result of studies 15 durum wheat and 20 bread wheat entries with valuable agronomic traits and characters were selected for further utilization in crop breeding activities.

Wheat Production in Bangladesh - An Overview

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Wheat in Bangladesh is the second most important cereal next to rice. Before 1965, wheat was grown on a negligible area. During 1965-75, wheat expanded to over 0.11 million ha per year. About 38% of the area was covered with introduced varieties, including Kalyansona, Sonora 64 and Dirk. From 1975 to 1985, Government undertook a massive wheat expansion program and Wheat Research Center released eight high yielding varieties. Sonalika, introduced in 1974, covered about 68% of the 0.40 m ha planted. During 1985-1995, the high yield wheat area rose to 0.60 m ha per year. Among the high yielding varieties released during this period, Kanchan (released in 1983) became the most popular variety (on 54% area). During 1995-2005, the average wheat area was 0.73 m ha per year with a yield of 2.20 t/ha and Kanchan remained predominant on 80% of the wheat area. Wheat reached a maximum area of 0.88 m ha during 1998-99 with an average yield of 2.32 t/ha. Since then the area planted has declined by ± 30% due to competition from many alternative cool (Rabi) season crops. Yields have stagnated because of input constraints, disease pressure and probably global warming. Six high yield potential varieties (Sourav, Gourab, Shatabdi, Sufi, Bijoy and Prodip) have been released since 1998 and are very popular among farmers due to their high temperature tolerance, bold grains, and resistance to leaf rust and bipolaris leaf blight. They are gradually replacing Kanchan that has become susceptible to both diseases. At present, 80% of the wheat is under irrigation and 20% is grown on residual soil moisture. During the last decade, the use of farm machinery in wheat production has increased significantly. At present, 80% of the wheat is broadcast seeded after reduced tillage (2-3 passes) by power tiller that has replaced conventional tillage by a bullock-drawn plough. The area of wheat planted by power tiller operated seeder is also increasing. About 50% of the wheat is threshed by machine. In most cases, wheat is sown on flat land, with a negligible area on raised beds. Most wheat growers use less fertilizer, especially P and K, than the recommendation. Late planting (terminal heat stress), bipolaris leaf blight, spike sterility, and soil acidity are the major yield constraints in Bangladesh. Among these, high temperature during grain filling is the most important constraint. The light soils of the main wheat belt in northwestern Bangladesh are deficient in B causing spike sterility and acidic, fixing P in the soil. Wheat productivity can be raised through quick dissemination of new varieties, and improved crop management. Scope remains for area expansion. About 1.75 m ha remains fallow throughout the country after one monsoon rice crop due to lack of irrigation facilities or late receding of floodwater and some of this area could be planted to wheat, especially in the south. Wheat Research Center continues research programs on the above issues. CIMMYT has helped the wheat program of Bangladesh for around 30 years with the supply of germplasm, human resource development, and expertize which should be continued. CIMMYT offices in South Asia should be strengthened to meet the challenges of wheat research and development in Bangladesh.

The Brazil Country Survey

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The mean wheat sowing area in the last 10 years in Brazil is around 2 million hectares. Ninety percent is concentrated in the states of Paraná and Rio Grande do Sul and around 95 percent is cultivated under reduced or zero tillage sistems. The average yield is near to 1,800 kg ha^{-1} in rainfed areas and over than 4,500 kg ha^{-1} in irrigated areas (less than two percent of the brazilian area is sowed under irrigation, in the Savanas region). Most of the area is covered by modern cultivars and less than one percent is sown with landraces. The breeding programs in Brazil released 429 wheat cultivars for the different production regions since 1922.

The current abiotic constraints are: low rainfall (drought) and heat stress at the Brazilian Savanas region; and lodging, cold (frost) and pre-harvest sprouting in the Southern Brazil. The most important diseases are: leaf rust (*Puccinia triticina*); scab (*Fusarium graminearum*); mildew (*Blumeria graminis*); glume blotch (*Stagonospora nodorum*); tan spot (*Drecshlera tritici repentis*); spot blotch (*Bipolares sorokiniana*)(*Helminthosporium sativum*); head blast (rice blast) (*Magnaporthe grisea*); and virus diseases (Barley Yellow Dwarf Virus and Soil borne Mosaic Virus).

Priority and Challenge of Wheat Production in China

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China produces around 95 million tons of wheat with sowing area of 23 million ha. Averaged wheat yield has risen from 1.0 to 3.9 t/ha, largely due to deployment of improved cultivars and management practices, and increased inputs in fertilizers, and mechanization. Further improvement of yield potential with acceptable quality, and reduced inputs are needed to meet the consumption demand. The major biotic stresses of wheat production include powdery mildew, stripe rust. *Fusarium* head scab, sharp eyespot, take all, and aphid. Decline of water resources, and heat after anthesis, and cold are the most important abiotic stresses. Small farmer size, low grain price, weak extension system, and shift to high value cash crops, could potentially slow down wheat production. Enhanced germplasm, training, and information from CIMMYT are crucial to Chinese breeding programs. Integration of various disciplines such as breeding, biotechnology, pathology, cereal quality, and agronomy are urgently needed to improve breeding efficiency.

Challenges of Wheat Production in Ethiopia

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Ethiopia is the second largest producer of wheat in sub-Saharan Africa. Wheat is the fifth most important cereal crops in Ethiopia in terms of area of production and 2nd to maize in productivity. It comprises more than 15% of the total cereal outputs. In Ethiopia, two types of wheat species are dominantly grown as rain fed crops. The current total area of production of both durum wheat and bread wheat is about one million hectares. This area is limited to the intermediate and high altitude production zones despite a potential for irrigated wheat production in lowlands. Both durum and bread wheat types hold almost equal proportions. In area coverage, however, since the last 5-10 years the area coverage and production of bread wheat is increasing. Other wheat species such as Emmer wheat is also cultivated to a limited extent.

Over the last fifty years, the area coverage of modern wheat varieties was limited. Although no estimated figures were obtained for area coverage of improved varieties during the first two decades, there had been a slight increments both in area coverage and total grain yield during the last thirty years. The increase in production during the later years may be attributed to the increase in area coverage and improved crop management practices. For the period from 1975 to 2004 the area coverage of modern varieties was increased by about 10% (63 thousand to 70 thousand ha) on the other hand the increase in crop yield per hectare over the same period remained marginal, despite the fact that the yield potential of modern varieties has been increased two to three fold.

So far the national wheat research program in Ethiopia has developed and released 40 in bread wheat, 22 in durum wheat and one in Emmer wheat since the last forty years of which more than 60% are under production. There are also many improved wheat crop management practices tested and released in the area of agronomy, crop protection, fertilizer management, etc. Extension and demonstration packages undertaken by national institutes have demonstrated that wheat crop yields can be easily tripled with the use of improved seeds and crop management practices. However, in the Ethiopian condition both past and present, the overwhelming majority of farmers, rely on landrace varieties and unimproved management practices. As a result the productivity of wheat crops did not show significant improvement over the years, although there were success stories for bread wheat. Major causes reported for the low level of productivities are low use of improved varieties due to high price, little or no use of modem agricultural inputs and improved management practices (for instance improved tillage practices), decline in soil fertility, pest problems, environmental degradation and recurrent drought and the scarcity of suitable technologies to unfavorable environments.

Yield Potential Survey – India

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India has firmed up its position as the second largest producer of wheat, in the world, only next to China harvesting 72.0 million tones during last crop season from an area of about 26.5 million hectare with a productivity of 2.7t/ha. The area under wheat crop in India has been hovering around 26-27 million ha for last ten years period maintaining the total production level above 70 million tones. It is also worth to mention here that the weather conditions during this decade also witnessed unusual changes during the wheat crop season which resulted in comparatively reduced growth. The availability of new and diverse varieties provided a mosaic suited to different production technologies that could sustain the productivity levels. The average productivity of wheat is quite high in high production areas of Punjab (4.2 t/ha) and Haryana (4.0 t/ha) with farmers achieving record production of 6 to 7 t/ha in certain areas of Punjab. Frontline demonstrations have indicated that there is a vast scope to enhance the productivity in the States of Uttar Pradesh, Madhya Pradesh, Bihar, Gujarat and Maharashtra.

The Directorate of Wheat Research is the nodal institution for coordinating the multidisciplinary and multi-location testing of wheat and barley technologies under AICW&BIP with the active support from a large number of funded and voluntary centres across the six mega zones of the country. Since 1965, nearly 312 wheat varieties have been developed to suit the various production conditions of six major wheat growing zones of the country. Since the advent of Green revolution in 1965 there had been a marked increase in the area and productivity of wheat. Besides other factors like expansion of irrigation facilities and 'pro-farmer' government's policies, the rate of the adoption of dwarf, photo-insensitive and nutrient responsive modern varieties by the farmers resulted in large areas being occupied by such varieties. Some of the high yielding landmarkvarieties like Kalyansona, Sonalika, Lerma Rojo, WL 711, WH 147, C 306, Lok1, HD 2009 and HD 2329 were very popular and widely grown by the farmers. PBW 343, a ruling variety for irrigated, timely sown condition of northwestern plains occupies 6 mha area and is currently the ruling variety. Other varieties like Lok 1, HUW 234 and UP 262, though now susceptible to rusts are still a favourite amongst farmers.

One of the major concerns of wheat researchers is to make Indian wheat globally competitive by reducing the cost of cultivation and increasing farmer's profitability. India has made concerted efforts in developing resource conservation technologies like zero tillage, bed planting, reduced tillage etc. With the joint efforts of Directorate of Wheat Research and Rice-Wheat Consortium nearly two million hectares is under zero tillage and there are good prospects of its further spread to nearly 4 mha by 2001-12. More than 82% per cent of wheat area is under irrigated agriculture and keeping in view the impending scarcity of water it has become imperative to manage the irrigation water efficiently. Bed planting or raised beds, which is now catching up, saves nearly 40% of water and 20% nitrogen. From the nutrient point of view, the soil health is deteriorating and there is an urgent need to remove this fatigue by balanced use of fertilizers (integrated nutrient management). Other major constraints affecting wheat production are low rainfall under rainfed agriculture, terminal heat stress, salinity/alkalinity. The important biotic stresses are yellow and brown rusts and leaf blight while the insect pests like termites and aphids are to a lesser extent and season specific. There has been no rust epidemic since last three decades and the efforts made to mange the diseases and pests through IPM, gene deployment, increased host resistance against rusts, leaf blight, Karnal bunt, head scab and powdery mildew have helped in reducing losses and maximizing the returns to the farmers.

CIMMYT, Mexico has played an important role in strengthening the Indian wheat programme since the advent of Green Revolution. This support, primarily, was through germplasm exchange in form of international nurseries and trials and human resource development. However, in recent years the component of HRD has been greatly reduced to almost negligible extent. In light of the fresh MOU between CIMMYT and ICAR, emphasis is to be given to exchange of material with special reference to the climatic change, revitalize the HRD through visiting scientists' programme, developing collaborative research projects tackle the emerging challenges to wheat production. Modern tools like molecular breeding, functional genomics, deployment of trangenes for abiotic stresses etc., should get priority to maintain pace with time and growth.

Wheat Production and Research in Iran: A Success Story

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About 6.5 million hectares are grown to wheat in Iran: 2.5 million ha are irrigated and 4.0 million ha grow under rainfed conditions. In 2003 - 2004 cropping season, the total production reached 14.6 million tons: 67% was produced in irrigated crop (average 3,827 Kg/ha) and 33% was produced in dryland conditions (average 1,187 Kg/ha).

The rainfed areas are divided in cold (60%), temperate (10%) and warmer areas (30%).
Irrigated wheat (95% improved cultivars) is grown in four different mega agro-ecological zones characterized as follows:

<u>Zone I (Northern Warm and Humid Zone): 8% or 204,000 ha</u>
Warm temperatures, high rainfall, humid conditions; altitude below 800 masl.
Average absolute min. temp. is –6°C; less than 30 freezing days.
Spring wheat cultivars.
Caspian sea shore (Mazandaran, Golestan, Moghan plains, and Gilan province)

<u>Zone II (Southern Warm and Dry Zone): 27.2% or 693,000 ha</u>
Warm temperatures, low rainfall; altitude below 500 masl.
Average absolute min. temp. is –5°C; about 15 freezing days.
Spring wheat cultivars.
Persian Gulf and Oman Sea coastal areas
(Khoozestan, Booshehre, Hormozgan, Sistan and Baluchestan, Ilam, and some parts of Yazd, Kerman, Lorstan and Fars Provinces)

<u>Zone III (Temperate Zone): 30.7% or 781,000 ha</u>
Temperate temperatures, Moderate rainfall; altitude around 1000 masl.
Average absolute temp. is –10 °C ; about 50 freezing days.
Spring and Facultative wheat cultivars.
Isfahan, Yazd, Kerman, Markazi province, Central parts of Khorasan and Fars, and some parts of Lorestan and Kermanshah provinces, Varamin and Karadj regions

<u>Zone IV (Cold Zone): 34.1% or 870,000ha</u>
Cold to very cold temperatures, low to moderate rainfall; altitude above 1000 masl
Average absolute min. temp. is –14 °C, about 3 months freezing days.
Winter and/or cold tolerant facultative wheat cultivars
Hamedan, Ardabil, East and West Azarbaijan, Zanjan, Qazvin, Chehar Mohal Bakhtiari, and some parts of Khorasan, Fars provinces.

Breeding objectives include:

- -High genetic potential, yield stability, wide and specific adaptation with desirable agronomic traits
- -Resistance to biotic stresses such as rusts (YR, LR & SR), Fusarium , Septoria, Powdery mildew, bunts, smuts, etc.
- -Tolerant to abiotic stresses such as cold, heat, drought, salinity and pre-harvest sprouting, etc.
- -High quality for traditional flat bread baking
- -High quality in durum wheat for macaroni industries
- -Dual Purpose barley and triticale
- -Agronomic and wheat crop management packages
- -Breeder and foundation seeds multiplication

During the 1978 – 2003 period, 26 wheat cultivars with CIMMYT origin have been selected and released. In 2004-2005 cropping season, 46 improved bread wheat and durum wheat cultivars 44.4% of which are of CIMMYT origin were grown in the different irrigated agro-ecological zones. Chamran (Attila 50Y) is widely grown (25% of certified seed planned to be supplied to farmers). Two recently released durum wheat cultivars: Arya and Karkheh (with CIMMYT origin) also comprise 54% of certified seed planned to be supplied to the farmers. The Seed and Plant Improvement Institute (SPII) remains the main scientific and technical supporter of this national plan.

Wheat Production in Mexico

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Wheat was introduced to Mexico by the Spaniards around the 1500. Most landraces were grown either under stored moisture or rainfed areas. By 1940 most landraces were highly susceptible to stem rust. Further introductions from Australia, Canada and the United States, alleviated temporarily the consecutive stem rust epidemics until the first resistant variety to Stem rust was release in 1950. Landraces were cultivated until 1965 in larger areas. In the period of 1992 to1994, CIMMYT-INIFAP came together to collected most of the remained landraces cultivated in small patches in many Mexican states. Today, very few introductions remain under cultivation, since modern varieties have almost completely replaced the landrace cultivars. Among the agronomic practices in the Irrigated areas, undoubtedly the use of raised beds, designed originally for weed control has been the most remarkable contribution from Mexican scientist of INIFAP at Sonora and currently followed by CIMMYT scientists and promoted in many areas of the world. Mexican wheat production areas are located under two contrasting systems, the Irrigated grown during Winter-Spring season and the rainfed system where wheat grows during Summer to Fall period. Since in the irrigated areas, water is becoming scarcy, drought tolerance must be a principal characteristic of the modern varieties. However, for the rainfed areas of Mexico, not only drought tolerance but earliness is required, since early frost is common. After the successful control of the stem rust, modern varieties must have the durable type of resistance to leaf and stripe rust. Many wheat varieties have been released in Mexico (from Yaqui 50 to Gema C2005) as result of the very close cooperation and partnership between INIFAP and CIMMYT. International Nurseries such as the ESWYT, IBWSN, EDYT and the IDWSN, have been the source of germplasm for the National Wheat Breeding Program from where new advanced wheat lines have been identified and released (i.e.Palmerin F2004, Rajaram F2004, Kronstand F2004, Samayoa C2004, Banamichi C2004, Bataques C2004 y Gema C2005 just to cite the most recent). New advanced lines with high yield potential and good industrial quality, with durable type of rust resistance for irrigated as well as drought tolerance and early germplasm for rainfed areas will be required from CIMMYT to contribute to the INIFAP efforts to assure the sustainability of wheat production in Mexico.

Challenges to Wheat Production in Morocco

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Wheat production is a major farm activity that has an important implication on the national economy of Morocco. On average, about three million hectares of wheat are grown annually in Morocco with nearly equal share between bread wheat and durum. The average wheat area cropped per farm is less than 5 ha, implying that most wheat production is undertaken by resource-poor farmers with small holdings. The total wheat area and production is mainly rainfed (about 94% and 74%, respectively) and takes place in drought-prone environments characterized by relatively low rainfall (between 200 and 450mm), high variable precipitation pattern and high occurence of drought. These translate into large inter-annual fluctuations. Moreover, abiotic stresses, e.g., terminal heat, and cold represent serious production constraints that may severely inhibit crop growth. These abiotic stresses are frequently exacerbated by biotic stresses, e.g., diseases, especially rusts, septoria, and root rots, and insects, especially Hessian fly, that severely inhibit crop growth and cause significant reductions in grain yield.

Wheat improvement program of Morocco has benefited greatly from its close collaboration with CIMMYT and the joint CIMMYT/ICARDA wheat program. As a result, over 40 varieties derived from CIMMYT/ICARDA germplasm were released in Morocco. Despite the large number of varieties released, the total area devoted to modern varieties is planted only with a few ones. The reason is the long time lag between the time of release of a variety and the time of its adoption by farmers. This situation is due to weaknesses in the seed production and delivery system, combined to targeted extension programs which are necessary to enable farmers to fully exploit developed technologies and reap the potential gains embodied in new varieties. With regard to crop management, research in Morocco has developed technologies that can boost wheat yield and production, e.g., integrated crop management, supplemental irrigation, reduced/no-till system, for water and soil productivity. Despite research results on the no-till system, the acreage is still very limited.

Insufficient number of scientists with high level of expertise, allocation of funds to research activities and access to information are among the current and emerging constraints to wheat improvement research activities. The relative importance of research partnerships to achieve the national wheat program goals reside mainly in (i) CG Centers helping in training, germplasm exchange, knowledge and technology sharing, developing joint projects, and capacity building; (ii) farmers groups involved in participatory farmers and community approach and technology transfer based on integrated ecosystem approach; and (iii) foreign research institutes collaboration in developing common projects, and networks.

The most useful and desirable outputs from CGIAR Centres still concern sharing of germplasm, especially advanced lines for northern zones, mountains and irrigated areas with generic traits (high yield potential, combined disease and hessian fly resistance, heat and drought tolerance, and quality); training and knowledge sharing through advanced courses for mid career scientists (on wheat improvement, biotechnology and quality), and mutual scientists' visits; development of mmethodologies, information system and publications flow.

Challenges to Wheat Production in Nepal

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Millions of resource poor farmers in Nepal derive their livelihood from wheat (*Triticum aestivum* L.) cultivation. In 2005, Nepal produced 1.440 million ton wheat from an area of 0.765 million hectares at 2.134 t/ha yield. The average national wheat productivity has increased at the rate of about 3.88% over the last 11 years. However, there are many abiotic, biotic, and socio-economic constraints to successful wheat cultivation in Nepal. The major abiotic stresses are terminal heat, declining soil fertility, wheat sterility, and drought. The important biotic stresses include diseases (yellow rust, foliar blight and leaf rust), insect-pest (aphid and weevil), and weeds (*Phalaris minor, Polypogon fugax* and *Chenopodium spp.*). The socio-economic constraints include lack of credit, unavailability of quality seed, high price and unavailability of fertilizers and farm machineries on time, shortage of labor during harvest, and low benefit-cost ratio from wheat cultivation. In the background of the above constraints, the wheat research activities in Nepal aim at increasing productivity, profitability and sustainability of wheat based farming systems. Options in terms of improved cultivars and technology are continuously being made available to the wheat growers and industries. Several improved wheat cultivars with high grain yield, bold kernels, resistance to prevalent diseases and pests, and tolerance to abiotic stresses that fit in the farmers' cropping systems have been developed. Resource conservation technologies such as surface seeding, zero and minimum tillage, using zero till seed drill and power tiller seed drill respectively, are being promoted through a pluralistic approach. Participatory varietal selection is being expanded for identifying cultivars suitable to specific agro-climatic and management conditions. Community based and farmers' collaborated seed production activities are being promoted to make improved seed available to the wheat growers. However, there are still several daunting challenges to improving productivity and profitability of wheat-based farming system in Nepal. While yield potential is continuously being improved, a great deal of efforts is needed towards efficiently managing wheat and improving socio-economic constraints. This is especially true for the hilly areas of the country where the poorest of the poor live. Wheat must be produced at a lower cost under increasing threats from abiotic and biotic stresses. The present 1.3% of the total wheat area under conservation tillage needs to be expanded. Participatory varietal selection and community based seed production must be accelerated to deliver cultivars as per need of the farmers and make seeds available to rural wheat growers. Additional sources of resistance to yellow rust and foliar blight are needed to improve the level of resistance in the commercial cultivars. New germplasm and technology are needed to breed wheat with heat tolerance. Early maturing rice cultivars that could allow for timely wheat seeding in the rice-wheat cropping system are also needed. Investment in wheat research must be increased in terms of infrastructures and manpower. Government policies in terms of credit and input availability, marketing, and support price need to be improved in order to alleviate poverty and to improve the livelihoods of the resource constrained wheat farmers in Nepal.

Increasing Wheat Productivity in Pakistan

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In Pakistan, introduction of modern varieties and use of chemical fertilizers helped greatly to improve national average wheat yield from 0.75 tonnes to 2.6 tonnes during 1955-2005. The development and release of about 68 irrigated and 19 rainfed improved wheat cultivars in the country contributed toward the adoption of modern varieties on 7.83 million hectares which is around 95% of total wheat area. Presently, average wheat yield of modern varieties is around 2.6 and 1.2 t / ha in irrigated and rainfed area, respectively. Farmers are not able to achieve the potential of wheat cultivars because of poor crop management and costly inputs. During 1995-2005, wheat farmers of rice-wheat area of Punjab are experiencing the reduced tillage / zero tillage nearly on 1.0 million hectares, however, it could not make inroads other cropping system like cotton-wheat and rain fed area. In irrigated area, the farmers are applying 208 Kg of NPK per hectare. On the other hand, rainfed farmers are applying 42 Kg of N P / hectare. The NP ratio is around 3:1 and use of potash is minimal. With the introduction of wheat threshers and combine harvester the fully mechanized area stand at 10% of the total area. In the country, most of the operation like land preparation, and threshing are fully mechanized; however, most of the harvesting is still done by hand. Wheat production is facing challenges like drought in rain fed area, declining water availability, terminal heat, yellow rust , leaf rust, aphids and weeds infestation. Wheat productivity is also affected by late planting, lower certified seed availability and costly input, like fertilizers and herbicides. The research centers working for the wheat improvement in the country needs the training for their scientists and required resources to carry out research work to meet the further challenges.

Wheat Yield Potential in Sudan

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Although wheat (*Triticum aestivum* L.) is an old crop in Sudan, but until the 1960s its production was restricted to the relatively favorable environment of the northern Sudan. Increased consumption, resulted from growing population, urbanization and changing food habits led to the expansion of the crop production southwards in the heat-stressed environments of the central clay plains. A number of high yielding and heat tolerant cultivars were released for cultivation in the new less favorable areas. Close collaboration with international and regional research institutes enhanced the development of elite production technologies. Consequently, annual areas under wheat increased from 21,000 ha during the period 1955-65 with an average yield of 1.5 ton/ha to 143000 ha during 1965-1975 with an average yield of 1.2 ton/ha and then to 263,000 ha during the period 1985-95 with an average yield of 1.5 ton/ha. During the period 1995-2005, areas under wheat decreased to 175000 ha annually with an average yield of 2.0 ton/ha due to many factors including the unavailability of credit and inputs at the right time in addition to the high competition from the low-priced imported wheat. Fluctuation in yield /ha was mainly due to variation in areas of wheat in the less favorable environment of central Sudan. In fact, most of the areas under wheat during the period 1955-1972 and 1995-2005 were in the northern Sudan. Almost all areas under wheat production are fully irrigated by gravity with an equivalent of about 100 mm of water applied every two weeks. Land preparation throughout the production areas is conventional. Similarly, sowing is on flat. Wheat in central Sudan is fully mechanized while it is partially mechanized in the northern Sudan. Wheat productivity is affected by a number of environmental constraints including heat and moisture stresses, low soil fertility, water logging, weed and aphid infestations. Unavailability of credit and production inputs at the right time in addition to lack of clear policies are serious socio-economic constraints. It is expected that the recent achievements as well as the anticipated technologies in wheat research regarding improved cultivars, crop management etc if transferred to farmers would greatly enhance productivity. It is realized that quality characteristics regarding nutritional and technological values are major considerations for successful competitive and sustainable production.

Wheat Yield Potential Improvement in Tajikistan

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Bread in Tajikistan is a staple food product and wheat growing is one of the most important agricultural activities. The total demand of Tajikistan makes about 1,5-2 mln tons of grain. However there is still a deficit of grain, despite the recent production growth. Over the last 10 years wheat areas all over the country increased up to almost 2,5 times. In 2005 about 890,000 tons of grain was produced, and though the demand was not fulfilled. Recent years wheat occupies about 360,000 ha, approximately 60% of which is under irrigation. Expansion of wheat areas led to epiphytotic changes and fungal diseases dissemination. In comparatively humid years with higher amount of precipitation outbreak of yellow rust is observed. Annual production of wheat makes 390–400 thousand tons, from which 65-70% is produced by private sector. However, in spite of production growth, there are scarce changes in wheat yield that in average makes 1,8-1,9 t/ha. The yield in the rainfed area is very low and depends on the amount of precipitation. Quality of the locally produced grain is low. Due to a delay with planting and harvesting of wheat as well as lack of inputs and machinery, the grain is damaged by heat stress, which makes it shriveled. Hence in Tajikistan, known as one of the center of origin of cereals, especially wheat, there is a diversity of wild relatives and landraces. Farmers still grow wheat landraces Surkhak and Safedak in the remote mountainous villages. In the valleys the farmers have more access to the improved varieties. Since 1970-s Tajik farmers used to grow a wheat variety named Siete Cerros 66, which was introduced in Tajikistan through Mexican breeding programs. During recent years a number of wheat varieties and advanced lines were tested in the different agro-ecological zones within the framework of GTZ-CIMMYT Project. Among primary selected genotypes such varieties as Steklovidnaya-24, Jagger-9, Atoi, Sulton 95 and Kenacil became very popular in many zones due to high yield and yellow rust tolerance. Now Jagger-9 dominates under irrigation and Steklovidnaya-24 in the rainfed zone. On the basis of the conducted uniform trials several new varieties were identified as rust resistant and high yielding. Among selected genotypes 6 were submitted to official trials as new varieties - Norman, Tasicar, Armon, Somoni, Ziroat-70 and Alex. As a further expansion of wheat area is not possible, the increase of grain production requires the increase of crop yield at the expense of crop management improvement and introduction of new varieties resistant to diseases, pests, tolerant to abiotic stresses and with good bread making quality.

Wheat in Turkey

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Turkey is among the 10 biggest wheat producers worldwide. Total wheat production of Turkey varies between 16 and 21 million tons, including 4–6 million tons of durum wheat. Around 65–70 % of the total arable land area of 27 million ha is devoted to cereal production of which wheat (9.5m ha), barley (3.5m ha) and annual fallow (5–6.5m ha) predominate. About 80-90% of all wheat in Turkey is produced under rainfed conditions. Winter and facultative wheat account for about 6 million ha and 60-70 % of the production. The average grain yield of 2 t ha^{-1} conceals wide disparities in production potential due to extremely diverse agro-ecological conditions and varies from 1 t ha^{-1} in the winter wheat areas of Eastern-Turkey to 3.5-4.5 t ha^{-1} in Thrace (European part of Turkey) and South-Turkey. Since 1967 Turkey has released 138 cultivars: 42 spring bread wheat, 24 spring durum wheat, 58 winter bread wheat and 14 winter durum wheat.

In the irrigated areas the majority of wheat is sown on flat but there is an increasing interest among farmers to adopt bed planting technologies. Likewise, most of the wheat in rainfed areas is grown using conventional tillage systems, although farmers who have been exposed to zero-tillage systems through farmer field days organized by the Research Institutes have shown great interest in this technology.

The main abiotic constraints for wheat production is drought due to low rainfall which can affect up to 80% of the total area and degradation of the soil structure due to excess soil tillage which can affect up to 70% of the total area. Other important constraints, but present in specific areas or years are heat, Zn and Bo deficiency, toxicity to certain micro elements, and lodging due to heavy rain. Major biotic constraints are yellow rust, leaf rust, and soil borne diseases and nematodes, while Suny bug and Zabrus are the most devastating pests. Of socioeconomic constraints, main problems are the lack of credit and high interest rates, together with distribution problems of high quality certified seed.

Main constraints for wheat improvement activities are a general shortage of research budget and an erosion of senior staff and scientific expertise due to lack of incentives, a lack of socio economic expertise, and a general need to update the information system to improve collaboration and data sharing.

Farmer groups remain the most important partner to achieving national wheat program goals, although the international centers, and particularly the Turkey-CIMMYT-ICARDA Winter Wheat Improvement Program (IWWIP), and to a lesser extent local private companies, remain important research partners.

The outputs of highest importance from collaboration with the CGIAR research centers are access to advanced lines with high yield potential, disease resistance and quality and the opportunity for younger scientist to receive basic training in plant breeding and agronomy. Other high valued outputs are the advanced courses for mid career scientists, access to information generated by the IWIS, and access to information and collaboration in particularly molecular technologies, pathology and physiology.

An Overview of Agriculture in Uzbekistan

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The country has total area of 44.8 mln hectares, but only 4.5 mln hectares are arable; 4 mln are irrigated. Agriculture provides approximately 40% of GNP. It has a population of 26.8 mln people growing at 2.20% per year. Agriculture plays an important role in the economy contributing 38% to the GDP and employing 44% of the population. The main strategic crops (80% irrigated area) cotton and winter wheat. Fruits, potato and vegetables are also important crops. During the first six years of independence, the area under cotton was reduced from 2 to 1.5 mln hectares and replaced by grain production. As a landlocked country with limited access to international markets, food security is of paramount significance. Since independence, wheat has become second in importance to cotton. In order to attain food security, wheat area under irrigation increased over the years, currently at 1.3 mln hectares including rainfed production. This increase in cultivated areas stimulated the use of modern production approaches in the national wheat program. Uzbekistan is now selfsufficient in grain production. The average yield of wheat is 4.2 tones per hectare, which is almost three times higher than in 1994. Annual average wheat grain production has reached up to 6 mln tones. In view of increasing of human population, changes in agronomic and economic conditions Uzbekistan is facing the necessity of further increasing of grain production. The reserves for that are in development of new high yielding varieties, tolerant to diseases and with good baking qualities. Taking into consideration that varieties, developed in Uzbekistan, are more suitable to local conditions, therefore, own breeding in seed production should be given a high priority. In view of drastic changes in economy (90% of land in private hands) new approaches in seed production must be elaborated to meet requirements of private sector. As for strategic crops of cotton and wheat, these innovations should be taken step by step. For other crops, market relations should be applied in the nearest future.

Wheat Production Constraints in Zimbabwe

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Rainfed wheat production in Zimbabwe has been attempted and failed due to high humidity, high day and night temperatures, disease and weed proliferation during the summer and autumn month in this Tropical Country (Rattray, 1969). The country thus depends irrigated spring wheat grown during the winter months within the calender window, May to mid - November.

The yield potential of irrigated wheat in Zimbabwe is highly dependant on temperature as affected by altitude (Cacket and Wall 1971; Mashiringwani, 1985). Temperature has a marked effect on season length yield and hecto- litre mass. The yield potential of wheat in the highveld (>1200m) ranges from 6 to 10 t/ ha.

In contrast, the yield potential in the lowveld (< 800 m) is in the range 4 to 6.5 t /ha because the crop experiences high temperatures at both ends of the growing cycle and sometimes suffers frost damage at flowering and during early grain fill. High temperatures reduce potential grain number and size (Cacket and Wall, 1971), leading to a reduction in yield potential.

Another major yield constrain in irrigated wheat crop in Zimbabwe is the limited irrigation water resource i.e. dam water distribution and capacities, as influenced by erratic rainfall and limited development capacity in the country (Mashiringwani and Harawa 1985 Associated with the problem is the limited irrigation management capacity of the farmers which has wotsened in the recent land reform exercise which substituted the experience farmers with the inexperienced and resource poor ones. Electricity supply problems water pump and delivery systems shortages and breakdowns are also aggravating.

Timely planting of wheat crop to maximise yield potential is now difficult due to shortage of machinery, timeouts crop chemicals and wheat seed delivery and crop rotational problems.

Disease pressure increases from the highveld region (>1200m) to the lowveld region (400 - 800m). Leaf rust (*Puccina recondita tritici*), stem rust (*Puccinia graminis tritici*) and powdery mildew (*Erysiphe graminis tritici*) are the major disease threats to wheat production in Zimbabwe. Of late *Alternaria* pathotype which has not yet been characterised is of major concern. *Quelea* birds, aphids and ball worms cause sporadic damage on wheat crop in Zimbabwe as well. Pre-harvest sprouting damage destroyed the Zimbabwe wheat crop in 1995 and is a threat to late planted crops.

CIMMYT deserves strong acknowledgement as the basic resource for high yielding agronomically adapted germplasm in wheat improvement in Zimbabwe. The genetic yield potential of cultivars has improved steadily at 1.2 percent / year from 1969 to 1991 (Mashringwani, 1993) and has been maintained at +/- 0.5 percent / year up to 2005.

A Vision for Fast and Non-Destructive Clustering of Plant Genetic Variation

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Detection of plant genetic variation within populations has primarily been identified by use of molecular marker techniques. These techniques have been used within characterisation and identification of core collections for germplasm conservation.

Classifying the degree of relatedness among individuals or groups of accessions is an essential step into clarification of the genetic structure, or partitioning of variation among individuals, accessions, population and species.

Thermal and spectral imaging are two potential, advanced techniques for non-destructively identification of relative variation within biological material. Differences or similarities within physiological condition and canopy architecture of crops can been quantified through infrared thermometry and spectral reflectance recordings[1].

Thermal and spectral imaging reveals temperature and reflected light of a specific target region. The two techniques allow the visualisation of differences in surface temperature and reflected light by detecting emitted radiation. Computer software transforms these radiation data into thermal and spectral images in which intensity levels are indicated by a false-colour gradient. These intensity levels are signatures of the architecture and physiology of the biological material, thus genetic structures among population, species or accessions.

We find that these two non-destructive and fast quantification techniques have promising potential within classification of plant genetic resources in many aspects and could in the future replace the initial molecular marker techniques when for example screening for core collections.

[1] Idso 1982; Garrity and O'Toole 1995

Wheat Improvement in India: Emerging Challenges

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India is the second largest producer of wheat in the world with its wheat production hovering around 68-75 million tones for past few years. The three Wheat producing states of India (UP, Punjab and Haryana) contribute to nearly 80% of the total wheat production. Productivity of food crops like wheat in India has largely been increased through new technology coming from Indian public research, international agricultural research centers like CIMMYT, proper transfer of technology and private research investment. Around 300 wheat varieties were released during past forty years. Although around sixty varieties are grown by farmers of different wheat zones of India, only few varieties occupy substantial area. Presently, the most dominant variety in India is PBW 343 which occupies around one fourth area out of the total of 27 million hectares and is mainly located in the Western Gangetic Plains.

India's population of more than a billion is growing at a rate of around 1.8% per year, almost going parallel with the annual growth rate of cereals. Therefore, the estimated demand of wheat production for the year 2020 is around 109 million tones which is 30 million tones more than the record production of 75 million tones harvested in the crop season 1999-2000. Since then, India is struggling to achieve the impressive figure of its record production and is facing a challenging task on the face of a regular growth in population. The current major challenges facing the future of Indian wheat production and productivity are, increasing heat stress due to global warming, dwindling water supply for irrigation, growing threat of new virulence of diseases such as wheat rusts (yellow, brown and black) and leaf blight in the eastern Gangetic plains, declining soil carbon and hence low response to fertilizer use especially the nitrogenous ones, continuous adoption of rice wheat system in around 11 million hectares, change is urbanization pattern and demand for better quality wheat. In addition, the threat of the new stem rust race UG 99 can not be undermined. Adoption of resource conservation practices especially zero tillage also demand proper attention in breeding and against any possible change in the pest scenario. The wide gap (around 2.5 tons/ha) between the potential and harvested yield in the eastern Gangetic plains also needs proper solutions. Another important problem that appear to affect the entire northern wheat belt of India is a significant increase in the number of foggy days during early growth stages of wheat crop. The growing foggy days in turn are causing low penetration of sunlight for wheat crop and thus demand breeding for high photosynthetic efficiency.

The future germplasm requirements from a dependable collaborator like CIMMYT are mostly being dictated by above factors. Although, germplasm requirements for India will vary from zone to zone, most of the locations would need high yielding adaptable genotypes having resistance to the three rusts and suitable tolerance to water stress. Leaf blight in eastern Gangetic plains and Karnal bunt in the western plains are also important priorities. For its major wheat buffer states, Punjab and Haryana, India will continue to look for genotypes superior to the dominating cultivar PBW 343. The recent CIMMYT nurseries have shown promise in this respect. Since, one of the major concerns of India is increasing temperature due to global warming; heat tolerant genotypes need to be developed with high priority. At present more than half of the Indian wheat area is facing the problem of high temperature stress and problem appears to grow with each year. One of the steps that can prove beneficial for germplasm enhancement targeting warmers areas would be a greater use of within country shuttle breeding approach by using suitable locations in the eastern Gangetic plains and Peninsular zone of India. Similarly, dwindling water resources demand germplasm having better performance under limited water availability. More than half of irrigated wheat of India gets only one to two irrigations. For most of the areas, a combination of both heat and water stress would be required. In addition, growing resource conservation practices especially zero till in Indo-Gangetic plains will demand germplasm performing well under these conditions. Therefore, the main traits to be targeted would be, higher yield and wider adaptability with relatively early maturity for warmer areas such as eastern Gangetic Plains, durable resistance to wheat rusts and diseases like leaf blight, suitability to Resource Conservation Technologies (RCTs), tolerance to abiotic stresses (heat, drought and salinity) and good grain and industrial quality. Grain quality is important from the point of growing urbanization and also for providing proper price to the poor farmers. In addition, any advances in hybrid wheat research would also be a welcome development. For addressing issues pertaining to different stresses, more effective sources of genes need to be searched out in the land races and wild relatives. Use of both conventional and non-conventional approaches is desired to meet the emerging challenges. For proper delivery of the technology in areas such as eastern Gangetic plains that suffer from poor linkages with farmers, participatory research needs to be strengthened.

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