Review of Project 7

Water productive wheat with appropriate quality profiles

Ciudad Obregon, Sonora

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Research highlights and achievements of the spring bread wheat improvement program targeted for rainfed areas

R. Trethowan and J. Lage

This program addresses the rainfed / drought prone spring wheat areas in LDC. Rainfed areas – spring and winter combined – represent around 50% of all wheat grown in LDC. A clear delineation between rainfed / drought prone areas and areas receiving high rainfall in some years is not possible. Therefore, the breeding efforts targeted at ME2 (high rainfall) and rainfed/drought areas (ME4) were combined. ME2 material was selected and integrated with the mainstream rainfed breeding materials targeted for ME4. This change also assures that this material will also perform well under supplementary irrigation – an irrigation system becoming increasingly common in many LDC. Development of water productive germplasm - drought tolerant and input (water) responsive - is furthermore addressed by crossing, selection and testing of materials in Obregon under managed stress regimes. Water-use-efficient (WUE) materials are developed by yield testing under both optimal and sub-optimal moisture. Those performing well in both are promoted and made available to IAP breeders, INIFAP and others. This year, the top performing bread wheat lines in on-farm trials in Sonora and in trials conducted by INIFAP in Sonora were lines developed by the rainfed program. These materials have enhanced WUE and are better able to cope with the sub-optimal conditions found on-farm.

The strategy employed by CIMMYT to breed for drought prone areas is described by Trethowan and Reynolds: Drought resistance: genetic approaches for improving productivity under stress; copy attached. The breeding work is done in close collaboration with other disciplines – Physiology, Pathology – Cereal Rusts, Foliar diseases, FHS, Root and Crown Rots and Nematodes – and Quality. Results from those disciplines are reported there.

Research Highlights for 2005

- High yielding genotypes with significant improvement in productivity under stress compared to our drought stress standards were identified and promoted to international nurseries for global distribution. The synthetic derivative Vorobey showed across 30 locations yield performance equal or better than the best locally adapted cultivar.

- High yielding lines with enhanced root health, largely developed using molecular markers and confirmed in Turkey, were identified and distributed internationally. In particular Pastor derivatives with resistance to various SBD have been identified – see Nicol for details.

- All segregating materials continue to be sown and selected under zero-tillage at Obregon and Toluca. CIMMYT is currently the only program worldwide which routinely selects under 0-till. Comparison of material derived from selection under 0-till and selected under conventional tillage showed significant interactions. Interestingly, the best material selected under 0-till performed also well under conventional tillage.

- More than 20,000 markers assays for key genes were used to assist selection. This number of assays is the maximum that the marker service laboratory can manage – the breeding program would use an additional 10,000 assays if the capacity is available.
• All milestones associated with the GRDC KB project were met. Two mapping populations have been phenotyped for KB resistance across 2 years and the marker-trait association work is now underway.

• All milestones associated with the GRDC funded drought genetics and physiology project were met (for details see Reynolds).

• All milestones associated with the CRC MPB project were met. The first elite, multiple stress tolerant germplasm targeted under this project will be ready for distribution by mid-2006.

• A number of lines sent to South Asia as part of our commitment to Harvest Plus were found to be higher yielding than the local checks and the recurrent parent across a wide geographic area (from northwestern Pakistan to eastern India). However, whilst Fe levels were higher (around 20% greater in the best materials with significantly higher yields), the Zn levels showed no significant difference. By contrast, the same materials sown in China at 3 sites showed up to 20% more Zn that the recurrent parent and local check cultivars.
Drought Resistance: Genetic Approaches for Improving Productivity under Stress.

Richard M. Trethowan and Matthew Reynolds

Drought and scarcity of water for irrigation severely limit wheat productivity in many different environments around the world. Wheat breeders have made significant progress in adapting cultivars to water limited conditions, even though the genetic control of drought tolerance and water-use-efficiency (WUE), the two primary mechanisms of adaptation to moisture deficit, are not well understood.

There are a number of options available to plant breeders for improving the productivity of wheat under moisture stress. These include: (1) analysis of genotype x environment interaction to improve parental selection and identify key evaluation sites; (2) physiological characterization of germplasm to identify parents with complementary traits and to identify tools that will improve the heritability of selection; (3) development of reliable and repeatable drought screening methods; (4) broadened genetic variation for drought adaptive traits (5) improved water harvesting via improved root health; (6) enhanced cultivar adaptation to moisture conserving crop management practices; and (7) identification and conservation of genomic regions that are associated with performance under moisture stress across environments and time. These options are examined in the context of a wheat breeding program and their application to wheat improvement in water limited environments is discussed.

Introduction

Drought severely limits wheat productivity in many environments around the world. Some estimates indicate that 50% of the approximately 230 M ha sown to wheat annually in the world is regularly affected by drought (Pfeiffer et al., 2005). Wheat breeders have made significant progress in developing cultivars better adapted to moisture limited conditions. Improvements in grain yield of between 0.4 and 1.3% per annum have been reported for many of the drier wheat producing areas of the world (Byerlee and Traxler, 1995). It is recognized that improved agronomic techniques account for a considerable portion of this variation (Bell et al., 1995). However, genetic improvement has also contributed significantly to improvements in yield stability and productivity, and in many instances, realizing the benefits of improved farming practices is dependent upon the availability of suitable or responsive cultivars. This paper examines the various genetic options available to wheat breeders to improve productivity under stress. A number of examples are drawn from the experience gained by wheat breeders at the International Maize and Wheat Improvement Center (CIMMYT) located in Mexico. We emphasize productivity under stress, or water use efficiency defined in this case as yield per mm water applied, rather than survival under stress or drought tolerance as this character is of greater economic importance to farmers.

I) Exploiting genotype x environment interactions to identify parents and key selection environments

The yield and yield stability of genotypes across many stress environments has always been an important criterion used by plant breeders to select candidates for release to farmers and to identify parents for crossing. At CIMMYT, wheat germplasm is developed by shuttling segregating materials between two contrasting environments, one located near Ciudad Obregon in northwestern Mexico (27° N, 60 masl) and the other in the central Mexican highlands near Toluca (19° N, 2600 masl). This germplasm shuttle allows two
generations to be grown each year and has been described in detail by Rajaram et al. (1994). The site near Ciudad Obregon is an arid, irrigated environment and drought and heat stress can be reliably generated by controlled irrigation and delayed planting date. The lines developed in this way are then distributed internationally through CIMMYT's international wheat network and collaborators from many countries grow the trials and return data for analysis. These data are then used by both CIMMYT and regional breeders to identify key discriminating locations and to select parents for crossing. Twenty years of data from the Elite Spring Wheat Yield Trial (ESWYT) were analyzed to examine associations among international locations with the aim of identifying those locations that discriminate germplasm in a similar way to CIMMYT's primary yield testing location located in northwestern Mexico (Trethowan et al., 2003a).

Figure 1. Summary of cluster analysis of 20 years of the Elite Spring Wheat Yield Trial. Sites are grouped based on non-significant cross-over interaction. Source: Trethowan et al. (2003)

Figure 1 summarizes the findings derived from cluster analysis of locations; these results have been used by CIMMYT breeders to source and exchange germplasm, particularly from regions that do not cluster with sites in Mexico. The international performance of genotypes is also used to examine both broad and specific adaptation.
Figure 2. Dendrogram of genotype associations from cluster analysis of 10 years of the Heat Wheat Yield Trial. Source: Lillemo et al (2005)

Figure 2 summarizes the findings of an analysis of CIMMYT’s High Temperature Wheat Yield Trial (HTWYT) (Lillemo et al, 2005). In this instance, genotypes were identified that performed similarly under different environmental conditions. These different genotype groupings represent different adaptive gene pools and breeders use this information to better target germplasm to specific environments and to design crosses among gene pools to broaden the adaptation of wheat germplasm.

II) Use of physiological tools to identify parents and improve the heritability of selection

While the predominance of an upstream focus in plant stress research has led to a greater emphasis on traits associated with survival under extreme stress than those associated with agronomic productivity under resource-limited conditions, crop physiologists have nonetheless identified many traits that are associated with adaptation of wheat to dry environments, albeit that understanding remains incomplete (Reynolds et al., 2006).

However, until recently, few wheat breeding programs have actively selected for physiological traits. This lack of application to some extent reflects the expense and time consuming nature of many physiological applications, making it difficult to select for physiological traits in segregating generations. Work at CIMMYT has shown that physiological tools can be effectively used to characterize parents for the presence of complementary physiological traits, therefore allowing plant breeders to combine these traits in crosses (Reynolds et al., 2006). Values for various physiological traits measured on key parental materials grown under drought stress in Mexico show significant variation among lines (Table 1).
Table 1. Physiological traits measured on parental materials at Cd Obregon 2003-2004

<table>
<thead>
<tr>
<th>Pedigree</th>
<th>Yield</th>
<th>Biomass</th>
<th>CT&lt;sup&gt;1&lt;/sup&gt; anthesis</th>
<th>CT Vegetative</th>
<th>Grainfill</th>
<th>Discrim. at anthesis</th>
<th>Stem CHO&lt;sup&gt;2&lt;/sup&gt;</th>
<th>Water extraction by roots</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>g/m²</td>
<td>g/m²</td>
<td>°C</td>
<td>°C</td>
<td>% stem dry weight</td>
<td>(% available water)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jun/Gen</td>
<td>338</td>
<td>424</td>
<td>19.2</td>
<td>21.8</td>
<td>-23.1</td>
<td>13.3</td>
<td>84</td>
<td></td>
</tr>
<tr>
<td>Weebill 1</td>
<td>348</td>
<td>513</td>
<td>19.3</td>
<td>21.7</td>
<td>-22.5</td>
<td>17.5</td>
<td>83</td>
<td></td>
</tr>
<tr>
<td>Synthetic</td>
<td>278</td>
<td>510</td>
<td>19.8</td>
<td>22.6</td>
<td>-22.5</td>
<td>19.1</td>
<td>79</td>
<td></td>
</tr>
<tr>
<td>Frame</td>
<td>213</td>
<td>503</td>
<td>20.5</td>
<td>23.2</td>
<td>-21.7</td>
<td>6.8</td>
<td>79</td>
<td></td>
</tr>
<tr>
<td>Klein</td>
<td>247</td>
<td>638</td>
<td>20.1</td>
<td>23.3</td>
<td>-22.6</td>
<td>3.4</td>
<td>82</td>
<td></td>
</tr>
<tr>
<td>Cacique</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prointa</td>
<td>223</td>
<td>572</td>
<td>20.0</td>
<td>22.9</td>
<td>-22.4</td>
<td>11.2</td>
<td>79</td>
<td></td>
</tr>
<tr>
<td>Federal</td>
<td></td>
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<td></td>
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</tr>
</tbody>
</table>

<sup>1</sup> Canopy temperature; <sup>2</sup> Carbohydrate

These data were collected on lines grown near Ciudad Obregon using a managed drought stress regime described in Trethowan et al. (2001a). Initially there was some doubt as to whether it would be possible to combine these traits as increases in one trait may be matched by decreases in another. However, evidence indicates that it is possible to combine different physiological traits through crossing as some parental lines with good yield performance under drought stress, such as Weebill 1 and Jun/Gen, already combine the expression of combined traits. Weebill 1 combines cooler canopy temperature with greater stem carbohydrate translocation and Jun/Gen combines cooler canopies, improved C isotope discrimination and better water extraction by roots with intermediate stem carbohydrate translocation. Furthermore, quantitative analysis of physiological traits in a broad range of genetic backgrounds (including materials derived from interspecific hybridization and selected landraces) suggest that traits like WUE, stem carbohydrates and access to water at depth in the soil, if combined into modern varieties could increase yields under drought by 30% or more over current elite checks (Reynolds and Condon, 2006).

During selection, easy to measure tools such as canopy temperature depression (CTD) can be used to select superior lines or bulks. The only limitation to the use of CTD is the presence of a canopy and clear sunny conditions. Reynolds et al. (2005) demonstrated a significant association between yield and CTD in wheat bulks grown under drought stress in northwestern Mexico. CTD is now used routinely by CIMMYT's wheat breeding program to complement visual selection under drought stress in the early generations of the wheat improvement program.

III) Development of reliable and repeatable drought screening methods

Determining the drought phenotype in any crop species is difficult because of the variable nature of drought in the field, the lack of correlation between field and greenhouse results and the confounding effects of constraints other than drought on phenotype. At CIMMYT, wheat germplasm is screened for adaptation to moisture stress in carefully managed stress scenarios in the field in northwestern Mexico. A combination of drip and gravity fed irrigation in an arid environment allows these drought stress scenarios to be generated each year. A
description of the irrigation methods employed by CIMMYT can be found in Trethowan et al. (2004).

Germplasm is developed by growing the F2, F3 and F6 generations under optimal moisture and foliar disease pressure, and the F4 and F5 generations under one dominant drought stress scenario (generated historically using gravity fed irrigation, but now managed using a drip fed system). The derived fixed lines are first yield tested under well watered conditions to identify those with yield potential, followed by testing under the same primary drought stress scenario. Selected lines are then tested under 3 different scenarios; optimal irrigation; pre-anthesis drought stress and post-anthesis drought stress. Those performing well under all three scenarios are sent globally for further testing in CIMMYT’s international wheat network and the best become parents.

Clearly, this methodology is effective only if the drought screening conducted in Mexico is relevant to the drought patterns found in target regions around the world. Whilst analysis of historical data shows that lines selected using gravity fed irrigation do associate well with many drier locations, particularly in South Asia, there are areas of the world that consistently differentiate wheat germplasm differently (Trethowan et al., 2001a). To examine if drought screening in Mexico could be managed more effectively to mimic the long-term drought patterns of locations that do not associate well with drought screening in Mexico, a series of different managed stress environments were generated over a four year period in Mexico. A tester set of genotypes that had already been extensively tested internationally were planted in these managed stress environments in Mexico to examine the relationships among Mexican and international trial locations. The results are summarized in Trethowan et al. (2005) and clearly demonstrate that it is possible to tailor drought stress in Mexico to develop more relevant germplasm for a broader range of geographical areas.

IV) Broadened genetic variation for drought tolerance and WUE

The wheat breeding program in Mexico has made good progress in developing bread wheats adapted to drier environments (Trethowan et al., 2002). However, it was recognized some years ago that if productivity under moisture deficit was to continue to be improved, new sources of genetic variability would have to be found and introgressed. Synthetic wheat, developed by crossing tetraploid durum wheat with Aegilops tauschii, the ancestral donor of the D genome in hexaploid wheat, has been a rich source of diversity for many characters including tolerance to drought stress (Villareal et al., 1998; Trethowan et al., 2003b). Data generated at CIMMYT shows that when these synthetic wheats are combined in crosses, the yield of the derived synthetic is considerably higher than the adapted recurrent parent under drought stress (Table 2).
Table 2. Yield of synthetic derivatives under drought stress expressed as a % of the recurrent or adapted parent in 2003/2004 and 2004/2005 from managed drought stress trials conducted at Ciudad Obregon.

<table>
<thead>
<tr>
<th>Cross</th>
<th>2003 - 2004</th>
<th>2004 - 2005</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Yield as % of recurrent parent</td>
<td>Yield as % of recurrent parent</td>
</tr>
<tr>
<td>SCA/AE.SQUARROSA (409)/2* PASTOR</td>
<td>119.1*</td>
<td>113.7*</td>
</tr>
<tr>
<td>SCA/AE.SQUARROSA (409)/2* PASTOR</td>
<td>124.9*</td>
<td>115.1*</td>
</tr>
<tr>
<td>CHEN/AE.SQ//OPATA/3/2* PASTOR</td>
<td>117.8*</td>
<td>103.8</td>
</tr>
<tr>
<td>D67.2/P66.270//AE.SQUARROSA (320)/3/CUNNINGHAM</td>
<td>113.4*</td>
<td>119.4*</td>
</tr>
<tr>
<td>D67.2/P66.270//AE.SQUARROSA (320)/3/CUNNINGHAM</td>
<td>115.5*</td>
<td>123.0*</td>
</tr>
<tr>
<td>CROC_1/AE.SQUARROSA (224)/2*KULIN</td>
<td>104.6*</td>
<td>129.0*</td>
</tr>
<tr>
<td>CROC_1/AE.SQUARROSA (224)/2*KULIN</td>
<td>104.3*</td>
<td>124.1*</td>
</tr>
</tbody>
</table>

* Yields from reduced (2 irrigation) irrigation trials, all other trials conducted with 1 irrigation; * significantly different from the recurrent or adapted parent at P<0.05

However, whilst improved productivity under drought stress has clearly been achieved in Mexico, the real test of the potential of these materials is performance in the regions targeted by the CIMMYT breeding program and partners. Preliminary evidence obtained from CIMMYT’s 11th Semi-Arid Wheat Yield Trial (11th SAWYT) indicates that the synthetic materials, developed specifically for adaptation to drought stress, perform well across a range of different locations (Figure 3).
Figure 3. Yield of the synthetic derivative Vorobey (•) in relation to the yield of the best locally adapted cultivar (●) at 30 international trial locations: data from the 11th SAWYT.

Figure 3 compares one such synthetic derivative, Vorobey, with the best locally adapted cultivar at each of 30 locations internationally. The performance of this line is either equivalent to or better than the local cultivar across many locations, including the more productive environments. Clearly these types of wheat, developed using the strategy outlined in this paper, have improved yield stability and productivity across a wide range of growing conditions.

V) Improved WUE via improved root health

In some dry environments much of the improvement in yield over time can be attributable to better root health (Trethowan et al., 2004), the inference being that healthier roots make better use of the available soil moisture. As there is genetic variability for nematode and root rot resistance and tolerance to micronutrient toxicities such as boron, and the mode of inheritance of these genes is relatively simple, wheat breeders in areas prone to these problems have found it easier to manipulate these gene systems rather than the complex character of drought tolerance per se. Molecular markers are now available for many of these simply inherited characteristics, and as marker assays are more cost effective than bioassays for root diseases or constraints, and have a higher heritability, they are increasingly being used by wheat breeders.

At CIMMYT, markers for genes conferring resistance to cereal cyst nematode, root lesion nematode, crown rot and tolerance to boron have been routinely used for many years (William et al., 2003). Advanced lines with improved root health developed using marker assisted selection have been developed at CIMMYT and distributed globally in the Semi-
Arid Wheat Screening Nursery. Interestingly, many of these lines are significantly higher yielding than their recurrent parents even in the absence of root disease (Table 3).

Table 3. Yield of improved germplasm selected using molecular markers for various root constraints under reduced irrigation and drought at Ciudad Obregon in 2004/2005.

<table>
<thead>
<tr>
<th>Pedigree</th>
<th>Target gene</th>
<th>Yield in reduced irrigation as % of source parent</th>
<th>Yield in drought as % of the source parent</th>
</tr>
</thead>
<tbody>
<tr>
<td>CROC_1/AE.SQUARROSA (205)//KAUZ/3/SILVERSTAR</td>
<td>Cre 1</td>
<td>107.0</td>
<td>125.3 *</td>
</tr>
<tr>
<td>CROC_1/AE.SQUARROSA (205)//KAUZ/3/SILVERSTAR</td>
<td>Cre 1</td>
<td>118.6 *</td>
<td>116.3 *</td>
</tr>
<tr>
<td>CNDO/R143//ENTE/MEX1_2/3/AEGILOPS SQUARROSA (TAUS)/4/WEAVER/5/2*FRAME</td>
<td>Bo1</td>
<td>114.1 *</td>
<td>167.6 *</td>
</tr>
<tr>
<td>CNDO/R143//ENTE/MEX1_2/3/AEGILOPS SQUARROSA (TAUS)/4/WEAVER/5/2*FRAME</td>
<td>Bo1</td>
<td>113.4 *</td>
<td>166.3 *</td>
</tr>
<tr>
<td>KRICHAUFF/2*PASTOR</td>
<td>Rin 1</td>
<td>120.1 *</td>
<td>133.2 *</td>
</tr>
<tr>
<td>KRICHAUFF/2*PASTOR</td>
<td>Rin 1</td>
<td>127.4 *</td>
<td>125.7 *</td>
</tr>
</tbody>
</table>

1 Cre 1, Bo1 and Rin 1 confer resistance to cereal cyst nematode, tolerance to boron toxicity and resistance to root lesion nematode, respectively.
2 The source parents are Silverstar, Frame and Krichauff. Reduced irrigation represents two applied irrigations and drought one applied irrigation.
* significantly different from the recurrent or adapted parent at P<0.05

VI) Enhanced cultivar adaptation to moisture conserving crop management practices

In many parts of the world farmers have adopted conservation tillage. These changes to the farming system, characterized by no tillage or reduced tillage and the retention of stubble from the previous crop, have improved water infiltration, reduced water loss and reduced soil erosion. Initially, most studies found no interaction between genotype and tillage practice (Dao and Nguyen, 1989; Ditsch and Grove, 1991). However, this lack of interaction is not surprising as small numbers of genotypes were tested, all of which had been developed under conventional tillage. Recently, the existence of significant tillage x genotype interactions among more diverse genotypes has offered plant breeders the opportunity to tailor cultivars to the farming system (Klein, 2003). At CIMMYT, breeders carefully select parental materials on the basis of their performance on zero-tillage and the subsequent segregating generations are planted and selected under zero-tillage. This process has developed advanced lines with significantly better performance under zero-tillage (Sayre and Trethewan, unpublished data). Improved emergence and establishment, particularly from deep planting, and enhanced resistance to foliar blights are also important selection criteria. Improved emergence is to some extent linked to removal of the GA-insensitive dwarfing genes Rht1 and Rht2. However, experience at CIMMYT shows that there is significant residual variation for coleoptile length that can be exploited (Trethewan...
et al., 2001b). Rebetzke and Richards (2000) have also characterized a number of GA-sensitive dwarfing genes and some these and other sources of variation are being used in crosses at CIMMYT.

VII) Identification and conservation of genomic regions that are associated with performance under moisture stress

It is difficult to see functional genomics playing a significant role in the short term in the development of drought tolerance or WUE cultivars. Large numbers of up and down regulated genes and the confounding effects of genotype x environment interaction make it very difficult to use these data. However, DNA fingerprinting is being used by many breeders to select parental materials and to calculate more realistic coefficients of parentage.

The CIMMYT wheat program and international partners have generated an extensive data set of yield and disease performance collected from CIMMYT yield and screening nurseries over the past 30 years. There is scope to use these data and fingerprints of the key germplasm representing this 30 year period to identify genomic regions linked to performance under defined sets of environmental conditions. It may be possible in the near future, to link drought performance with specific genomic regions always present in materials performing well under drought stress. Wheat breeders could then ensure these regions are present in their parental materials and could actively select for them in segregating populations. This work continues.

Conclusion

Clearly there is no optimum strategy for developing wheat cultivars better adapted to drought conditions. The existence of large genotype x environment interactions makes it difficult to pin point the underlying genetic control of adaptation. To make progress, the wheat breeder must try and separate performance under drought into manageable sub-objectives each with measurable genetic variation. The seven strategies outlined in this paper each address a different component of adaptation to drought stress. However, the challenge is to combine these different strategies most effectively to produce well adapted wheat germplasm.

References


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Summary of Physiology Research undertaken at CIMMYT in 2005

M. Reynolds

Physiological/genetic basis of abiotic stress tolerance

I) Phenotype 167 RILs of Seri/Babax to identify QTLs associated with abiotic stress adaptation using a molecular map generated by Australian collaborators (CSIRO, Brisbane). Canopy temperature (CT) and water soluble carbohydrate (WSC) concentration in stems have been associated with stress adaptation under drought and heat stress. The current hypothesis is whether the physiological expression has a common genetic basis when expressed in either environment, and hence to determine whether MAS for such traits could be applied generically across the two stresses. The RILs and parents were sown under drought and hot irrigated conditions in Obregon 2005. Ground cover, phenology and seed weight characteristics were measured in both environments in addition to CT and WSC. A conference paper describing the molecular mapping procedure and QTLs for some of these traits has been submitted for the upcoming Australasian Wheat Breeders Meetings (McIntyre et al).

II) Physiological characterization of genetic resources/quantifying a conceptual model (GRDC). The principal objective was to determine which of the many traits identified in the literature as important in drought adaptation could be expected to provide the greatest benefit to yield, using as a frame of reference the range of genetic diversity expressed in exotic hexaploid germplasm. Quantitative analysis was performed using data from elite landraces and drought tolerant checks collected in 2002, 2004 and 2005 under drought stressed field conditions in Obregon. Analyses estimated the potential benefit of the drought-adaptive trait expression in landraces, were they to be theoretically expressed at the same level in the elite checks. The results indicated that improved water use efficiency (WUE) was the most promising with many of the landraces showing excellent biomass despite modest values for HI. Other traits strongly indicated were increased ability to access water deep in the soil and levels of stored stem carbohydrates at heading. Results were submitted in October to Euphytica for peer-review publication (Reynolds and Condon).

III) Characterize DREB-transformed wheat plants in soil plantings in a screen-house (GCP). DREB transformed plants were grown in 4 environments in field soil profiles inside screen-houses. Environments were (i) continuous drought, (ii) drought interrupted at late boot stage, (iii) drought interrupted at anthesis+7d, (iv) irrigated check. DREB transformants were not better performing than checks and extensive physiological characterization failed to reveal biologically significant differences that might be associated with superior drought adaptation. Data reported as part of GCP conference, September 20-28th, Rome (Crouch et al).

IV) Phenotyping genetically diverse lines for comparison with allelic diversity (GCP). From 100 lines with diverse backgrounds grown in Obregon (2004 & 2005) under drought and well watered conditions, a subset that contrasted in drought adaptation were selected for evaluation of tissue expansion characteristics in 2005. Leaf expansion and stem expansion rate were measured on 12 lines in the field under drought and well watered conditions. The 7 most contrasting lines (in terms of tissue
expansion rate in the field) were grown in pots in controlled environments during the summer in El Batan so that tissue expansion rate could be measured with controlled soil water potential. While tissue expansion rate showed a strong interaction with water status in the field, this was not observed when soil water status was controlled in pots. Tissue expansion rates at soil water potentials between -1 to -10 bars were higher than when measured at -17 to -22 bars. However, the correlation between environments was very high ($r^2=0.77$) indicating that the trait was more constitutive than adaptive in this germplasm. The experiments will be repeated and evaluated also in more diverse germplasm taken from the elite landraces. Data reported as part of GCP conference, September 20-28th, Rome (Sawkins et al).

V) Physiological characterization of synthetic derived wheats (GRDC). Synthetic derived (SYN-DER) lines and their recurrent parents were grown under drought and irrigated conditions in Obregon in 2004 and 2005. A large suite of physiological measurements were taken in both environments, including estimates of root biomass down to 1.2m soil depth, in order to identify the traits that explained superior performance of SYN-DER lines. Despite superior yield and biomass especially under drought, SYN-DER lines display a negligible (14%) increase in root:shoot compared with recurrent parents (>100%) in response to water stress. However, SYN-DER lines showed a marked change in root distribution under drought with approximately 50% of their root biomass found between 30-120cm compared with 25% for recurrent parents. This adaptation likely explains their ability to extract more water from deeper in the soil profile and more water in total (25 mm). While the absolute reduction in root biomass (45 g/m2) was in the same order as the gain in yield of SYN-DER lines (65 g/m2), the gain in biomass was an order of magnitude higher (525 g/m2). Using the average SYN-DER value of WUE an extra 25 mm of water would account for 150 g/m2 of additional biomass. Additional mechanisms that may help explain a larger WUE are increased transpiration efficiency and decreased losses of soil water early in crop establishment due improved early ground cover. This data was submitted to Journal of Experimental Botany for peer-review publication (Reynolds et al).

VI) Develop pops to study gene-action of canopy temperature (GRDC-Post-Doc). Populations were developed during 2004 and 2005 from parents identified as contrasting in canopy temperature and stem carbohydrate concentration at anthesis. A total of 650 lines from 5 crosses have been sown with parents, F1s, and F1BCs for evaluation of CT under drought & irrigation by the new Post-Doc appointee.

VII) Pre-breeding for stress-adaptive physiological traits (GRDC). A number of populations (maintained as relatively large families [5,000 plants/cross] and subjected to disease screening in the summer and mild visual selection under drought in the winter from F2) were planted for selection by the drought breeder (RT). Populations constituted crosses between lines with specific physiological traits and elite checks. The following numbers of populations remained in Y04-05: 28 F5 populations, 34 F5-Tops, 20 F6 and 6 F7s. Spikes from most of these populations were selected for stripe rust screening during MV05. Selected lines were entered into PYTs in the drought breeding program.

VIII) Advance selected populations to develop RILS (GRDC). Populations (34) from the same parents used in pre-breeding were advanced to F6 and F7 generations respectively in Obregon. Selections have been made among the most promising crosses for production of RILs populations during 2006.
Traits for Raising Yield Potential.

I) Organize workshop on yield potential (ACIAR). Yield Potential Symposium (YPS) venue set for Obregon (March 20-24th) and agenda developed. Survey designed and distributed for participation of national program staff from all major wheat growing regions in a one-day workshop: Challenges to Wheat Production Internationally. Program of speakers from CIMMYT, ARIs and NARS being developed.

II) Measure stomatal aperture related traits (SATs) on breeder derived populations. Canopy temperature measured on breeder selected materials. SATs appear to compliment visual selection, identifying the highest yielding lines. MvG to present full analysis at YPS.

III) Integrated analysis of value of SATs as indirect selection criteria. Among SATs, carbon isotope discrimination predicts irrigated yield the best, but stomatal conductance and canopy temperature also explain significant variation in yield and are much more practical in terms of application in a breeding program. Paper submitted in October to Euphytica for peer-review publication (Condon, et al.).

IV) Analysis of traits associated with source or sink limitation in 3 populations of RILs. Three 'sink-related' traits (growth rate in boot phase, spike mass at anthesis, and partitioning to spike at anthesis) explain 60% of variation in final yield in RILs. Data prepared for path analysis being conducted in collaboration with biometrics; data in preparation for presentation of conference paper at YPS and peer-review.

V) Evaluate large spike, spike fertility, and leaf angle material. Best lines from all trials were selected based on agronomic parameters as well as traits expression (eg multi-ovary, leaf angle, large spike) and yield trials prepared for final evaluation in 2006.
Drought Adaptive Mechanisms from Wheat Landraces and Wild Relatives

Summary

Exotic parents are being used to increase allelic diversity in bread wheat breeding through (i) inter-specific hybridization of the ancestral genomes to produce so called synthetic derived (SYN-DER) wheat, and (ii) crossing with landrace accessions -originating in abiotically stressed environments- that have become isolated from mainstream gene pools. Evaluation of the inherent genetic diversity encompassed by drought adapted landraces in comparison with checks confirmed that landraces were not only distant from checks but also showed considerably diversity among each other. Increased yield and biomass of SYN-DER lines in comparison to recurrent parents was not associated with a larger overall investment in root dry weight, but rather an increased partitioning of root mass to deeper soil profiles (between 60 and 120cm) which was associated with an increased ability to extract moisture from those depths. The best Mexican landraces also showed superior ability in terms of water extraction from depth as well as expression of soluble stem carbohydrates. An attempt was made to quantify the potential value to yield of this exotic germplasm, which represents some of the broadest and most promising genetic resources available to CIMMYT’s drought breeding program. A rough assessment was made by identifying the highest expression of any trait amongst all genetic resources, comparing the value of expression with that of the check cultivar, and estimating what the theoretical yield would be if the trait were expressed at the same level. This approach suggested that improvements in water use efficiency, water extraction from soil depth, and levels of soluble carbohydrates in the stem could each potentially contribute around 20% extra yield or more, though the extent to which these traits could be combined was not explored.

Introduction

Genetic improvement of crops, whether approached empirically or strategically, depends on new types of gene expression that will result in more optimal growth and development in a given environment. For example crosses among conventional lines can achieve new levels of trait expression as a result of transgressive segregation of alleles. On the other hand, exotic parents can also be used to increase allelic diversity. The bread wheat breeding program of The International Maize and Wheat Improvement Centre (CIMMYT) is exploiting new genetic diversity from inter-specific hybridization of the ancestral genomes of bread wheat, more commonly known as synthetic hexaploid wheat (Mujeeb-Kazi et al., 1996). Specifically these derive from crossing tetraploid durum wheat (AB genome) with the diploid wild species T. tauschii (D genome). Crosses between elite wheat cultivars and synthetic wheat have resulted in lines with improved drought adaptation (Trethowan et al., 2005) though the physiological and genetic basis is not established.

A more direct way to exploit novel allelic diversity is to cross elite material with genetic resources of the same genome, for example landrace accessions originating in abiotically stressed environments that have become isolated from mainstream gene pools. The assumption is that such accessions may provide novel alleles that will complement existing stress-adaptive mechanisms. Since landraces collections frequently exist in the thousands, in order to identify useful physiological traits it is usually necessary to subject them to a pre-screening under the appropriate stress to identify the most promising genotypes. Again, while landraces have been used for some time in breeding barley for adaptation to abiotic stresses (Ceccarelli et al., 1995), their use in bread wheat breeding is less common and physiological basis of drought adaptation of cereal landraces is not well studied.
This study describes some of the physiological mechanisms associated with novel genetic resources expressing superior drought adaptation. Firstly two synthetic derived lines (SYN-DER) and their recurrent parents (REC-PAR) are examined under well watered and post-anthesis drought scenarios. The second part of the study briefly describes how approximately 2,000 Mexican landraces were screened for yield under drought, permitting a handful to be selected for more detailed physiological measurements along with other genetic resources. A DNA fingerprinting study of the selected landraces was also conducted to give an indication of their genetic distance amongst each other and from standard check cultivars. However, the main objective in the second part of the study was to compare the relative expression of drought-adaptive traits of these genetic resources (GEN-RES) with an elite drought-adapted check cultivar. By considering the full range of trait expression represented by these lines, the theoretical impact of combining their best values of expression into the check cultivar was estimated to gain some insight into which traits may hold most promise in terms of genetic enhancement.

Results

Synthetic derived wheat

The interaction of genotypes with the two growth cycles (years) was not statistically significant for agronomic traits. The effects of SYN-DER germplasm and drought treatment (DRT) -averaged across both genetic backgrounds- for above and below ground growth parameters are summarized in Table 1. There was no significant interaction of SYN-DER with DRT for yield. While DRT reduced overall yields by approximately 40%, the main effect of SYN-DER was to increase yield by approximately 20% in both environments in comparison to REC-PAR. However, above ground biomass did show a strong interaction with treatments; SYN-DER increased biomass by 70% under DRT and only 30% under irrigated conditions (IRR) (Fig. 1). For harvest index and kernel weight there was no interaction and SYN-DER was associated with a reduction in harvest index of 18% and an increase in kernel weight of 25% averaged across environments (Table 1). However, there were clear interactions for root growth parameters (Fig. 1). While total root biomass increased under DRT the effect was larger for REC-PAR (52%) than SYN-DER lines (21%) and this was reflected in root:shoot ratios (Table 1). However, when considering only the roots in the top 30cm of the soil, the SYN-DER lines showed a small decrease in root mass of 17% in response to DRT while REC-PAR showed a sizeable increase of 85% (Table 1; Fig 1).

The SYN-DER derived material showed a greater capacity for water uptake especially at intermediate root depths (Fig. 2). By the end of the cycle, REC-PAR had approximately 50 mm of water remaining in the soil profile (down to 120cm) while SYN derived lines has less half that amount, representing an increase in total water absorption of 11%. The increased capacity of SYN-DER lines to take up water was noticeable at anthesis as well as after physiological maturity (Fig. 2).On average SYN-DER lines used 253mm of water throughout the cycle down to 120cm while REC-PAR used 227mm; using total biomass data (above ground + root biomass), water use efficiency values were calculated as 5.35 g/m2/mm and 3.69 g/m2/mm for SYN-DER and REC-PAR, respectively.

Landrace selection and genetic diversity

The result of initial screening of the 2077 landraces for yield under drought are shown (Fig. 3). The top 50 yielding lines from the hill plot screening gave an average yield of 280 g/m² in the 2001 yield trial (LSD = 95 g/m²). The top 8 lines (yielding from 315 and 415 g/m²) were those included in the experiment GEN-RES (Table 2). Seven of the eight landraces were
subjected to DNA fingerprinting along with drought adapted check lines, Weebil-1 and Sokoll also from the experiment GEN-RES, and an additional drought susceptible but high yield potential line W15.91. The DNA fingerprinting of the landraces revealed a very wide range of genetic diversity among the lines selected. The dendrogram generated from similarity coefficients indicated two major groups (Fig. 4). One group was relatively homogeneous consisting of three landraces (2 from the state of Mexico and one from the neighbouring state of Puebla), and a much more heterogeneous group including the landraces from Mexico and Oaxaca as well as the check lines. The closer association of the synthetic derivative, Sokoll, with the adapted wheats W15.91 and Weebill 1 to a large extent reflects selection for genomic regions present in the adapted parents used to produce Sokoll. These regions likely confer improved agronomic type and quality, whereas the drought tolerance from the original primary synthetic is probably linked to a relatively smaller area of the genome.

**Genetic Resources**

The interaction of genotypes with the three drought environments (years) was statistically significant. However, trait expression across years was generally highly correlated among genotypes indicating that there was relatively little crossover interaction. Therefore, growth (Table 2) and water relations parameters (Table 3) are presented as main effects across the three cycles. Evaluation of performance under well-watered conditions was not a prime objective in this experiment, most of the material not being adapted for high yield environments. Nonetheless, irrigated yields are presented in Table 2 as a point of reference. The highest yielding line was the check variety Weebil-1 while the landraces showed a considerable range. The effect of drought on this material was to reduce yield by over 50% on average, with the exception of one landrace with very low yield potential. The check was among the highest yielding lines under drought along with the synthetic derived line Sokoll, and the high spike density line MES, which all yielded just over 300 g/m². The lines that were high yielding under drought, Sokoll and MES both showed significantly higher biomass than the check by 17% and 25% respectively, indicative of superior drought adaptive mechanisms. Kernel weights and harvest indices were within fairly normal ranges for these conditions while some of the landraces were up to 10 days later in maturity than the check (not shown).

Traits that correspond to differences in pre-anthesis growth showed significant variation (Table 2). Differences in early ground cover were estimated using spectral reflectance (Babar et al., 2006), specifically the normalized vegetative difference index (NDVI) which estimates green area. Most of the genotypes showed superior values than the check, indicating a greater potential for early ground cover. The percentage of soluble stem carbohydrate (SSC) shortly after anthesis showed a range with several landraces showing values larger than the check, while SSC measured in straw residues at physiological maturity were not different (Table 2). The total remobilization of SSCs was calculated using these values (and those of straw mass measured at the same time) and ranged from 30 to 130 g/m² (not shown). Genotypes showing the highest values for SSC shortly after anthesis also had some of the lowest final biomass.

Traits relating to water uptake and water use efficiency (WUE) also showed significant variation (Table 3). Landraces generally showed better water uptake characteristics than the check at soil depths below 60cm, but not between 30-60cm. On the other hand WUE was largest for the two lines showing the highest biomass while most landraces showed values of WUE lower than the check. Canopy temperature measured in the driest of the 3 cycles (2002) showed a very good relationship with water uptake between 30-120cm (Fig. 5). Osmotic adjustment (OA) and carbon isotope discrimination showed significant variation
between genotypes (Table 2). Values of OA showed no association with WUE or water uptake parameters. Carbon isotope discrimination was associated negatively with residual water as might be expected since genotypes with intrinsically high discrimination would be more likely to require extensive root systems to sustain larger stomatal aperture associated with the discrimination trait (Condon et al., 2002).

**Discussion**

**Synthetic derived wheat**

The use of inter-specific hybridization to widen the hexaploid wheat gene pool is a revolutionary step in terms of overcoming the genetic bottle-neck that occurred when the genomes (AB + D) first combined, at least ten thousand years ago (Mujeeb-Kazi et al., 1996). While the diploid D genome has been exploited for disease resistance genes for some time (Villareal et al., 1995), it is only more recently that the potential for increasing drought adaptation has been realized (Trethowan et al., 2003; 2005), though there is already evidence for impact in drier regions worldwide based on data from recent international drought trials (Trethowan and Reynolds, 2005). The data presented in this study indicate a response of SYN-DER to moisture stress in terms of changes in partitioning of assimilates to roots and an increased ability to take up water from a greater depth, along with greater water use efficiency.

Increase in root:shoot and absolute root mass in response to moisture stress have been shown previously in wheat (Blum et al., 1983) and were observed in this study (Table 1). Perhaps counter intuitively, despite superior yield and biomass SYN-DER displayed a relatively modest increase in total root mass and root:shoot (21% and 29% respectively) compared with REC-PAR (52% and 110% respectively) in response to drought (Table 1). However, SYN-DER showed a marked change in root distribution under drought with 63% of their root biomass between 30-120cm compared with 42% for REC-PAR -and approximately 50% for either under irrigated conditions- (Table 1). This would appear to be a significant drought adaptation which likely explains their ability to extract more water from deeper in the soil profile (Fig. 2) and more water in total (26 mm) compared with REC-PAR. Large investment of roots in the top 30cm of soil makes biological sense for well watered conditions, but not with a receding moisture profile. Nonetheless, neither the increased water extraction nor the small reduction in total root mass (8g/m²) were of sufficient magnitude to explain the increase in biomass of SYN-DER relative to REC-PAR. Using the SYN-DER value for WUE of 5.35 g/m2/mm, an extra 26 mm of water would account for 140 g/m² of additional biomass. Possible mechanisms that may explain a larger WUE are increased transpiration efficiency associated with intrinsically low stomatal conductance and carbon isotope discrimination (Condon et al., 2002; 2004; Rebetzke et al., 2002), and decreased losses of soil water early in crop establishment due improved early ground cover (Richards et al., 2002). Although neither trait was estimated in this experiment, SYN-DER lines have been reported to display considerable early vigour and increased ground cover (Trethowan et al., 2005).

The data presented here on root mass also demonstrate that assumptions about genetic effects using above ground biomass can be somewhat erroneous. Values of WUE calculated using above ground biomass instead of total biomass were overestimated by 6% and 10% for SYN-DER and REC-PAR respectively; similarly harvest index under drought was underestimated by 9% and 13% respectively when not taking estimated root mass into account.

*Genetic diversity of landraces*
The origin of the wheat lines introduced by Spanish colonists to Mexico is unknown and their potential value as a genetic resource has gone largely unrecognized; though records of introduction date back to the early 16th Century (Skovmand et al., 2002). Given the dry climate in Mexico and the genetically diverse nature of landrace populations, there is good reason to believe that natural and human selection would have favoured drought-adaptive mechanisms. The screening of over 2000 Mexican landraces for yield under drought suggested considerable phenotypic diversity (Fig. 3) and DNA fingerprinting confirmed large genetic difference between landraces and checks as well as among landraces themselves (Fig. 4). Given the generally favourable agronomic and drought-adaptive characteristics of the selected lines, this is a very positive outcome, suggesting that such approaches can be employed to broaden the genetic base of modern wheat in terms of abiotic stress adaptation. To some extent these data confirm the value of the screening methodology employed, i.e. using economical hill plots.

Specific drought adaptive characteristics of the selected landraces were determined in these experiments (Table 2 and 3) and included ability to extract water from the deepest part of the soil profile. The best Mexican landrace (Pub94.15.1.12) in terms of water extraction from depth, extracted 8.5 mm more water between 60-120cm than the check line, which at a WUE of the check cultivar (3.7 g/m²/mm) is equivalent to an extra 30 g/m² of biomass (a 13% increase over the mean trial yield). A number of the selected landraces also showed high values of soluble stem carbohydrates (up to 26% of dry mass) shortly after anthesis. Selected landraces have already been employed in CIMMYT's drought crossing program and are providing initially promising results (Trethowan and Reynolds, 2005).

Genetic Resources. Research into the physiological basis of drought adaptation in crops is well established (Fischer and Turner, 1978; Blum, 1988; Loss and Siddique, 1994; Richards et al., 2002) and molecular technologies have added a new dimension to the research (Chaves et al., 2003). While some of the research has been applied to wheat improvement (Condon et al., 2002; Rebetzke et al., 2002; Richards et al., 2002), much has yet to be applied (Araus et al., 2002). While new molecular technologies offer powerful ways to identify and manipulate drought adaptive genes, applications are ultimately limited by the availability of suitable genetic resources in which novel allelic diversity can be utilized. Notwithstanding transgenes from alien taxa, novel trait expression must be identified within germplasm collections. However, a large number of drought-adaptive responses exist and it can be overwhelming for researchers to know which traits to prioritize given a lack of quantitative information. The main objective of comparing the lines in GEN-RES was to assess the theoretical value of the genetic diversity of a range of different traits in terms of yield improvement under drought. The 12 lines represented some of the broadest and at the same time most promising genetic resources available to CIMMYT's drought breeding program.

There are different ways of exploring how yield in a check variety would change if a trait could be manipulated to reach the level observed in a landrace, etc. A comprehensive approach is the use of a simulation model (Muchow and Sinclair, 2001; Dreccer et al., 2002). This tool is helpful because it produces a probabilistic outcome, attached to the different weather and hence stress patterns observed in a particularly region during a series of years. While we explore this avenue a rough quantitative assessment was made by identifying the highest expression of any trait amongst all lines of GEN-RES comparing the value of its expression with that of the check cultivar, and estimating what the theoretical yield would be if the trait were expressed at the same level in the check cultivar (Table 4). The best expression of soluble stem CHO at anthesis (22.5%) was used to calculate the
additional potential for remobilization of CHO to grain if expressed in the check, which showed a value of 16.9%. Assuming the check’s own value for biomass at anthesis, this would increase the availability of soluble stem CHO by 25 g/m².

Applying the best value of WUE (4.3 g/m²/mm expressed by Sokoll) to the check variety would theoretically achieve the largest gain in yield with an increase of 60 g/m² (assuming 220 mm of available water and the HI of the check). The best values for water extraction applied to the check would translate into a gain of approximately 20 g/m², assuming no additional net investment in root biomass, which is not implausible given the results presented here for the SYN-DER. The above estimates were calculated using the 3 year average values of trait expression for genotypes shown in Tables 2 and 3, thus giving relatively conservative estimates. The same calculations were performed for each year and the range of potential benefits in terms of yield gain are presented in Fig. 6 where a conceptual model developed previously for important trait groups was used as a frame of reference. The model and it’s theoretical basis are described elsewhere (Reynolds et al., 2005) but essentially defines four main groups of traits relating to: (I) Pre-anthesis growth: rapid ground cover to shade the soil from evaporation (Richards et al., 2002), and strong assimilation capacity between jointing and lag-phase to permit accumulation of stem carbohydrates (Blum, 1998). (II) Access to water as a result of root depth or intensity that would be indicated by a relatively cool canopy (Reynolds et al., 2005) or favourable expression of water relations traits (Blum et al., 1989). (III) Water use efficiency (WUE) of canopy growth as indicated by relatively higher biomass per mm of water extracted from the soil, transpiration efficiency of growth (TE = biomass per mm water transpired) indicated by C-isotope discrimination ($\Delta^{13}$C) of leaves (Condon et al., 2002, (IV) photo-protection including anti-oxidant systems (Niyogi, 1999; Havaux and Tardy, 1999), and anatomical traits such as leaf wax (Richards et al., 2002). Not all of the traits mentioned above were within the scope of this study, nonetheless the results for those that were, are summarized (Figure 6). However a number of the traits measured in this study cannot be extrapolated directly to yield gains.

For example, differences in early ground cover estimated using spectral reflectance (Babar et al., 2005) of which most of the genotypes showed superior values than the check, indicating a greater potential for early ground cover and water savings. Previous analysis using estimates of transpiration efficiency based on 13C analysis and final biomass with a larger selection of genotypes (including those represented in this trial) estimated that genetic effects on water losses due to evaporation from the soil could vary from 20-40% (Reynolds and Condon, 2005) indicating a substantial potential advantage associated with increased ground cover. Osmotic adjustment and carbon isotope discrimination were estimated also but the genetic variation did not indicate any significant advantage over the check line. Canopy temperature showed genetic effects associated with soil moisture extraction (Fig. 5) but cooler leaves may also be associated with increased photo-protection.

Conclusions

Exotic germplasm such those described appear to have considerable potential to improve drought-adaptive mechanisms in wheat. In this experimental environment at least, novel genetic sources could potentially contribute to increased water extraction from depth in the soil, accumulation of soluble stem carbohydrates, and water use efficiency. The degree to which these traits could be additive in terms of yield if combined in a single background will require further analysis.
Table 1. Above and below ground growth parameters for synthetic-derived wheat lines and recurrent parent lines under drought and irrigated conditions, averaged across two genetic backgrounds, NW Mexico, 2004 and 2005.

<table>
<thead>
<tr>
<th>Moisture level</th>
<th>Genotype</th>
<th>Grain Yield (g/m²)</th>
<th>Biomass above-ground (g/m²)</th>
<th>Harvest Index</th>
<th>Kernel weight (g)</th>
<th>DW roots 0-30cm (g/m²)</th>
<th>DW roots 0-120cm (g/m²)</th>
<th>Root:shoot ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Irrigated</td>
<td>SYN-DER</td>
<td>530</td>
<td>1350</td>
<td>0.396</td>
<td>38.6</td>
<td>52.6</td>
<td>96.5</td>
<td>0.071</td>
</tr>
<tr>
<td></td>
<td>REC-PAR</td>
<td>450</td>
<td>1040</td>
<td>0.444</td>
<td>32.3</td>
<td>40.7</td>
<td>85.0</td>
<td>0.082</td>
</tr>
<tr>
<td>Drought</td>
<td>SYN-DER</td>
<td>335</td>
<td>1275</td>
<td>0.270</td>
<td>27.6</td>
<td>43.6</td>
<td>117.2</td>
<td>0.092</td>
</tr>
<tr>
<td></td>
<td>REC-PAR</td>
<td>270</td>
<td>752</td>
<td>0.364</td>
<td>21.3</td>
<td>75.1</td>
<td>128.9</td>
<td>0.171</td>
</tr>
<tr>
<td>P (SYN v REC)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>*</td>
</tr>
<tr>
<td>P (moisture)</td>
<td></td>
<td>**</td>
<td>*</td>
<td>**</td>
<td>*</td>
<td>**</td>
<td>**</td>
<td></td>
</tr>
<tr>
<td>P (interaction)</td>
<td></td>
<td>ns</td>
<td>*</td>
<td>ns</td>
<td>ns</td>
<td>**</td>
<td>*</td>
<td></td>
</tr>
<tr>
<td>LSD (p&lt;0.05)</td>
<td></td>
<td>36.5</td>
<td>138</td>
<td>0.048</td>
<td>2.5</td>
<td>11.9</td>
<td>16.4</td>
<td>0.010</td>
</tr>
</tbody>
</table>
Table 2. Yield components and pre-anthesis growth parameters for wheat genetic resources selected for drought adaptation, average values from 3 growth cycles under moisture stress, (except for yield potential *) NW Mexico

<table>
<thead>
<tr>
<th>Cross</th>
<th>Yield Potential *</th>
<th>Yield</th>
<th>Biomass above-ground</th>
<th>Kernel Weight</th>
<th>NDVI at Zadoks 30</th>
<th>Stem CHO anthesis +7d</th>
<th>Stem CHO Maturity</th>
</tr>
</thead>
<tbody>
<tr>
<td>WEEBILLI1.1 (Check)</td>
<td>793</td>
<td>309</td>
<td>757</td>
<td>38.6</td>
<td>0.707</td>
<td>19.1</td>
<td>2.2</td>
</tr>
<tr>
<td>MES (genetic resource)</td>
<td>752</td>
<td>303</td>
<td>945</td>
<td>25.9</td>
<td>0.754</td>
<td>4.9</td>
<td>1.6</td>
</tr>
<tr>
<td>SOKOLL synthetic derived (SYN)</td>
<td>715</td>
<td>316</td>
<td>884</td>
<td>39.3</td>
<td>0.757</td>
<td>15.9</td>
<td>1.8</td>
</tr>
<tr>
<td>MEX94.2.19 (landrace)</td>
<td>658</td>
<td>248</td>
<td>656</td>
<td>32.6</td>
<td>0.778</td>
<td>15.7</td>
<td>2.4</td>
</tr>
<tr>
<td>CROC_UAE.SQUARROSA (224)APAATA (SYN)</td>
<td>647</td>
<td>227</td>
<td>609</td>
<td>34.4</td>
<td>0.731</td>
<td>18.9</td>
<td>2.0</td>
</tr>
<tr>
<td>MEX94.15.34 (landrace)</td>
<td>584</td>
<td>164</td>
<td>378</td>
<td>37.4</td>
<td>0.798</td>
<td>19.9</td>
<td>2.3</td>
</tr>
<tr>
<td>MEX94.2.18 (landrace)</td>
<td>563</td>
<td>202</td>
<td>640</td>
<td>38.0</td>
<td>0.768</td>
<td>15.2</td>
<td>1.8</td>
</tr>
<tr>
<td>MEX94.12.2.39 (landrace)</td>
<td>516</td>
<td>218</td>
<td>519</td>
<td>38.8</td>
<td>0.749</td>
<td>24.1</td>
<td>3.1</td>
</tr>
<tr>
<td>PUB94.16.24 (landrace)</td>
<td>486</td>
<td>212</td>
<td>614</td>
<td>39.7</td>
<td>0.790</td>
<td>23.1</td>
<td>4.1</td>
</tr>
<tr>
<td>PUB94.15.1.12. (landrace)</td>
<td>427</td>
<td>224</td>
<td>569</td>
<td>41.0</td>
<td>0.756</td>
<td>25.8</td>
<td>3.6</td>
</tr>
<tr>
<td>MEX94.27.1.20 (landrace)</td>
<td>418</td>
<td>213</td>
<td>477</td>
<td>39.3</td>
<td>0.698</td>
<td>26.1</td>
<td>3.6</td>
</tr>
<tr>
<td>OAX93.24.35 (landrace)</td>
<td>200</td>
<td>182</td>
<td>501</td>
<td>34.2</td>
<td>0.769</td>
<td>20.2</td>
<td>2.2</td>
</tr>
<tr>
<td><strong>Mean</strong></td>
<td><strong>563</strong></td>
<td><strong>235</strong></td>
<td><strong>629</strong></td>
<td><strong>36.6</strong></td>
<td><strong>0.755</strong></td>
<td><strong>19.1</strong></td>
<td><strong>2.55</strong></td>
</tr>
<tr>
<td>SLD(5%)</td>
<td>51.8</td>
<td>38.0</td>
<td>133</td>
<td>2.34</td>
<td>0.072</td>
<td>7.36</td>
<td>1.91</td>
</tr>
</tbody>
</table>

*Yield potential based on a single cycle with irrigation
Table 3. Water use efficiency, water uptake parameters, for wheat genetic resources selected for drought adaptation, average values from 3 growth cycles under moisture stress, NW Mexico, osmotic adjustment also estimated in controlled environment

<table>
<thead>
<tr>
<th>Cross</th>
<th>Water use efficiency</th>
<th>Residual H2O 30-120 cm</th>
<th>Residual H2O 30-60 cm</th>
<th>Residual H2O 60-90 cm</th>
<th>Residual H2O 90-120 cm</th>
<th>Δ¹³C</th>
<th>Osmotic Adj field</th>
<th>Osmotic Adj controlled</th>
</tr>
</thead>
<tbody>
<tr>
<td>WEEBILL1 (Check)</td>
<td>3.7</td>
<td>29.2</td>
<td>5.2</td>
<td>10.7</td>
<td>13.4</td>
<td>22.10</td>
<td>-0.462</td>
<td>-0.284</td>
</tr>
<tr>
<td>MEX (genetic resource)</td>
<td>4.1</td>
<td>47.6</td>
<td>18.0</td>
<td>15.1</td>
<td>14.6</td>
<td>22.15</td>
<td>-0.238</td>
<td>-0.166</td>
</tr>
<tr>
<td>SOKOLL synthetic derived (SYN)</td>
<td>4.3</td>
<td>25.1</td>
<td>6.7</td>
<td>7.5</td>
<td>10.9</td>
<td>22.26</td>
<td>-0.553</td>
<td>-0.134</td>
</tr>
<tr>
<td>MEX94.2.19 (landrace)</td>
<td>3.4</td>
<td>29.0</td>
<td>6.5</td>
<td>10.8</td>
<td>11.8</td>
<td>21.94</td>
<td>-0.491</td>
<td>-0.029</td>
</tr>
<tr>
<td>CROC_I/AE.SQUARROSA/OPTA (SYN)</td>
<td>3.0</td>
<td>33.3</td>
<td>9.2</td>
<td>11.0</td>
<td>13.1</td>
<td>22.36</td>
<td>-0.556</td>
<td>-0.189</td>
</tr>
<tr>
<td>MEX94.15.34 (landrace)</td>
<td>2.1</td>
<td>42.2</td>
<td>10.9</td>
<td>15.7</td>
<td>15.6</td>
<td>22.05</td>
<td>-0.470</td>
<td>-0.089</td>
</tr>
<tr>
<td>MEX94.2.18 (landrace)</td>
<td>3.3</td>
<td>32.3</td>
<td>6.4</td>
<td>11.5</td>
<td>14.4</td>
<td>22.10</td>
<td>-0.424</td>
<td>-0.083</td>
</tr>
<tr>
<td>MEX94.12.29.39 (landrace)</td>
<td>2.7</td>
<td>23.6</td>
<td>7.4</td>
<td>6.7</td>
<td>9.5</td>
<td>23.00</td>
<td>-0.525</td>
<td>-0.192</td>
</tr>
<tr>
<td>PUB94.16.24 (landrace)</td>
<td>3.1</td>
<td>25.7</td>
<td>9.2</td>
<td>7.8</td>
<td>8.7</td>
<td>23.10</td>
<td>-0.479</td>
<td>-0.183</td>
</tr>
<tr>
<td>PUB94.15.1.12 (landrace)</td>
<td>2.8</td>
<td>24.2</td>
<td>8.7</td>
<td>7.9</td>
<td>7.7</td>
<td>22.79</td>
<td>-0.451</td>
<td>-0.192</td>
</tr>
<tr>
<td>MEX94.27.1.20 (landrace)</td>
<td>2.5</td>
<td>22.6</td>
<td>4.6</td>
<td>7.0</td>
<td>11.0</td>
<td>23.21</td>
<td>-0.422</td>
<td>-0.055</td>
</tr>
<tr>
<td>OAX93.24.35 (landrace)</td>
<td>2.7</td>
<td>28.0</td>
<td>8.9</td>
<td>8.3</td>
<td>10.7</td>
<td>22.68</td>
<td>-0.514</td>
<td>-0.048</td>
</tr>
<tr>
<td>Mean</td>
<td>3.15</td>
<td>30.2</td>
<td>8.5</td>
<td>10.0</td>
<td>11.8</td>
<td>22.48</td>
<td>-0.5</td>
<td></td>
</tr>
<tr>
<td>SLD(5%)</td>
<td>0.59</td>
<td>6.7</td>
<td>2.78</td>
<td>2.87</td>
<td>2.61</td>
<td>0.384</td>
<td>-0.236</td>
<td>-0.196</td>
</tr>
</tbody>
</table>
Table 4. Theoretical potential yield gains from combining the best trait expression among 11 elite wheat genetic resource accessions into the check cultivar, Weebil-1, using average values of trait expression across three drought cycles, NW Mexico.

<table>
<thead>
<tr>
<th></th>
<th>CHO (ant-mat)</th>
<th>WUE</th>
<th>---WATER</th>
<th>AVAILABILITY</th>
<th>--</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>%</td>
<td>g/m²/mm</td>
<td>30-60 cm</td>
<td>60-90 cm</td>
<td>90-120 cm</td>
<td></td>
</tr>
<tr>
<td>Check (Weebil-1)</td>
<td>16.9</td>
<td>3.7</td>
<td>5.2</td>
<td>10.7</td>
<td>13.4</td>
<td></td>
</tr>
<tr>
<td>Best trait expression</td>
<td>22.5</td>
<td>4.3</td>
<td>4.6</td>
<td>6.7</td>
<td>7.7</td>
<td></td>
</tr>
<tr>
<td>Difference</td>
<td>5.6</td>
<td>0.63</td>
<td>ns</td>
<td>4.0</td>
<td>5.7</td>
<td></td>
</tr>
<tr>
<td>Potential yield gain (g/m²)</td>
<td>25</td>
<td>60</td>
<td>0</td>
<td>7.5</td>
<td>10.5</td>
<td></td>
</tr>
</tbody>
</table>

Assumptions
- no CHO resired
- 220mm H₂O, HI of check
- best WUE, HI of check, no extra root growth
Fig. 1. Average difference (%) between two synthetic derived wheat lines and their recurrent parents for grain yield, total biomass (above + below ground), root:shoot ratio, and root dry weight in the top 30 cm of soil, NW Mexico, averaged across 2004 and 2005 spring wheat cycles.
Fig. 2. Average difference between two synthetic derived (SYN) wheat lines and their recurrent parents (REC) for residual moisture in different soil profiles, shortly after anthesis (ant) and after physiological maturity (mat), averaged across 2004 and 2005 spring wheat cycles. (Standard error of differences between means within depth profiles increased sequentially with depth as follows: 0.30, 0.61, 0.79, 2.1mm)
Fig. 3. Distribution within yield categories for 2077 Mexican landraces grown as hill plots with 150mm of available water (applied at sowing), NW Mexico, 2000.
Fig. 4. Dendrogram showing relative genetic distances among hexaploid wheat genotypes, namely 7 drought adapted Mexican landraces, a drought adapted synthetic-derived cultivar (Sokoll), a high yield potential check with drought sensitivity (W15 91) and an elite drought adapted check (Weevil 1) based on DNA fingerprinting with 50 single sequence repeats.
Fig. 5. Association between canopy temperature measured at high vapour pressure deficit in the field during grain-filling and residual soil moisture measured on genotypes after physiological maturity, NW Mexico, 2002.
Fig. 6. Potential genetic gains associated with over-expression of drought-adaptive traits
theoretically expressed in an elite check background, based on empirical data from controlled field
studies involving 11 elite genetic resource genotypes and the check cultivar. Potential genetic gains
are expressed for the range of differences in trait expression (i.e. comparing the check with the best
are grouped according to a conceptual model for drought adaptive traits (Reynolds et al., 2005).
Background

Durum Wheat represents approximately 10% of the wheat planted and produced worldwide. Its importance is greater than this statistic may indicate as it is concentrated in relatively small areas where it plays a critical role in the food security of urban populations and the livelihoods of rural communities. Our main target countries are located in Central Asia and North Africa-Middle East, drier parts of Eastern India, and finally, the irrigated areas of Northern Mexico. The main "Mega-environments" we deal with are the irrigated (fully to partially) to the rainfed (relatively favorable to very erratic and scarce rainfall).

Most durum wheat growing countries have replaced the great majority of their landraces and local cultivars with modern, semi-dwarf, input-responsive types bred first at CIMMYT, then also at ICARDA and in many National Programs. As a result of semi-dwarf cultivars adoption, average national yields and production have increased significantly in most of these countries. However, relatively very few cultivars are currently grown over wide areas across countries and continents owing to the proven stability of their performance in environments that are often highly variable and unpredictable. This obviously makes a large portion of the durum production in our target countries genetically vulnerable to diseases such as rusts and septoria but also prevents growers from responding to the increasingly strong demands for different or better industrial grain quality.

For improvements in disease resistance and quality attributes to be effectively adopted by farmers, they must be embedded in a genetic background that has the capability of performing well, in a stable manner, over a wide range of water availabilities and distributions. Hence, the critical need for addressing water productivity in our breeding program.

Overall strategy, issues addressed and current status of implementation

Water productivity was traditionally addressed at various levels, first through the improvement of yield potential per se (maximum performance under favorable conditions to take maximum advantage of water and other inputs when those are available), by identifying germplasm that combines drought tolerance (relatively good and stable performance under limited water availability, or a guarantee of a minimum in bad years) and responsiveness to improved water availability (stepping up its performance when conditions are relatively better). This strategy of seeking maximum "plasticity" in performance with regard to water availability remains essentially the one adopted in the current durum wheat breeding program at CIMMYT.

In addition to water utilization attributes, performance and stability in water-limited environments is substantially affected by early crop establishment attributes and, often unknowingly, by soil factors or pathogens (crown or root rots, nematodes) that can
affect root health and their capacity to make best use of soil water. The latter two issues have started to be addressed directly relatively recently.

During the last few years however, the effective implementation of this strategy was hampered by the need to address the widespread and very serious problem of leaf rust susceptibility in CIMMYT durum germplasm. This has limited its use in countries such as Morocco, and culminated, with the 2001 appearance of a new virulent race that defeated the resistance of all commercial cultivars grown in Northern Mexico (after 16 years of durable resistance) as well as most CIMMYT elite material. While finally giving us the opportunity to select for leaf rust resistance in our main breeding program in Mexico, the identification, incorporation and accumulation of different genes for resistance to leaf rust into our material had to become our first concern and breeding objective, often at the expense of other objectives. After the 4th year of major emphasis on diversification for leaf rust resistance, we are finally again in a position to aggressively address water productivity issues at all the levels described above, while ensuring at the same time the improvement of critical industrial quality traits.

Recent results

"Elite" and parental material: This material consists of the advanced lines present in our breeding pipeline that have demonstrated acceptable resistance to leaf rust in Mexico and other locations. Overall, this material is characterized by a genetic yield potential (as measured by performance under most optimal conditions) somewhat lower than that achieved in our pre-leaf rust elite material. Since this material should logically be considered as the primary parental pool in our crossing program, we have invested substantial resources to characterize it in terms of its performance under limited water availability (reduced irrigation) and its quality attributes. Results obtained from replicated yield trials sown over the last two seasons under various irrigation regimes (full or reduced) and methods (standard gravity, central pivot or drip) indicated that 25 out of the 86 new elite lines tested had the same or higher yield potential under full irrigation than the local commercial check, Jupare C2001 (the first leaf rust resistant cultivar released for Northern Mexico after the leaf rust epidemics). At the same time, they showed similar or better performance under reduced irrigation. Of those 25 relatively superior lines, 10 demonstrated industrial quality attributes (gluten strength and yellow color) ranging from slightly to substantially better than those of the commercial check.

New leaf-rust resistant advanced material: This material consists of advanced progenies from crosses made after the appearance of the leaf rust in Mexico. These crosses were planned either to transfer effective resistance genes into our highest yielding but now susceptible elite backgrounds or to combine different sources of resistance with the hope of accumulating resistance genes in the progenies. In all crosses both performance under reduced irrigation (when information was available) and quality attributes were considered in parent selection. Two groups of leaf rust resistant lines are currently being tested in the program, both consisting of lines that have shown over the past 1-2 years a yield potential under full irrigation and a quality profile at least similar but most often better than the commercial local check. The first group includes 448 lines tested in 2004 in non-replicated preliminary yield trials and in 2005 in replicated yield trials. The second group includes 763 newer lines tested in
non-replicated yield trials for the first time in 2005. Now that leaf rust (as well as yellow rust) resistance has been confirmed over several seasons, and yield potential under full irrigation as well as acceptability for quality have been reasonably ensured, we are testing all these 1211 lines (representing 674 different crosses) in the current season under both fully irrigated and reduced irrigation conditions. This allows us to start addressing on a wide scale issues of water productivity in our new generation germplasm.

**Newest material tested for the first time:** This material, also bred to combine various leaf rust resistance sources/genes, includes 3024 lines currently planted in non-replicated, preliminary yield trials under full irrigation for an initial evaluation of yield potential and quality attributes. For the first time in the history of our program, a large set of advanced material entered the yield testing phase after being selected (in small plots) under high-residue, zero-till conditions. This allowed us to implement a strong selection pressure for aggressive and rapid stand establishment or stand recovery, attributes critical for better use of available water in dry environments. Given the large number of lines at this stage of the breeding program, it is not feasible to test under more than a single water regime; in addition, we need to first ensure adequate yield potential and quality profile before investing in large scale testing under different water regimes.

**Addressing root health issues, current status and future prospects**

Critical to better utilization of available water in rainfed conditions, root health is determined by several interacting factor and addressing it routinely in a breeding program is not straightforward. It is therefore being tackled using several approaches, some yet to be proven effective in durum wheat:

**Generalized selection under zero-till conditions:** As mentioned earlier, we have started to implement, in the pre-yield testing phase (F₅ generation), preferential selection of more aggressive stand establishers by planting our segregating bulks under high residue and zero-till conditions. This practice will be generalized to earlier segregating material, starting with the next summer cycle in the F₃ generation and next year in the F₂. By doing so, we are also hoping to exert a greater selection pressure for improved generic (not specific to any particular pathogen) root health at an early enough stage to obtain a genotypic response to this selection pressure.

**Tolerance to nematodes:** As useful molecular markers linked to the gene conferring improved tolerance to cereal cyst or root lesion nematodes become available in bread wheat, a subset of 3 could be readily transferred to durum wheat. Rust resistant durum wheat types (late segregating lines) are now under final selection in Mexico and upon confirmation of the markers’ presence, lines will be evaluated for tolerance to nematodes by Julie Nicol, our nematologist based in Turkey. If effective field tolerance to relevant nematode populations is demonstrated to be associated with the markers’ presence in durum as it is in bread wheat, then the approach will be generalized in our program in Mexico, at least on the most strategically important populations.

**Tolerance to crown and root rots:** Addressing tolerance to these pathogens, to which durum wheat is particularly sensitive, remains a major challenge given the practical
difficulties in testing for tolerance and the lack of availability of reliable molecular markers that could be used in durum wheat. Sources of resistance exist in bread wheat but resources need to be mobilized to also identify usable genetic variability for tolerance to these pathogens in durum or other wild tetraploid wheats. A practical selection scheme is needed to transfer such tolerance, wherever it comes from, to elite durum backgrounds.

TRITICALE BREEDING
(10% of financial and human resources)

Background

Triticale is grown on over 3.6 million hectares worldwide. About 1.2 million ha are sown to spring grain types which are mostly CIMMYT derived. Given the lack of adoption of triticale as a food grain in developing countries, more than 5 years ago CIMMYT changed its vision for triticale, considering it and promoting it for what it is best suited, that is, as a low-production cost feed or forage option in systems where integration of livestock is important.

However, upon recommendation of the last CCER two years ago, the triticale program was reduced to a level that could be sustained exclusively through the special project funding it could attract (approximately US$ 46,000 annually). The last EPMR made the same recommendation last year, but nothing had to be changed since it had already been implemented.

This funding level ensured the continued distribution of a small set of lines in our international nurseries system and allowed us to keep a small, but relatively complete breeding effort.

Main problem addressed during the last 3 years

Similarly to durum wheat, but to a much greater extent, our triticale breeding program was challenged by the appearance of a new race of yellow rust in the Mexican highlands, to which more than 85% of our elite and segregating material became highly susceptible. Most of the CIMMYT-derived cultivars released worldwide turned out to also be susceptible to this race, which, fortunately has not yet been reported outside Mexico or Ecuador. Consequently, our main objective during the last years was to identify and distribute, as rapidly as possible and often at the expense of normal yield testing procedures, as much resistant germplasm as possible. Our second objective was to produce new populations representing a much wider genetic variability for yellow rust resistance. Very few sources were found in the most advanced germplasm so we had to make use of agronomically non-adapted genetic resources including very old primary triticales. Because these resources are agronomically so unsuitable and have many sterility and chromosomal instability problems, very few lines made it through the selection process. In fact, about 20% of the $F_6$ lines planted this year in Obregon (for evaluation in yield trials next year) were derived from crosses involving primary triticales. We are hoping that, starting next year, the triticale program could return to focusing in a critical fashion on identifying genotypes with improved water productivity,
among the new set of advanced lines with a wide genetic basis for resistance to yellow rust. This would follow a similar strategy to that described for durum wheat.

**Results for water productivity in current set of “elite material”**

While the genetic basis for yellow rust resistance was amplified as described above, we concentrated our testing efforts on the few resistant elite lines that we could select after the appearance of the rust in 2002. For the last 2 years we have evaluated 90 lines for yield potential under full irrigation and performance under reduced irrigation. Over the 2 seasons, 10 of those exhibited performance equal or better than the local commercial check under both water regimes.

**RESEARCH PROJECTS**

**Evaluation of water use efficiency in new elite durum material**: This self-funded project is designed to provide information on genotype x water availability interaction, both for yield and quality, in new leaf rust resistant elite material extensively used as parents in our crossing program. Preliminary results were briefly mentioned in the “Recent results” section of this report. A second year of data is being collected during the current season to provide a stronger data set and characterize with more reliability the water-use properties of this set of genotypes.

**Evaluation of adaptation to zero-till and genotype by tillage interaction**: Extensive information is available in terms of adaptation to zero-till and genotype x tillage interactions in bread wheat, but there is limited information for durum wheat and triticale, especially in the post leaf rust/yellow rust germplasm. This self-funded study is in its second year and should provide information to address, through breeding, enhanced adaptation to conservation agriculture practices, which in themselves represent one effective way to save water.

**Field evaluation of molecular response to water stress of a dehydration induced gene in durum wheat and Triticale**: This is a collaborative project between our program and the laboratory of Dr. Patrizia Galeffi of ENEA-Rome (funds provided to cover operational costs). Dr. Galeffi’s team has identified and molecularly characterized a durum wheat analogue of the Dreb genes (dehydration responsive), designated as TdRF1. The expression of this gene was followed molecularly by quantifying its gene products upon dehydration in greenhouse grown plants of drought tolerant durum cultivars from CIMMYT and Italy. A Triticale line and cultivar specific expression patterns were identified. In order to assess whether or not these results have some relevance to field drought tolerance, we are involved in studying the gene expression of the same material (and more) but in field grown plants, comparing patterns under full irrigation and drought in Obregon.

**Identification of genomic regions for yield, water-use efficiency and nitrogen use efficiency in durum wheat**: This is a fully funded project in collaboration with PSB-DISTA-Italy and ICARDA. It involves a very extensive and in-depth field evaluation (agronomic, physiological and nutritional) of a diversified collection of 187 durum lines from the Mediterranean basin and CIMMYT under full irrigation, reduced irrigation and
low nitrogen conditions in Obregon, 2 dryland sites in Italy and 2 others in Syria. In addition, an in-depth molecular characterization is being conducted in Italy of the same germplasm to identify (through association mapping) genomic regions or QTLs for yield, water-use and nitrogen-use efficiency in durum wheat. From the CIMMYT side, this is a collaborative effort between our program, Matthew Reynolds, Ivan Ortiz-Monasterio and Jose Crossa.

**Study of the inheritance and genetic variability of yellow rust resistance in Triticale:** Six sources of resistance were crossed to two susceptible lines and the inheritance was studied in F₃ families indicating in a preliminary fashion that, in most cases, the resistance is not monogenic but involves several genes, including putatively minor genes. In addition, resistant lines were inter-crossed to each other and preliminary results indicate that different genes are possibly present in the different sources suggesting the availability of a wider genetic variability than suspected. Resistant x susceptible populations are being advanced and F₆ will be available this coming summer cycle to confirm inheritance and serve as mapping populations, to identify markers linked to the different yellow rust resistance genes. If markers are identified, this could have an impact beyond Triticale and could be used to transfer novel genes to bread wheat. This project has so far been conducted using the triticale program self-generated special project funds.

**NETWORKING & KEY ALLIANCES**

**Spain:** The Spanish National Program as well as Agrovegetal (a public-private venture) are certainly the most critical alliances we have for durum wheat and triticale (Agrovegetal) breeding as they represent the majority of our funding. Germplasm provided as part of our agreement with these key allies is thoroughly and reliably tested and the results are provided back to us. As a result we receive valuable and reliable information on our material's performance in rainfed conditions ranging from high rainfall to severe drought, on the effectiveness of resistance to rusts and septoria and finally on the quality acceptability of the lines tested there.

**Mexico:** Historically, CIMMYT’s alliance with the growers’ organization (Patronato) of Northern Mexico was critical for our success in Mexico and abroad as it provided in kind and financial support either directly or through various state foundations (Fundaciones) to all field activities conducted in Mexico. Our other key ally in Mexico is the National Program or INIFAP with whom we have worked in tight collaboration. Since durum wheat is the most important crop in Northern Mexico, it is critical for our program to take every measure to enhance this three-way collaboration. The best and most dramatic example of achievement of this three-way collaboration was the accelerated release and seed production of the leaf rust resistant cultivar Jupare C2001, barely 18 months after leaf rust was first reported. We are now trying to contribute as much as we can to the adoption of newer cultivars with different resistance genes and a much better quality than Jupare C2001. With regards to triticale, we are heavily involved in the promotion and seed production of the newly released cultivar, Pollmer TCL2003, with our collaborators from Patronato and INIFAP and the main market provider, the association of pig producers of Sonora, which has been instrumental in the support of triticale. Additional networking (funded through state foundations) is being conducted for triticale with the states of Mexico and Guanajuato.
Morocco: Morocco is an essential partner for testing the effectiveness of our leaf rust resistant new germplasm, as it is a hot spot where older CIMMYT germplasm was under-used because of susceptibility to leaf rust, and for addressing Hessian fly resistance issues. New leaf rust resistant material, which has been genetically characterized, is currently being tested and should provide us with strategic information on the effectiveness of our breeding for resistance to this disease. With regards to Hessian fly, they have developed the first resistant cultivars and we are collaborating to introduce this Morocco-bred resistance into leaf rust resistant, higher yielding and better quality backgrounds.

Tunisia: This country is a primary hot spot for septoria on durum wheat. Historically many lines showing good resistance in Mexico turn out to be susceptible in Tunisia. Through a visit last year and effective information and germplasm exchange, we were able to identify a few CIMMYT lines that demonstrated good resistance both in Mexico and Tunisia. We are now in a position to effectively address septoria resistance in our crossing program in a manner that is relevant to the problem in North Africa.

USA: We have established contact with a private company, WestBred, which has a long tradition of developing premium quality cultivars, recognized as such by the most stringent pasta makers around the world. We were able to access their material and use it in crosses to improve the quality attributes of our material.

Australia: We have established contact with one of the durum programs in Australia to test their material for leaf rust resistance under our conditions. This allows us access to their material and has laid the basis for potential future collaborative projects. Regular exchange of germplasm and information is also occurring for triticale.

Canada: Historically, Canada has been a major partner with CIMMYT’s triticale program. We are continuing this collaboration, through regular germplasm and information exchange. Some limited funds were provided to us to support triticale activities and collaborative projects are being considered.

ICARDA-CIMMYT Alliance: This newly revived alliance is critical for durum wheat given the importance of this crop in CWANA. As the technical framework of this alliance is defined in the near future, we are expecting and welcoming the merging of research and networking efforts from the two institutions in some key areas (breeding for drought tolerance, rust, septoria and Hessian fly resistance, for example) for the benefit of the National Programs in the region.

MAJOR PROBLEMS & EMERGING CONCERNS

In terms of technical issues, we have already mentioned the challenge ahead of us to address the problem of crown and root rots in durum wheat. Technically, there is no easy solution (e.g., reliable molecular markers, availability of reliable and inexpensive selection methods) to this problem and substantial resources should be sought and allocated to a collaborative effort between our breeding program, the root disease program in Turkey headed by Julie Nicol, key allies with extensive experience in the area and key National Programs.

In terms of research management issues, the durum program, as most programs at CIMMYT, is funded almost exclusively through special project funds which were, until recently, sufficient to maintain a critical size and viable global program. However, with the sudden implementation of a “full cost recovery” policy and the resulting extreme chargeback pressure for experimental stations and laboratory use, computer and
vehicle use, and with the transfer of most Nationally Recruited Staff salaries and benefits to special project funds, one can only question our ability to maintain viable programs in the medium to long term at the current level of funding. For this "full cost recovery" model to be viable - and for our programs to survive it - substantial new funding needs to be raised urgently and allocated directly to research activities and research infrastructure maintenance.

By far, this is the most serious concern and preoccupation for all scientists and NRS alike and it has started not only to affect the morale of all, but also the productivity and effectiveness of the interactions between colleagues who are now increasingly engaged in a service provider/service consumer relationship rather than in a collaborative one, for the benefit of all.
Report on High Latitude Wheat activities by CIMMYT in Northern Kazakhstan.

The area of high latitude spring wheat production covers Northern Kazakhstan and Western Siberia of the Russian Federation, with a total area of close to 20 million hectares. The environment represents dryland with a fallow-wheat production system and precipitation ranging from 250 to 450 mm/yr. Spring bread wheat remains the dominant crop in the region and the major constraints are drought and diseases (leaf rust, Septoria, tan spot and others). The average yield is 1-1.5 t/ha. This area has a relatively limited cultivation history: the whole region of virgin lands was brought to cultivation 50 years ago to satisfy the growing demand of the population for grain. However, over the course of this short history substantial damage was done to the soil fertility due to excessive cultivation especially in fallow seasons. CIMMYT started systematic work in the region with the focus on Kazakhstan (the Russian Federation is outside the mandate) in 1997 when the first bilateral workshop took place. In 1999 CIMMYT established an office in Almaty Kazakhstan and from 2000 more diverse and intensive activities were initiated in Northern Kazakhstan. The initial workshop in 1997 and the follow up visits, traveling seminars and discussions resulted in the formulation of a research and co-operation agenda for the high latitude wheat of Northern Kazakhstan.

The main objective of CIMMYT’s co-operation with Kazakhstan in the high latitude wheat area is the development and promotion of a sustainable, diversified system of production based on conservation agriculture principles. There are two specific tasks:

1. Development and promotion of spring wheat varieties combining stable yield, drought tolerance and grain quality from the Kazakh gene pool with disease resistance and specifically leaf rust resistance from Mexican germplasm.
2. Development and promotion of conservation tillage practices to protect the soil from erosion and offer more economic options to producers.

The brief summary report below emphasizes CIMMYT activities in these two areas.

Kazakhstan-Siberia Network on Spring Wheat Improvement (KASIB).

The network was established to facilitate the germplasm exchange and communication among the breeders of Northern Kazakhstan and Western Siberia. Presently there are 18 breeding and/or research programs participating in the network. The network is united through a regional germplasm exchange nursery. In 2005, the KASIB Network developed further and entered into its sixth year.

The KASIB nursery methodology remained the same: replicated yield trials with 2-3 varieties/lines from each participating institution grown. In 2005, the 6th KASIB was formed both for bread and durum wheat. It is being tested for two years: in 2005 and 2006. The data from the 4th and the 5th KASIB (2003-04) was compiled, analyzed, published and distributed to all the co-operators. For the first time the grain quality was also analyzed and distributed to the co-operators. The micronutrient content was determined in the KASIB entries from seven sites. Two KASIB meetings were held in 2005: in July in East Kazakhstan and in August in Astana. The network is establishing its own multiplication and testing site near Astana. One private farm was used in 2005 for this purpose. The participants of KASIB are determined to continue co-operation in the future. A survey is being conducted among co-operators to evaluate the impact of
KASIB as well the future direction of its development. However, it is obvious that the network contributed both to the germplasm exchange and diversification of the genetic base, as well as to communication among the scientists. The performance of the best lines spring wheat lines/varieties is presented in Appendix 1.

Shuttle breeding between Kazakhstan and CIMMYT-Mexico to incorporate resistance to diseases.
Shuttle breeding was established in 2000 to incorporate leaf rust resistance into germplasm adapted to conditions in Kazakhstan. Leaf rust in the seasons with slightly higher precipitation represents the single most dangerous pathogen accounting for the loss of up to 25-30% of yield in some years (eg. 2001, 2002 and 2005). The movement of the germplasm is presented in Appendix 2. There is a special area in Mexico where the shuttle germplasm destined for Kazakhstan is grown under artificial light to allow selection of day-length sensitive genotypes. The crossing program conducted in Mexico emphasizes Kazakh x Mexico crosses as well as top crosses with the relevant US and Canadian germplasm. CIMMYT Mexico has never targeted high latitude areas and the shuttle, which started relatively recently, presented a challenge for the breeders.

The shuttle breeding program reached its full potential in 2005 with almost 1000 entries coming annually to Kazakhstan and Siberia. The movement of germplasm continues in the same manner: in the first year the germplasm comes to the three quarantine nurseries in Kazakhstan and Siberia and then the best entries are selected to make the Kazakhstan Shuttle Breeding Nursery (KSBN) which is distributed to all co-operators. In 2005 the 3rd KSBN data was analyzed, published and distributed to co-operators. The 4th KSBN was distributed to co-operators in Kazakhstan and Siberia and the evaluation/selection was made. The entries from the quarantine nursery were selected to make the 5th KSBN for 2006. The adaptation of the germplasm gradually improves. Some of the lines selected previously have entered breeding nurseries in different breeding programs. The shuttle breeding program was discussed and evaluated with Dr. Richard Trethowan during the visit to Cuidad Obregon in March, 2005. A visit to Canada was made in August 2005 to see how the shuttle breeding program can be better integrated with Canadian institutions. A special shuttle breeding crossing block has been assembled and sent to Mexico for crosses. Co-operation with the Cereal Rust Laboratory in the University of Minnesota (Dr. J. Kolmer) and the Plant Breeding Institute at the University of Sydney (Dr. C. Wellings) has been established for the development of rust resistant germplasm. The data from the best shuttle germplasm is presented in Appendix 3.

Zero tillage for the wheat-dominated production system in Northern Kazakhstan.
The work on zero tillage in Northern Kazakhstan started in 2000 when Dr. Pat Wall (CIMMYT Dryland Agronomist) made his first visits. Although located outside the region, he guided and supervised this activity. So far the following main activities on zero tillage have been undertaken:

A) Establishment of 3-4 research sites in Northern Kazakhstan where multifactorial experiments have been conducted. The data from these sites are being utilized for the development of recommendations as well as for demonstration to the farmers.

B) Implementation of Kazakhstan-FAO-CIMMYT Project on zero tillage where the technology was introduced on four selected farms in different regions. The
project brought very important publicity to conservation agriculture and demonstrated the possibility of its utilization in real farms.

C) Implementation of GEF-Kazakhstan Dryland Management Project to convert abandoned land into pasture to contribute to carbon sequestration.

D) Numerous seminars, field days, publications, etc to promote conservation agriculture principles.

The work on zero tillage in 2005 continued in Northern Kazakhstan and the following major activities were undertaken jointly with Drs. P. Wall and Post Doctoral Fellow Akmal Akramkhanov:

- Consultation with the four farmers who introduced zero tillage in the framework of the FAO project and who continued in 2005.
- On-station and on-farm research with zero tillage in Karagandy, Karabalyk, Aktobe, Pavlodar and Ust-Kamenogorsk.
- Replacement of abandoned land with perennial grasses in the Dryland Management Project.
- Seminars, presentations and publications on zero tillage to promote it in the farming community and among the policy makers.

Conservation tillage is expanding in Northern Kazakhstan partly because of CIMMYT's efforts, as well as the need to replace farmers' existing machinery. In 2004 the MOA developed a program to introduce conservation agriculture on an area of 1.5 million hectares using subsidies for inputs and machinery as incentives. The MOA requests CIMMYT to assist in this program.

The data of the longest zero tillage experiment is presented in Appendix 4.

Capacity building, training, publications, communication and partnership.

Over the last 7-8 years substantial efforts have been made to improve the capacity of research partners in Northern Kazakhstan through provision of essential items for research and breeding as well as training and support for business trips. One of the highlights of co-operation in Northern Kazakhstan was the training of young scientists at CIMMYT headquarters in Mexico. Representatives of practically all the research institutes and stations from Northern Kazakhstan attended the six month wheat improvement course in Mexico. Now they represent the new young generation of English speaking scientists with a wide international experience.

CIMMYT has published a number of books and periodicals in Russian to provide new information to all wheat scientists in the region, as well as to share results. From 2005 a new regional journal has been established entitled “Agromeridian”.

One of the areas CIMMYT emphasizes is promotion of wider international collaboration and in this respect several international workshops, meetings, courses and conferences have been established. The most successful was the 1st Central Asian Wheat Conference conducted in 2003 in Almaty, Kazakhstan. It attracted 250 researchers from 25 countries and excellent presentations and discussions were held. The 2nd Central Asian Cereals Conference will take place in Kyrgyzstan in June 2006.

The partnerships established in the region are quite diverse. The main focus of co-operation and the partners are the following:
• KASIB Network and shuttle breeding: Winrock International, GTZ, Washington State University, Farmer’s Union of Kazakhstan; Cereals Disease Laboratory of USDA, University of Sydney, Catholic University of Lovain (Belgium), Semi-Arid Agricultural Research Station (Canada).
• Conservation agriculture in Northern Kazakhstan: Winrock International, GTZ, World Bank through the Dryland Management Project; Washington State University, Farmer’s Union of Kazakhstan, FAO.
### Appendix 1. The highest yielding and leaf rust resistant entries of the 4th and the 5th KASIB.

<table>
<thead>
<tr>
<th>Nursery</th>
<th>Entry #</th>
<th>Variety/line</th>
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#### Yield, t/ha

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#### Leaf rust, %

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<td>Chelyabinsk ARI</td>
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<td>10</td>
<td>13</td>
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Appendix 2. Germplasm movement in spring wheat shuttle breeding program between Kazakhstan and Mexico.

- Local varieties
- F4-F5 lines
- Advanced lines
- Advanced lines
- Crosses/selection
  - Mexico
  - Breeders:
  - Kazakhstan

200

200
Appendix 3. The list of highest yielding entries across 6 locations from the 3rd Kazakhstan Shuttle breeding nursery.

<table>
<thead>
<tr>
<th>Nursery</th>
<th># plot</th>
<th>Assessment</th>
<th>Selection history</th>
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<th># plot</th>
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<td>KAZAKHSTANSKAYA-15/2*PASTOR</td>
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<td>243</td>
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Appendix 4. Effect of fallow treatment of four-year wheat-fallow rotation on wheat productivity (x 100 kg)

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<td>South slope</td>
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<tr>
<td></td>
<td>1CAF*</td>
<td>2CAF</td>
<td>3CAF</td>
<td>1CAF</td>
<td>2CAF</td>
<td>3CAF</td>
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<tr>
<td>Without N fertilizer</td>
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<td>18.0</td>
<td>20.1</td>
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<td>13.3</td>
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* CAF – crop after fallow.
Winter Wheat Activities

Program Committee of the BoT
March 2006

Arne Hede

Targeted crosses for ME7-ME12.

All crosses are now made in Izmir (a spring wheat environment) as seed set from crosses, and survival of F1 plots is much higher in Izmir than in Eskisehir, where on a normal year up to 40% of the total number of F1 entries easily can be lost due to winter kill. A total of around 1200 crosses were planned with approximately 60% targeted for rainfed areas and 40% for irrigated areas, reflecting the increased emphasis on rainfed areas.

Of the 1200 crosses around 500 are simple crosses, and 700 top crosses. For all top crosses, the top cross parent is taken from a group of selected entries with good combining ability and grain yield, superior industrial quality and resistance to main diseases (especially yellow rust, YR). For simple crosses, the choice of parents is less strict but it is always marked if a top cross is needed for a particular combination due to weaknesses of one or both of the parents.

Good levels of quality has become of increased importance as most national programs will not release cultivars without adequate levels of quality. Through the assistance of Dr. Pena at the CIMMYT quality laboratory we get detailed analysis on both HMW and LMW subunits in our germplasm and planned crosses are designed in order to shift the frequency of desirable subunits in the winter wheat germplasm.

Segregating generations

During the 2004-05 crop cycle, segregating nurseries were planted at several locations in Turkey and at ICARDA headquarter in Aleppo, Syria. During the crop cycle various visits were made to make observations together with national program staff. Main locations for obtaining grain yield data are Ankara, Eskisehir and Konya. Data for YR are obtained from Ankara and Syria, LR from mainly Adapazari and Edime, Furthermore observation nurseries are planted in other locations like Erzurum (cold) and Diyarbakir (drought).

The breeding strategy implemented involves picking individual spikes in the F3 and F5. Since YR is a major constraint in winter wheat growing areas, a special focus is placed on selection for YR resistance and F3 populations are planted in Haymana (Ankara) under irrigated conditions and artificial inoculation for YR. The same F3 populations targeted for rainfed conditions are planted in Konya under rainfed conditions. Through this process we are able to select YR resistant spikes in order to secure PYT's with higher levels of YR resistance. However, due to irrigated conditions selection for drought resistance is difficult. By using both sets of data, we were able to select YR
resistant spikes from populations with superior performance under rainfed conditions in Konya.

This kind of approach including intensive utilization of the capacity of the Turkish national program to create high levels of YR epidemics, has resulted in IWWIP germplasm with high levels of resistance to YR. Figure 1 shows the maximum YR score from the evaluation of the 11th Facultative and Winter Wheat Observation Nursery (FAWWON) across 10 locations in Iran (5), Turkey, (1), Azerbaijan (1), Tajikistan (1), Syria (1) and China (1).

International Nurseries

Germplasm exchange and evaluation is facilitated through the yearly shipment of various international nurseries, to a number of collaborators around the world. These nurseries are being prepared in Konya during the spring so they can be shipped to cooperators in time for planting in the fall. The nurseries are evaluated for grain yield potential, and resistance to various abiotic and biotic diseases and quality. The data returned to IWWIP are utilized in the continuous breeding program. Germplasm selected by cooperators is either being utilized as parents in their breeding programs or as direct cultivar releases. In the near future the International Nursery data will be accessible through the Internet.

The following nurseries are being distributed from the IWWIP program;

FAWWON
The Facultative and Winter Wheat Observation Nursery (FAWWON) has served as the main vehicle for facilitating germplasm exchange among winter wheat programs. This nursery consists of lines developed by the IWWIP program and of cultivars submitted by National Programs, University Programs or Private Companies from countries in CWANA, Western and Eastern Europe, China, South America and the USA.

WON-IRR and WON-SA:
The Wheat Observation Nursery for Irrigated Areas and Wheat Observation Nursery for Semi-Arid Areas consist of lines developed by the IWWIP program. These lines have been selected based on performance in yield trials in Turkey and Syria and on their resistance to diseases, in particular to yellow rust and common bunt. The WON-IRR and WON-SA are targeted at wheat growing areas in Central and West Asia. The WON-IRR and WON-SA nurseries normally consist of between 100-125 entries with 15 gram per entry and are distributed to 40-50 cooperators.

EYT-IRR and EYT-RF:
The Elite Yield Trial for Irrigated Areas and the Elite Yield Trial for Rainfed Areas each consist of 25 entries with 3 Replications, with 160-180 gram per replication. The entries were selected from the previous WON-IRR and WON-SA respectively. The EYT-IRR and EYT-RF nurseries are distributed to 40-50 cooperators.

EURAWWYN, previously WWEERYT
The Eurasian Winter Wheat Yield Nursery (EURAWWYN, previously known as the Winter Wheat East European Yield Trial, WWEERYT)
Variety Releases

Since 1980, thirty two varieties from the IWWIP program have been released in CWANA, and alone in 2004 and 2005 eight varieties were released Azerbaijan (2), Kyrgyzstan (4) Turkey (1), and Turkmenistan (1) (see Table 1). Furthermore forty cultivars are presently included in registration trials in throughout the region. The area under these cultivars is still low, but seed multiplication is underway.

<table>
<thead>
<tr>
<th>Country</th>
<th>Registered</th>
<th>Reg. Trials</th>
</tr>
</thead>
<tbody>
<tr>
<td>Afghanistan</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>Armenia</td>
<td></td>
<td>7</td>
</tr>
<tr>
<td>Georgia</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Iran</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Kazakhstan</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Kyrgyzstan</td>
<td>4</td>
<td>9</td>
</tr>
<tr>
<td>Pakistan</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Tajikistan</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Turkey</td>
<td>15</td>
<td>5</td>
</tr>
<tr>
<td>Turkmenistan</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Uzbekistan</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>32</td>
<td>40</td>
</tr>
</tbody>
</table>

Table 1. IWWIP derived wheat cultivars released since 1980 in CWANA.

The winter wheat program draws heavily on the winter x spring crosses. A major contribution to the winter wheat program is made through the spring wheat lines developed in Mexico, which are crossed with winter wheats. Many of the most successful CIMMYT spring wheats were derived from winter x spring (WS) crosses. More than 75% of the IWWIP lines released or in registration trials are selected from crosses between winter and spring wheat lines and three way crosses (Winter/ Spring /Winter). As can be seen from Figure 2 these WSW derived cultivars are now making their way into registration trials throughout the CWANA region.
Development of winter wheat populations with Zn efficiency.

Crosses made during the 2002-03 cycle between advanced WW cultivars and a set of triticale and bread wheat substitution lines provided by Dr. Lukaschewski from Riverside University were backcrossed and advanced. These backcross populations have been planted in Zn-deficient soils in Konya during the 2005-06 crop cycle for observation for performance under Zn-deficient conditions and for selection of superior genotypes. Furthermore, samples have been sent to Dr. Ismail Cakmak from Sapanci University for analysis for Zn-efficiency.

Development of winter wheat populations with Zn efficiency and resistance to the root lesion nematode (*Pratylenchus thornei*).

*Pratylenchus thornei* has been identified to be widespread throughout West Asia where Zinc deficiency is also a common constraint. It has therefore been a high priority to try to combine resistance to *P. thornei* and high Zn efficiency in advanced breeding lines from the IWWIP program. A total of 72 F$_8$ entries were tested under greenhouse conditions for their resistance against *P. thornei*. All of these lines were sister lines from the cross between the *P. thornei* susceptible Turkish winter wheat line (338-K1-1//ANB/BUC) and the partially resistant Australian spring wheat line GS50A. Furthermore, the same lines have been screened for Zinc efficiency under greenhouse conditions by Professor Cakmak at Sabanci University and several of the entries have been found to have both a high level of *P. thornei* resistance and high levels of Zinc efficiency (Table 2). During the 2004-05 cycle these lines were also planted as yield trials under field conditions where their grain yield potential was confirmed.

<table>
<thead>
<tr>
<th>Cultivar/Line</th>
<th><em>P. thornei</em></th>
<th>Zn efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Per plant</td>
<td>S.E</td>
</tr>
<tr>
<td>338-K1-1//ANB/BUC/3/GS50A (56)</td>
<td>255.7</td>
<td>46.5</td>
</tr>
<tr>
<td>338-K1-1//ANB/BUC/3/GS50A (57)</td>
<td>336.4</td>
<td>55.6</td>
</tr>
<tr>
<td>338-K1-1//ANB/BUC/3/GS50A (58)</td>
<td>232.6</td>
<td>58.4</td>
</tr>
<tr>
<td>338-K1-1//ANB/BUC/3/GS50A (59)</td>
<td>200.6</td>
<td>33.2</td>
</tr>
<tr>
<td>338-K1-1//ANB/BUC</td>
<td>765.8</td>
<td>221.0</td>
</tr>
<tr>
<td>GS50A (donor parent)</td>
<td>492.3</td>
<td>115.5</td>
</tr>
<tr>
<td>GEREK (susc. Check)</td>
<td>962.0</td>
<td>222.6</td>
</tr>
<tr>
<td>ASLIM-TCL</td>
<td>4.13</td>
<td>69.9</td>
</tr>
<tr>
<td>BEZOSTAYA</td>
<td>3.63</td>
<td>67.2</td>
</tr>
<tr>
<td>KUNDURO-DW</td>
<td>1.38</td>
<td>26.9</td>
</tr>
</tbody>
</table>

Table 2. Combining resistance to *Pratylenchus thornei* and Zn efficiency in advanced winter wheat germplasm.

Development of winter wheat cultivars with high Zn grain concentration.

Through collaborative work with Professor Ismail Cakmak at Sapanci University, a set of *T. monococcum* and *T. diccoides* from the germplasm collection in Turkey and Israel has been screened for high Zn concentration. Four *T. diccoides* were identified with extra high concentrations. During the 2003-04 cycle these accessions were
crossed to several Turkish cultivars and backcrossed to the recurrent parent. In the coming years segregating generations from these crosses will be evaluated for high Zn concentration.

Development of Tan spot resistant WW populations

Due to the likely event of increased levels of Tan spot in farmer fields with an increased farmer practice of zero-tillage, introgressing tan spot resistance into WW has been initiated using Tan Spot resistant lines provided by Etienne Duveiller as the source.

Collaborative Turkey/UK study on the genetics of YR resistance in WW

In collaboration with a Turkish scientist Dr. Muge Sayar and Dr. Lesley Boyd from JIC in the UK a study has been initiated to look at the level of genetic diversity behind resistance to YR in WW cultivars and advanced lines from Turkey and Central Asia. Based on field testing, a set of 100 WW lines were submitted all showing resistance to YR under field conditions in Turkey. These included released Turkish cultivars and advanced lines, advanced lines from Central Asia and IWWIP material. The study includes seedling testing with 8 different YR pathogen isolates and NBS-AFLP profiling of selected germplasm. So far 78 polymorphic bands have been obtained using 7 primer/enzyme combinations and cluster analysis has been performed to look at diversity within and between the different germplasm groups (Figure 3).
FIGURE 1. Maximum YR scores across 10 locations in six countries in CWANA of 146 entries in the 11th FAWWON. Entries within each group of origin are sorted by ascending susceptibility.

FIGURE 2. Frequency of WxS, WxW and WxSxW crosses in IWWIP derived varieties registered since 1980, or lines presently in registration trials in CWANA.
Figure 3. Spider diagram showing diversity within and between different groups of winter wheat germplasm. Spider center for each group given as position of indicator of clock) Turkish cultivars (10), Turkish Genetic Resources (9:30), Turkish advanced lines (8:30), IWWIP lines (7:00), Central Asia (5:00) and European lines (2:00).
Wheat in Afghanistan

Introduction

Afghanistan is a land-locked country that lies between 29°40' and 38°40' northern latitude and 60°31' and 75°00' eastern longitude. Over most of the country, the climate is arid and semi-arid, with rainfall ranging from 100 mm to 400 mm per annum. Cold winters and hot summers contribute to the harsh climate found in many parts of the country. Accumulated winter snow from the high mountains sustains agriculture in the summer. The country has six distinct climatic regions, but most of the area is steppes. Most of the arable land falls under temperate ecologies, with a few lowland areas similar to subtropical ecologies.

The total area of the country is 652,000 km² (65,200,000 ha) but due to its steep topography or dry deserts only 7.6 million ha or about 11% of it is arable. The agricultural sector in Afghanistan previously contributed 53% of the GDP and employed two-thirds of the population. Before 1978, the irrigated area provided roughly 85% of all food and industrial crops. The area currently under annual crops is approximately 3.7 million ha.

The country's main crop is wheat, which occupies around 2 million ha or about 80% of the total cereal area. About 90% of all wheat is planted in the fall, two-thirds of this being spring habit (ideally sown November) and the rest equally divided between facultative and winter wheat, which is sown in October only in the north. The other 10% is spring planted. Bread wheat predominates in the country, with a little durum wheat grown in the northern area. Much of the wheat is irrigated; approximately three-quarters of production is estimated to come from irrigated lands.

The national annual wheat yield is around 2-4 million tons (see Appendix 1). The national average yield of wheat is a scant 1.5 t/ha, while the yield potential for irrigated wheat is 5 t/ha. The main constraints to wheat production for small-scale farmers are: a lack of improved adapted varieties; inefficient and ineffective production technologies; lack of quality agricultural chemicals, farm machinery and equipment; poor market infrastructure; and damaged irrigation systems.

It is expected that sustainable wheat improvement in production and productivity can assure food security and can contribute to a reduction in poverty and an improvement of livelihoods.

Dryland Wheat in Afghanistan

Drought is the major constraint in improving agricultural productivity and stability in the dry region of Afghanistan. Drought stress varies over time and space; it could be short, long, mild, or severe. Rainfall quantity, quality, and distribution are integral to the incidence of drought. Wheat and barely in Afghanistan are mainly grown in areas characterized by mild to severe drought with erratic rainfall and frequent dry spells.

The major problems of crop production, in dryland agriculture (rain fed) are drought, low water productivity, lack of appropriate technology and inefficient production practices. There is a clear need for more options on crop/resource management to be offered to
farmers in these areas with highly variable physical, ecological, social, and economic conditions.

Wheat productivity depends on the crop's development pattern and process physiology in response to its management and environment. High yields are associated with a positive interaction between genotype, management and environment but no one aspect dominates. Water and temperature influence the growth and yield response under field conditions.

In Afghanistan total precipitation is a better indicator for plant water relations rather than rainfall alone where winter snowfalls are common. Rainfall quantity, quality and distribution through the season are important in predicting crop season and wheat yield. Precipitation is subjected partially to water losses and water storage in the soil. Water losses occur due to run off, deep drainage and soil erosion. Soil water can partially be used by the crop while part is stored in the soil and cannot be extracted by crops. Increased yields can be attributed to improved water use efficiency (WUE). Other agronomic measures, such as an increasing ratio of transpiration to evaporation, contribute to yield increase. Thus there are achievable challenges to improve WUE in drier areas through technical, economic and political interventions. Here, some of the technical points are briefly discussed.

The management of drought and minimizing its effects are vital issues. Two important aspects are key in improving crop productivity in moisture-limited environments in Afghanistan. These are improving the productivity of the crop and the water.

1. Improving the genetic basis of productivity- wheat, barley, chickpeas and flax respond to water deficit reasonably well in Afghanistan. Thus by selecting and identifying superior improved varieties through conducting multi-location drought trials (MLDT), increased and more stable yields are expected. Work has already started on this by introducing drought nurseries and trials from CIMMYT which are tested in dry areas. Continued efforts are needed to identify suitable varieties.

2. Improving water productivity through agronomic practices- such as soil moisture conservation, crop management, weed control and plant protection measures.

Drought affects wheat growth during each phase of development, but how the response is controlled may well differ between phases in Afghanistan:

1. Early stage of growth- wheat sown into dry soil, or subjected to drought shortly after sowing, will face difficulty in stand establishment, thus emergence from a deeper sowing depth is a useful trait. At the later stage, drought affects tiller establishment and spike initiation which both affect grain yield.

2. Terminal floret formation and anthesis – this is the rapid growth of the development of the spike, involving important morphogenetic events in the growing florets, and the elongation of the upper internode. Drought during this period and during grain filling results in a small spike with dead, bleached spikelets.

3. Anthesis to maturity – grain number and grain size may be reduced by water deficit at this stage, with a consequent reduction in grain yield.
In drylands the wheat yield is reported to be about 1 t/ha in a normal year, with total crop failure in dry years. This indicates the severity of drought in dry years. This also suggests that efforts should be made to manage and minimize the effects of drought on crop yields in dry years by maintaining yield stability in dry years as well as yield potential in good years. Such technical interventions have proved successful in similar conditions. The local varieties may maintain some degree of drought tolerance/resistance but they are susceptible to rust which loses the yield potential in wet years.

Achievements, Contribution to Increased Production

Along with the provision of seed, we also encouraged farmers to use technologies such as quality treated seed, timely planting, appropriate seeding rate, water and nutrient management, and integrated weed and pest management, with little or no use of pesticides. Consequently, local farmers reacted positively to other new technologies and, "are pleased to have access to new varieties with better yields and other advantages, compared to their old varieties." Farmers using the new technology have reported yields of up to two to three times higher than their neighbors, as reported by the FAO and various NGOs. According to the yield data analyses reported by AKF, three kinds of wheat planted by farmers in the five districts of Baghlan province are outlined below in percentages.

1. The yield increase of new improved varieties in comparison to the improved varieties of farmer's seed is 25%.

2. The yield increase of improved varieties to local varieties is 56%.
   - Average yield of improved wheat: 4.79 t/ha
   - Average yield of farmer-improved wheat: 3.58 t/ha
   - Average yield of local varieties: 2.65 t/ha

Developing and adapting appropriate technologies in wheat-based production systems has shown a significant increase in productivity. It can be predicted that if planted and managed correctly, the high yielding varieties (HYV) SOLH-02, Lalmi1, Lalmi2, Ghori, Dayma and many others in the pipeline for release should substantially boost wheat production in Afghanistan in the coming years.

Approaches to Increased Wheat Production

The overall aim of agricultural development oriented towards food security is to achieve a sustained increase in wheat production and productivity in Afghanistan through research, training, and technical interactions. This will be achieved via the following specific objectives:

A. Research, training and networking

1) Identification of promising new wheat lines/varieties through testing of improved germplasm

CIMMYT has involved NARS and other partners in a process that uses nurseries and yield trials from the relevant breeding programs of CIMMYT, ICARDA, and neighboring countries, in the recently rehabilitated research stations of MAAHF in key locations
around the country. The key output for this objective is the identification of promising suitable new materials for Afghanistan and a better understanding of G x E interactions, leading to better matching of varieties to production environments and systems.

In addition to international wheat trials and nurseries, trials were planted this fall at Darul Aman (DA) in Kabul and seven other Research Stations throughout the country. PYT, AYT and NUT are planned and designed from the materials selected and advanced from the international trials and nurseries in collaboration with NARS and FAO. Agronomic experiments are conducted in collaboration with NARS and NGOs. Breeder seed production is initiated in collaboration with relevant partners.

Yield trials and nurseries including BW, DW and barley were planted in 2004-2005 at 11 sites in 9 provinces. The bread wheat consisted of spring type, facultative and winter wheat, both irrigated and rainfed. The quality is suitable mainly for flat bread, while some raised breads are becoming of concern. Durum is currently mixed with BW for making a special bread in the Northern provinces (Mazar and Samangan provinces).

In collaboration with NARS, FAO and NGOs actively conducted international wheat experiments and maize trials and nurseries in multiple sites. A total of 80 wheat experiments in 11 sites and 10 maize experiments and seed multiplications in 8 sites were successfully conducted in 2005. A considerable amount of time was spent in planning, designing, conducting, and managing the experiments. Experiments are prepared, hand carried or dispatched along with the necessary information and seeds. In a majority of the sites the experiments were successfully conducted. The results of the international trials have been already sent to CIMMYT. Further efforts are being undertaken to enhance the collaboration and improve the quality of research results.

Table 1. Improved germplasm obtained and evaluated during 2002/03, 2003/04, 2004/05 and 2005/06 in Afghanistan.

<table>
<thead>
<tr>
<th>Source</th>
<th>No. of trials/Nurseries</th>
</tr>
</thead>
<tbody>
<tr>
<td>CIMMYT</td>
<td>24 34 58 41</td>
</tr>
<tr>
<td>Turkey/CIMMYT/ICARDA</td>
<td>12 9 18 15</td>
</tr>
<tr>
<td>Turkey (national)</td>
<td>2 - - -</td>
</tr>
<tr>
<td>Iran (selected elite lines)</td>
<td>3 3 4 -</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>41 46 80 56</strong></td>
</tr>
</tbody>
</table>

Widespread on-farm testing with farmer participation should identify materials that warrant advancement and possible release. On-farm trials were conducted in collaboration with the ISE, Agency d'Aide a la Cooperation Technique et au Development (ACTED), and the Aga Khan Foundation (AKF). Farmers' fields were jointly visited problems, identified and technical solutions found. Results and findings were shared with all partners. Responses to disease of some varieties, seed treatment problems, and possible corrective measures were also discussed.

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II) Production and dissemination of sufficient breeder seed of current and new varieties of wheat.

This is normally, in public breeding and testing systems, the responsibility of research stations. Several MAAHF stations have now been rehabilitated and should provide the infrastructure for breeders' seed production. The establishment of Private Seed Enterprises is expected to facilitate seed availability. Furthermore, NGOs involved with foundation seed will be assisted.

The seed policy now calls for certified seed production to be grown by farmers. The total amount of certified seed to be produced in 2006 is 6000 t of which 24% is by NGOs, 42% by the public sector and 34% by the private sector. Seed multiplication is expected by 5 NGOs, 6 Improved Seed Enterprises (ISE), ARIA farms and the 8 recently established private seed enterprises in 8 provinces with initial support from FAO.

In 2006, breeder and foundation seed will be produced by implementing partners such as FAO and ARIA. It is planned to produce 20 t of breeder seed and 340 t of foundation seed. The 72 selected head rows of Parva-2 DW, which were produced in Toluca in Mexico, produced 126 to 486 g/row, a total of 19.63 kg. The materials were planted in progeny blocks in Mazar, Kunduz for high quality breeder seed production to clarify the procedures and set a standard. Also we have advanced the originally selected 2000 heads of Solh-02 in progeny blocks for breeder seed production. Given the situation we have also tried to plant the whole spike without threshing. This minimizes the chances of seed mixing.

III) Adaptation of improved management practices for wheat, including new varieties, under local conditions

Conservation agriculture techniques for plant establishment, weed control measures and water and soil fertility management have high merit. This is generally applied/adaptive research, both on-station and on-farm, borrowing from experiences in neighboring countries and in similar environments. This work is assisted by the increased availability of input supplies.

Base line information on production statistics has been gathered. An informal diagnostic survey of yield-limiting factors was conducted in collaboration with NGOs. This explains better the factors responsible for the yield gap and allows us to propose and prioritize possible technical interventions. The effect of K fertilizer on wheat yield was studied. The result suggests that the response of wheat to K can be only seen under high levels of N and P application. The results of planting studies clearly show that by planting late farmers are losing wheat yields up to 30%. The loss is greater if winter wheat is planted late. Efforts are underway to identify improved varieties for early, timely and late planting. Fall grazing is practiced in the Northern provinces; it appears that over-grazing occurs if snow falls are delayed. This may be a factor in late planting. In Kunduz where wireworms damage wheat seedling of if planted early. Improved germplasm is being tested for identification of tolerant materials.
IV) Promotion of new varieties and improved management practices

This will be the task of many stakeholders. Fortunately, there are many NGOs operating in the country, as well as a national extension service that is being rehabilitated. Experience suggests that seed of desirable new varieties can be disseminated and adopted rapidly; the use of better practices faces more obstacles and may take longer, particularly in cases where farmers require access to credit to invest.

Conservation agriculture, bed planting and minimum tillage and crop management experiments are being conducted. Agronomic work on crop management of new and pre-released varieties, fertility management and conservation agriculture in collaboration with NARS is being undertaken. Germplasm was provided to a recently established unit within ARIA for pathology work to be undertaken. Technical materials and technical assistance have been provided. Conservation agriculture and resource conservation technologies were tested/verified on farmers’ fields. This year mechanized minimum tillage using two-wheel and four-wheel tractors was conducted in Mazar, in close collaboration with JDA and ARIA. Planting maize and soybean in standing wheat stubble was impressive for visitors in Kunduz.

V) Building Afghan scientific capacity in wheat and maize research

The focus has been on short training courses for MAAHF personnel and partners, delivered both in country and externally. In addition, day-to-day interactions with CIMMYT staff will help build capacity. With stable staffing and flexibility to promote dynamic researchers, the output of a strong local wheat and maize improvement team should be achieved in three years.

Capacity building and training of national staff was given special attention. There has been a problem with this in the past, with issues about nomination of appropriate candidates for training. Luckily the approach I have taken worked well. We have followed up and worked closely with Afghan researchers who received training in-country and the 25 researchers and production agronomists who have attended courses in CIMMYT regional and HQ since opening the CIMMYT office in Afghanistan. We have successfully managed to find funds locally for sending a group of ten people to CIMMYT for wheat and maize training courses in 2005. The trainees were collaborators from NARS, FAO and AKF.

In country training and technical interaction has been simultaneously provided during the process of planning and conducting the experiments, collecting data, tabulation and interpretation of the results. The international trials and nurseries also facilitated training activities and provided opportunities to demonstrate potential technologies. We organized a number of training workshops, for NARS and NGOs among which one was on maize seed distribution and multiplication at the village level. Another was for FAO field staff on conducting and managing trials, nurseries and breeder seed production.

Training on field plot techniques made it possible to use the incomplete block (Alpha Lattice) with 2 replications instead of RCBD with 4 replications. Capacity was developed to use the Alpha Lattice in PYT, AYT and NUT, and to perform the statistical analysis. We have analysed data from 2004 & 2005 trials locally, tabulated it and produced a brief 100-page report, which was distributed to relevant partners. A copy of the report has been filed with the CIMMYT-Turkey office.
In addition to training workshops, we have actively participated in meetings and provided advisory services to MAAHF. An improvement in technical interactions and exchange of ideas has been achieved; we have discussed various aspects of cereals research methodologies, a contribution to improving the quality of research results. We provided information on crops, nursery and experimental management, contributing to more reliable results. Direct involvement and supervision of activities has resulted in an improvement in the quality of research results.

Networking, Collaboration and Linkages

CIMMYT is one of the many organizations that have taken up the challenge of helping rebuild the agricultural sector in Afghanistan. CIMMYT draws on strong and effective partnerships to create, share, and use knowledge and technology to increase food security, improve the productivity of farming systems, and sustain natural resources.

Progress has been made on development of breeding, pathology and agronomy work through the establishment of networks and strengthening of collaboration with NARS, ICARDA, FAO, and relevant NGOs in exchange of ideas, information and germplasm. In addition to international trials and nurseries, promising materials are advanced in PYT, AYT and NUT in multi locations.

Efforts have been made to initiate and establish collaboration with various partners who are involved or interested in improving wheat and maize production in Afghanistan. Linkages have been fostered with NARS, FAO, the Improved Seed Enterprise (ISE), and ICARDA, other CGIAR centers, and several NGOs. Collaborative activities with the ARIA were initiated in three important areas: availability of suitable germplasm, developing/adapting appropriate production technologies, and capacity building.

We have established good linkages with government and NGOs interested in wheat and maize production in Afghanistan. We participated actively in technical and policy meetings and contributed to the identification of problems and practical solutions. This contributed to the recognition of the role that CIMMYT can play in improving wheat and maize production in Afghanistan. Based on the request of the Minister of Agriculture and Animal Husbandry, I have served as a member on a technical advisory committee to the Ministry.

We have actively participated in a number of meetings and contributed in formulation of policies and procedures. The idea of duty exemption on agriculture inputs was well received and approval of the President of the country through the proper channel was obtained. This should contribute to and facilitate the use of improved varieties and essential inputs, and ultimately increased production will be achieved.

B. Ideas and Opportunities

Challenges Ahead
- water shortage/drought
- breakdown of existing resistance
- site specific response of genotypes/varieties
- increasing incidence of different stresses
• wheat quality to meet the demands Afghan farmers/consumers
• productivity and marketing

Thoughts for Discussion
• International, regional and national researchable issues
• Germplasm enhancement and exchange
• Developing/adapting RCT/CA
• NARS capacity building
• A new look at old issues
• Future strategies
• Funding

C. Major problems and emerging concern

• Status of CG centres as NGO, MoU
• Government Taxation
• Non-existence of a dry-land research farm

D. Key alliances/partnership

CIMMYT has fostered close links to scientists in Afghanistan since the late 1960s. International nurseries of improved germplasm have been sent to the country for many years so that most of the wheat varieties grown in Afghanistan now are of CIMMYT origin. CIMMYT has been regaining its momentum in the country to improve wheat production systems by focusing on the critical technical constraints. Afghanistan is a poor country, has suffered tremendously, and deserves consideration. Over time it received attention, then was ignored, and now is regaining some attention.
Appendix 1

Figure 1. Wheat area, production, and yield in Afghanistan.

Total production of cereal in 2005 is estimated at 5.24 million tonnes, of which wheat is estimated at 4.27 million tonnes. Milled rice production is expected to be 325,000 t, maize and barley production are estimated at 315,000 t and 337,000 t respectively.

Table 1. Wheat Area and Production in 2005 in Afghanistan

<table>
<thead>
<tr>
<th>Wheat</th>
<th>Area ('000 ha)</th>
<th>Yield (t/ha)</th>
<th>Production ('000 tonnes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Irrigated Wheat</td>
<td>1094</td>
<td>2.47</td>
<td>2,704</td>
</tr>
<tr>
<td>Rainfed Wheat</td>
<td>1255</td>
<td>1.24</td>
<td>1,581</td>
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</table>

Source- FAAHM

It should be noted that the area under the rainfed wheat has increased drastically since 2003. Prior to this the rainfed area was about 1/3 of irrigated area. Reasons given are that the pasture and grazing land have been ploughed.
Water productive wheat with appropriate quality profiles.

Progress report on Quality Improvement of Wheat

Roberto J. Peña

Introduction

At present, in a globalized world where the free international trade of diverse goods is a common activity even in developing countries, processing quality and quality uniformity are attributes, which make the difference between profit and loss for those selling their commodities. This is particularly true when trading grain crops, because the market price is largely defined by the quality of the grain.

When wheat is cultivated with the farmer's expectation of generating an income, the wheat crop must possess the quality attributes demanded by the market and by the consumer. This is also true when wheat is used as a staple food because the wheat crop has to possess certain quality attributes necessary to manufacture at the village and household levels acceptable traditional foods.

Approximately 50 million hectares (roughly 50% of all wheat cultivated in developing countries) are cultivated under rainfed environments, which receive less than 600mm of rainfall annually. Some of the poorest and more disadvantaged farmers live in rainfed areas receiving less than 350 mm of rainfall. These farmers frequently rely on whatever they can harvest under severe drought stress to obtain grain for their own consumption and to generate income, and for forage for their animals. Given the great importance grain quality has on benefiting farmers and the livelihoods of their families, the CIMMYT Cereal Chemistry and Quality Laboratory (CCQL) participates dynamically in the objective of developing wheat germplasm carrying high yield potential, resistance to multiple diseases, adaptation to marginal environmental and cropping conditions, and acceptable quality attributes. The full package is necessary to impact positively on the livelihoods of poor farmers in the developing world. Water-productive wheat (Project P7 of the CIMMYT Business Plan and projects within the RFWS of the former MTP) should also have appropriate quality profiles.

CIMMYT's Cereal Chemistry and Quality Laboratory (CCQL) takes into consideration several factors associated with wheat quality improvement in rainfed areas.

1. Improving knowledge on the end-uses of wheat in rainfed, wheat-producing areas.
2. Understanding grain quality attributes which are more relevant to achieving quality-acceptable (market, processing and consumer) wheat-based products.
3. Understanding the genetic and G x E factors influencing wheat quality attributes.
4. Applying quality screening/characterization tools within an efficient scheme of wheat improvement.
5. Crop improvement. Screening schemes.
6. Interacting with NARS to learn their actual needs in order to support the improvement of their capabilities through:
   • Germplasm characterization and exchange (International Nurseries, shuttle breeding)
Activities, milestones and products

I) End-use quality requirements.
Based on interactions with NARS, visits within several regions, and information gathered from colleagues in NARS, at CIMMYT we have been able to develop general criteria with regards to the quality requirements for manufacturing flat breads, leavened breads and Chinese noodles, both at the industrial and small bakery/household levels. This is the basis of our wheat quality improvement targeting. The wheat breeding program addresses wheat quality improvement based on required quality attributes according to the identified end-uses in the various different regions where CIMMYT distributes improved germplasm.

II) Desirable grain quality attributes.

III) Genetic and functional factors associated with grain quality.
   a. A set of 20 BW standards were used to examine electrophoretic patterns in the region where low molecular weight glutenins are resolved. At present we are able to differentiate 4-5 allelic variants for this locus. To determine differential quality effects of GLU-D3 allelic variation, nine diallelic populations were examined regarding glutenin composition. It was found that in at least five populations the parental lines showed variations at the Glu-D3 locus. These populations were sent to Obregon to multiply seed (Y-05-06) with the objective of determining differential quality effects associated with, among others, Glu-D3 variants. Grain samples will be available in late-May to initiate this comparative study.
   b. At present we determine all the allelic variation at Glu-1 and Glu-3, to ensure that the main genetic factor associated with quality improvement is deployed in the wheat program. A substantial improvement on gluten strength and extensibility has been achieved. Germplasm derived from crosses with synthetic wheat have been selected to discard those derivatives possessing negative glutenin alleles associated with some Aegilops tauschii sources.
   c. Initiated work to compare conventional with molecular markers for the determination of genetically-controlled quality traits.

IV) Quality screening/characterization tools for wheat quality improvement.
   a. In the past we were able to perform quality screening only between late-April and early-May, and had to transport thousands of lines to El Batan for their testing. This overloaded our work at El Batan from June through October, and sometimes we were not able to provide quality data to perform quality screening efficiently. A project funded by SAGARPA-Mexico in 2004 allowed
us to acquire new equipment for the El Batan laboratory and to move the used equipment to Cd. Obregón. A new wheat quality laboratory was set up in 2004 in Cd. Obregón. This permitted the rapid screening of key, simple quality traits (protein content, grain hardness and sedimentation), using NIR Spectroscopy, the sedimentation test (gluten quality-related test and dough mixing properties using whole grain flour). 10,000 lines were screened in 2004 and 2,000 lines in 2005.

b. Quality testing efficiency using NIRS was improved substantially. Its immediate application in breeding activities has resulted in lower costs of addressing quality improvement. In general, the quality testing/screening capacity we have now at CIMMYT is resulting in a rapid decrease of quality-unacceptable germplasm. Now CIMMYT can offer germplasm for diverse food uses to respond to specific needs around the world.

c. A new NIRS nondestructive analyzer has been acquired and will be installed in Obregon to increase quality screening, particularly at the early developmental stages (early advanced and in some cases in the segregating stage).

d. Initiated a collaborative study to compare conventional (chemical, biochemical, and rheological) tools with molecular markers. This study was set to determine when it is more reliable (faster, more cost-effective) to use marker assisted selection as opposed to conventional testing. Candidate genes (traits) are:

   i. Specific high molecular weight glutenin: *Glu-1* (1B7x overly expressed)

   ii. Grain hardness (puroindolin proteins): *Pin A; Pin B*

   iii. Amylose/Amylopectin: GBSS genes.

   iv. A set of 400 lines from the CB Spring and a set of 56 lines from CBME4SA, were analyzed for relevant quality traits using chemical/biochemical tests and *Glu-1/Glu3* allelic variations), as well as by MAS associated with Glutenin 7 overexpressed, Puroindoline genes, and Starch composition. The new quality laboratory in Obregon can be used in the future to collect DNA samples for MAS at El Batan. This is a plus, benefiting not only quality screening but other trait-screening activities: a very significant step!

e. Upgrade Fusarium-related toxin (DON) analysis laboratory. Assessed performance of two ELISA-based DON analysis tests, and defined the best choice. Standardized the official Flourimetric toxin (DON) analysis method. Finally the old HPLC equipment dedicated to fusarium-related mycotoxin was put in working order. Now we have a reference method to help the development of a lower cost methodology than the one presently available. Important advances were achieved in determining the chemical and processing conditions for performing toxin analysis at half the price of the commercially available tests kits we use.

V) Crop improvement. Screening schemes.

a. Early advanced (PYTs) and segregating lines were handled in the laboratory set up in Obregon. Lines in the early advanced (PYTSAME4; PYTAUSSY) stage were screened for grain hardness, protein content and gluten strength (sedimentation volume and dough mixing properties). Only those with acceptable quality traits were advanced to yield trials.
b. In 2005, the laboratory at El Batan received roughly 9,500 grain samples, including CB, YT's, candidates for International SN's, the high latitude program (targeting mainly Kazakhstan), CIMMYT's regional programs (Turkey's Winter wheat program), the SRegional trial from the Southern Cone, and national programs (Mexico and China).

c. All parental lines from the drought breeding program were characterized in relation to physical and rheological properties and by electrophoresis in relation to gluten protein composition (Glu-1, Glu-3, Gli-1 controlled protein subunits). Lines with the best strength and extensibility were identified and recommended as the best quality sources for new crosses.

d. Elite Lines in the advanced stage (YTSAME4), the candidate lines for International Nurseries (Cand. SAWSN), and elite lines previously selected to be included in International Nurseries (SAWSN), were characterized in relation to potential end-use.

e. Grain hardness, protein, and SDS-sedimentation, and glutenin (HMW and LMW) composition were determined in the winter wheat parental material and advanced lines (1000 entries). This germplasm serves the ICARDA-CIMMYT joint breeding effort and serves the CWANA Region. Best sources of quality traits were identified and recommended to Arne Hede to deploy them in the new crosses.

f. Evaluated quality effects associated with heat and management conditions (CA and N-fertilization). Results yet to be analyzed and interpreted.

g. Determined Fusarium-related toxin (DON) levels in breeders’ lines from the Fusarium project.

VI) Interaction with NARS.

a. Information on glutenin and gliadin composition as well as 1B/1R translocation status, specific quality traits and potential end-use of elite advanced lines (F9 and above, CSNs, some International Nurseries and parental lines), were put into the IWIS to make the quality information available to NARS. This should be very beneficial for breeding programs not having quality testing capabilities.

b. In-house Training. Several lectures to the wheat improvement training group (4 half days); Dr. Manoj D. Oak (Biochemist), Agharkar R. I. Pune India (One month); Mrs. Mi-ja Lee (breeder), HARI, Korea (Two months).

c. Visiting Scientists. Dr Zaidi, Pakistan (three months). To characterize glutenin composition, grain hardness and sedimentation volume (gluten quality-related parameter) in elite synthetic wheat populations characterized by their resistances/tolerances to biotic and abiotic stresses.

d. Quality Course in China. Twenty-two participants from North China NARS and Universities. Held at the Xinjiang AAS, Urumqi, China.

Milestones

- Wheat Germplasm with high improved quality traits.
- Molecular markers for relevant quality traits, optimized and being validated.
- Laboratory for routine toxin (DON) analysis fully functioning.
- New quality laboratory in North West Mexico for the non destructive screening of segregating and early advanced wheat germplasm.
• Training courses on Cereal Chemistry and Quality offered once a year to scientists of NARS and other research institutions. Regional quality training course upon request.

Outputs

• Appraisal of demand for specific grain quality attributes of wheat.
• Value-added traits incorporated into CIMMYT elite germplasm for international distribution and exploitation by wheat breeders.
• Safer food from wheat through reduced mycotoxin content.
• Enhanced farmers' access to markets by providing bread and durum wheat varieties with broad or specific niche value-added traits (e.g., improved quality for making leavened, steamed and flat breads, diverse noodle requirements).

Staff

One Cereal Chemistry Specialist (PhD) and 6 Technicians. There is the need of a scientist (at least Masters Degree level but better a Post Doctorate Fellow) to be able to fully address quality issues and breeding for quality activities.

Within whom do we do it?

Mexican funding institutions (CONACYT, the Ministry of Agriculture, State-Funding agencies in NorthWest (Baja California and Sonora), Central (Guanajuato) and High Lands (ICAMEX), have been providing financial support for research and for upgrading of infrastructure during the last 5 years.

INIA (Spain)-PROCISUR-CIMMYT project on genetic resources. This project was set to run between 2005 and 2007 (08). This project has 5 modules (end-use quality, fusarium-mycotoxins, rusts, genetic resources and foliar blights).

Project with Korean HARI on the quality improvement of wheat using DH technology. I lead the project at CIMMYT. The project has a duration of 3 years.

ICARDA, Harvest Plus Challenge Program network, Private Sector, Milling and baking Industry, NARS; Mexican Funding Institutions

Where do we do it?

CIMMYT locations: Mexico, Southern Cone, Asia and CWANA (both in Asia and North Africa through partnership with NARS, NGOs, CSOs and farmers). Southern Cone (in partnership, through special projects with Brazil, Uruguay, Paraguay, Argentina, Chile).

Who benefits?

Farmers through increased income from value-added wheat; wheat consumers worldwide through better quality wheat with higher value and improved food safety.

Who are the clients?

Public and private wheat breeders are users of germplasm. Consumers and markets of value-added wheat products.
Infrastructure

Fields in the experiment stations in Mexico; Biotechnology laboratory for upstream and applied research; Grain quality labs (Obregon and El Batan).

Potential impact

Millions of wheat consumers, in particular malnourished children in the developing world (especially in those areas where wheat is the staple food), will improve their daily intake by adding micro-nutrients to their diets. High quality wheat also may reduce food waste (through improved freshness retention and therefore longer shelf life) and provide extra income to farmers and processors of wheat. Safer wheat products through reduced contamination with mycotoxins.
Marker Assisted Selection

Manilal William

In relation to the use of molecular markers in wheat improvement efforts, currently CIMMYT has the capacity to use about 20 different markers that address traits such as root health, resistance to rust diseases as well as some aspects of quality. A robust root system allows uptake of moisture under water-limiting conditions. We have made considerable efforts in acquiring and optimizing a set of markers for race specific genes that confer resistance to stem rust. These were optimized with the objective of deploying them along with a durable stem rust resistance gene complex Sr2 in gene pyramiding efforts to deploy cultivars with multiple genes that confer resistance to stem rust.

We are also in the process of scaling up our wheat MAS efforts in order to be able to handle increasing demands from our in-house wheat breeding efforts, as well as making the molecular breeding contributions more efficient and more economical.

Currently, approximately 25,000 marker assays are being conducted annually. The crosses analyzed are F1Top, F2 segregating populations and advanced lines from previously characterized germplasm for the relevant markers. Markers used extensively were: Cre1, Cre3 (for CCN resistances derived from an Afghan land race and Triticum tauschii respectively), Rinn1 (root lesion nematode resistance), 2.49 marker for crown rot resistance, BYDV and Boron tolerance (Bo-1). The segregating progeny is selected based on agronomic type followed by MAS. Plants with good agronomic qualities are screened for carrying the trait or gene of interest (identified by MAS) and advanced. All molecular breeding efforts are being conducted jointly with the wheat breeders.

In addition, the crossing blocks of ME4 and ME1 were characterized for some quality markers that were optimized during 2004. These were Pin genes (Pin a and Pin b – hardness loci, GBSS 4A null allele; Glu B1 Over expression allele, Rht1 and Rht2). Except for the two Rht genes, the rest of the optimized markers work well.

During 2005 several other marker systems were acquired and optimized. These include markers for race specific resistance to stem rust – Sr24, Sr26 and Sr39 – and optimization of markers for a durable Sr2 complex. These were done with the objective of providing support to the stem rust initiative in providing tools for combining the Sr2 complex with other race specific genes that are still effective against the new stem rust race. In addition, markers were validated for race specific leaf rust resistance genes Lr29, Lr25, Lr47 and Lr39. There is no plan to use the Lr markers in CIMMYT germplasm but if it is necessary to provide them to a national program that wants to use it, then that option is available.

A Tissue Lyser was acquired and currently optimized for efficient 96 well plate based DNA extractions. Plate based extraction in Obregon is now in place, where lyophilization facilities are not available. As a cost cutting measure, PCR volumes were reduced from 20 to 10 µl.
## Wheat Molecular Breeding Efforts

<table>
<thead>
<tr>
<th>Gene/Trait</th>
<th>Type of marker</th>
<th>Gene</th>
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<th>In use</th>
<th>Ready</th>
<th>In Optimization</th>
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<tr>
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<td>STS/SSR</td>
<td>Cre3</td>
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<td>High Protein</td>
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<td>STS</td>
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Soil Borne Pathogens (SBP) Highlights for the Board Visit
Obregon March 2006

Prepared by Dr Julie Nicol 13 February 2006, in relation to research objectives

Objective # 1  Identification and incorporation of sources of Cereal Nematode and Root Rot resistance in wheat and their subsequent validation and distribution (47% time allocation).

Achievements:

1. Identification of winter and spring wheat cultivars with resistance to Soil Borne Pathogens: more than 40 advanced high yielding lines have confirmed root disease resistance against Soil Borne Pathogens including cereal nematodes (Cyst and Lesion) and/or Cereal Root Rots (*Fusarium* spp.). Many of these sources have pyramided genes against 2 or more Soil Borne Pathogens (see *International Conference Paper 1*). Some of these sources from Mexico and known Australian resistant sources, crossed with the CIMMYT line Pastor, have now been shown to yield up to 45% more than either parent with SBP resistance incorporated (see Table 1).
<table>
<thead>
<tr>
<th>Genotype</th>
<th>Resistance to</th>
<th>Genotype</th>
<th>Resistance to</th>
<th>Genotype</th>
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</table>

**Table 1:** Summary of the confirmed spring and winter wheat lines identified from the joint TURKEY/CIMMYT screening program with resistance to one or more Soil Borne Pathogen(s).

1* indicates a higher level of resistance than the best known resistant check;
1 indicates resistance equivalent to the best known resistant check line;
2 indicates moderate resistance, not as high as best known check but still effective.

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Partially resistant (PR) and Susceptible (S) check lines used for each soil borne pathogen. Refers to characterized single gene for resistance against various different pathotypes of the Cereal Nematode *Heterodera avenae* (see Nicol et al., 2003). These sources also have known resistance against *Fusarium Head Blight* (*Fusarium graminearum*) from CIMMYT Mexico. 

AUS - Australia, IVWIP - International Winter Wheat Improvement Program, MX - Mexico, SP - Spain, TK - Turkey.

2. Distribution of wheat cultivars with confirmed resistance into the standard CIMMYT International Wheat Nurseries: in close collaboration with breeders there are now several lines that have entered the CIMMYT International Spring Wheat Nurseries in high-yielding adapted backgrounds. This has risen from 3% in 2002 to 16% in 2005 for the semi-arid nurseries.

3. Distribution of Special Disease Nurseries to Iran, Syria (ICARDA) Tunisia, Morocco, China, Spain, Australia and CIMMYT Mexico with respective traits relating to SBP provided.

4. Targeted breeding to incorporate and validate resistance: more than 100 targeted crosses have been made in 2005 in Turkey (as in 2003/2004) to incorporate sources of Soil Borne Pathogen resistance into the background of winter wheat. Every year more than 200 advanced, high-yielding spring germplasms are sent from Mexico for validation of the resistance that was incorporated more than 5 years ago. Where appropriate Marker Assisted Selection has been used to confirm resistance.

5. Clear understanding of the genetic control of Iraqi landrace and CIMMYT source of *P. thornei* resistance indicating the value of pyramiding different sources.

<table>
<thead>
<tr>
<th>P. thornei resistance</th>
<th>GRDC project</th>
<th>Chromosomal location</th>
<th>Sig a</th>
<th>SSR</th>
<th>Group</th>
<th>Source actively used in breeding programs</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Synthetic hexaploid CPI 133872</td>
<td>Zwart PhD, Lesley Research Centre</td>
<td>D6</td>
<td>D6, AL</td>
<td>AS</td>
<td>QDPI - Zwart et al.</td>
<td>limited LRC</td>
</tr>
</tbody>
</table>
| 2 Middle eastern landrace line 43 (AUB12) and Morocco 426 (AUB12124) | NRWMMP - CSIRO 
Brisbane Component 
(CSP348) | B B B D6 | CSIRO - Schmit et al. | unknown |
| 3 Q550a wheat line | NRWMMP - LRC 
component with CSIRO PI Canberra | D6 | CSIRO - Lagudah et al. | extensively in Northern Region and CIMMYT |
| 4 CIMMYT wheat lines | NRWMMP - CIMMYT 
Component (CIM12-Pri) 
CSIRO Durra wheat | B D | CSIRO - McIntyre et al. | extensively in CIMMYT |
| 6 | NRWMMP - CIMMYT 
Component (CIM12-Pri) 
CSIRO Durra wheat | B D | CSIRO - McIntyre et al. | extensively in CIMMYT |
| 9 | NRWMMP - CIMMYT 
Component (CIM12-Pri) 
CSIRO Durra wheat | B D | CSIRO - McIntyre et al. | extensively in CIMMYT |
| 10 | NRWMMP - CIMMYT 
Component (CIM12-Pri) 
CSIRO Durra wheat | B D | CSIRO - McIntyre et al. | extensively in CIMMYT |

Sig a = *** <0.0001, ** <0.01, * <0.05, (*) <0.10

Table 2: Summary of the chromosomal distribution of *P. thornei* resistance with the five identified *P. thornei* sources. Source 4 and 5 were concentrated on with this CIM12 project. (See International Scientific Journals, publication 5).

It is clear from this work that pyramiding different sources of resistance against *P. thornei* can improve the level of resistance. Some of the crosses and phenotypic screening have actually identified some segregates with immune reactions (no nematodes). These lines have been further promoted for breeding purposes.

6. More than 20 sources of bread wheat have been confirmed to hold a high level of resistance to Crown Rot (CR) and also *Fusarium Head Scab* (FHS) from Mexico. These sources have been sent to T. Ban's group in CIMMYT.
Mexico, along with the very best CR sources to validate their FHS resistance reactions. More material from Mexico is currently under multiplication and will be screened in 2006 against CR.

Objective # 2
Establish the distribution and importance of Cereal Nematodes in the winter wheat areas of the Central Anatolian Plateau of Turkey (20% time allocation)

1. Establish the biology/epidemiology of nematode populations under field conditions to establish their yield loss impact on winter wheat in Turkey.

   The Cifteler and Haymana yield trials, which have been conducted over a period of 2 years, showed very low yield gains with the addition of Temik (nematicide) in March 2004 (3% yield gain) in comparison with 36% in February 2003 with the application of Temik. The 2004 season was highly favorable for wheat production, with yields being in most cases twice as much as 2003 (see Tables 3 and 4, below). Under these conditions, Temik was not highly effective (in 2004) for controlling the Cereal Cyst Nematode.

   This result is supported by the international literature; for this reason these nematodes are considered important under dryland (i.e. rainfed, stressed conditions). This result was also found from my work in Obregon - (see Nicol and Ortiz-Monasterio, 2004) where no yield losses were found under full irrigation but significant losses under reduced irrigation. The implication of this result is that we need to take into account water availability when stating the importance of cereal nematodes in a region.
### Yield (t/ha) 2004

<table>
<thead>
<tr>
<th>Variety</th>
<th>WITH TEMIK H04 C04</th>
<th>WITHOUT TEMIK H04 C04</th>
<th>YIELD CHANGE H04 C04</th>
<th>average across location 0203</th>
</tr>
</thead>
<tbody>
<tr>
<td>Altay</td>
<td>4.50 2.77</td>
<td>4.55 2.92</td>
<td>1.10 5.14</td>
<td>3.12</td>
</tr>
<tr>
<td>Bagci</td>
<td>4.14 2.68</td>
<td>4.04 2.87</td>
<td>-2.48 6.62</td>
<td>2.07</td>
</tr>
<tr>
<td>Bezostya</td>
<td>4.22 2.53</td>
<td>3.65 2.39</td>
<td>-15.62 -5.86</td>
<td>-10.74</td>
</tr>
<tr>
<td>Dagdas</td>
<td>4.30 2.63</td>
<td>4.14 2.70</td>
<td>-3.86 2.59</td>
<td>-0.64</td>
</tr>
<tr>
<td>Gerek</td>
<td>4.42 2.53</td>
<td>4.37 2.89</td>
<td>-1.14 12.46</td>
<td>5.66</td>
</tr>
<tr>
<td>Gun</td>
<td>4.58 2.67</td>
<td>4.39 2.56</td>
<td>-4.33 -4.30</td>
<td>-4.31</td>
</tr>
<tr>
<td>Kalayci</td>
<td>4.67 3.75</td>
<td>4.66 3.85</td>
<td>-0.43 2.60</td>
<td>1.08</td>
</tr>
<tr>
<td>Karma</td>
<td>3.86 3.51</td>
<td>3.30 3.33</td>
<td>-16.97 -5.41</td>
<td>-11.19</td>
</tr>
<tr>
<td>Kutuk</td>
<td>4.50 2.90</td>
<td>4.13 2.77</td>
<td>-8.96 -4.69</td>
<td>-6.83</td>
</tr>
<tr>
<td>Silverstar</td>
<td>3.08</td>
<td>3.00</td>
<td>-19.67</td>
<td></td>
</tr>
<tr>
<td>Goldmark</td>
<td>3.59 3.00</td>
<td>4.01 3.49</td>
<td></td>
<td></td>
</tr>
<tr>
<td>average yld and % loss considering all varieties</td>
<td>4.07 2.54</td>
<td>3.86 2.56</td>
<td>-6.23 1.21</td>
<td>-2.51</td>
</tr>
</tbody>
</table>

### Yield (t/ha) 2003

<table>
<thead>
<tr>
<th>Variety</th>
<th>WITH TEMIK H03 C03</th>
<th>WITHOUT TEMIK H03 C03</th>
<th>YIELD CHANGE H03 C03</th>
<th>average across location 0203</th>
</tr>
</thead>
<tbody>
<tr>
<td>Altay</td>
<td>2.67 1.86</td>
<td>2.73 2.06</td>
<td>-4.61 -20.44</td>
<td>-33.03</td>
</tr>
<tr>
<td>Bagci</td>
<td>2.53 1.76</td>
<td>2.76 1.45</td>
<td>-43.65 -21.68</td>
<td>-32.66</td>
</tr>
<tr>
<td>Bezostya</td>
<td>1.88 1.80</td>
<td>1.30 1.21</td>
<td>-45.19 -46.17</td>
<td>-46.68</td>
</tr>
<tr>
<td>Dagdas</td>
<td>2.44 1.66</td>
<td>1.37 1.31</td>
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<td>-52.43</td>
</tr>
<tr>
<td>Gerek</td>
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<td>1.83 1.47</td>
<td>-41.31 -19.87</td>
<td>-30.59</td>
</tr>
<tr>
<td>Gun</td>
<td>2.21 1.75</td>
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<td>-55.17 -15.32</td>
<td>-35.25</td>
</tr>
<tr>
<td>Kalayci</td>
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<td>-7.27 -8.32</td>
<td>-7.79</td>
</tr>
<tr>
<td>Karma</td>
<td>3.21 2.36</td>
<td>2.24 1.97</td>
<td>-43.44 -20.19</td>
<td>-31.82</td>
</tr>
<tr>
<td>Kutuk</td>
<td>2.37 1.60</td>
<td>1.33 1.29</td>
<td>-79.08 -23.73</td>
<td>-51.40</td>
</tr>
<tr>
<td>Silverstar</td>
<td>1.80 0.74</td>
<td>1.07 0.54</td>
<td>-68.52 -36.38</td>
<td>-52.45</td>
</tr>
<tr>
<td>Goldmark</td>
<td>0.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>average yld and % loss considering all varieties</td>
<td>2.38 1.65</td>
<td>1.62 1.30</td>
<td>-50.97 -32.76</td>
<td>-41.87</td>
</tr>
</tbody>
</table>

Tables 3 and 4: Two location, two year summary data from the Central Anatolian Plateau (H- Haymana and C - Citteler) with and without the application of Temik (Aldicarb - Nematicide).

It is important to note that considering plus and minus Temik results only is a very inaccurate way of data interpretation, as the actual nematode population in each plot is knot known. I prefer to look at the population dynamic data (the initial population of nematodes in relation to yield) as this gives more information about the tolerance and numbers of nematodes involved.

If we consider some of the data in this light, the low yield results for March 2004 are clearly shown compared with February 2003, when we contrast the winter wheat Altay in the two graphs in Figure 1 below.
These graphs show that, with the Winter Wheat cultivar Altay, in 2004 the relationship between yield and population of Cereal Cyst Nematodes is not as strong as in 2003 (R=0.43 vs. R=0.81), but the trend is clear. The slope of the line is much steeper in 2003 and the yield much lower than 2004. This reinforces observations that under stress conditions (ie. yields around 2.0t/ha) the nematode is causing significant yield loss; however if the season is more favorable (ie. yields around 4.0t/ha) the losses are smaller and the symptoms are not as obvious.

The inference of this yield data is that the losses due to Cereal Nematodes are influenced greatly by the seasonal conditions so we need to run trials over several (ie. more than two) consecutive years. This is necessary in order to obtain a clear understanding of the overall importance of cereal nematodes and also to provide some estimates of population dynamics to related to economic yield loss. As a result it was agreed that the trial would run for one more year in Haymana last season (April 2005); this data is currently being analysed.

2. Limited Cereal Nematode Survey published from Turkey and Syria work conducted in 2001-2003 to indicate the widespread distribution of the Cereal Cyst Nematode

In 80 wheat and 63 barley fields in Syria, *Heterodera latipons* was identified as the most dominant species, found in 96% of cereal fields, whilst *H. filipjevi* was detected only in one field. In Turkey, 27 wheat and 3 barley fields revealed *H. filipjevi* and *H. latipons* to be widely distributed, occurring as single species in 27.5% and 33.3%, whilst 29.2% were a mixture of both species (see *International Scientific Journals*, publication 2).
3. Extensive Cereal Nematode Survey completed on the Central Anatolian Plateau (CAP)

289 soil samples were collected from different provinces on the CAP during March 2003, 2004 and 2005 using a systematic survey technique. Cereal parasitic nematodes were measured, in addition to soil parameters (pH, soil type, Electric Conductivity (EC), Organic Matter (OM), Iron and Zinc) as well as other groups of nematodes (fungivour, bacterivour, predator/omnivour and the combination of these which is free living). The frequency of isolating the different nematode groups within the soil was CCN (78%), RLN (37%), fungivour (64%), bacterivour (82%), predator/omnivour (49%) and free living (83%). The most predominant cyst nematode was *Heterodera filipjevi* followed by *H. latipons* and further work is underway to classify the cyst species using both morphological and molecular tools.

Using PCA and Correlation Association, the % sand in the soil showed a clear association (P<0.05%) with CCN. This is further illustrated below where it is clear in the middle and southern parts of the CAP there is a high distribution of CCN. The pH and Zn concentration did not relate to either CCN or RLN. Within RLN species there was no direct association with any of the nematode or soil parameters. There was a slight positive correlation for *P. thornei* and % clay. In addition there was a significant negative correlation of *P. neglectus* with % clay (P<0.05%) and a slightly positive correlation with % sand (P<0.10%). The free-living nematodes were highly correlated with electric conductivity (P<0.0001) and Zinc concentration (P<0.01).
4. Extensive Cereal Root Rotting Survey completed on the cereal growing regions of Turkey
The final analysis of data from more than 500 samples taken from cereal crown and root tissues shows that more than 40% of samples had one or more species of root rot, crown rot (F. pseudograminearum and F. culmorum), common root rot (Bipolaris sorokiniana) and Sharp Eyespot (R. cerealis). The most frequently isolated species was Rhizoctonia cerealis (18%), followed by F. culmorum (14%), B. sorokiniana (10%) and lastly F. pseudograminearum (2%). The frequency of the more common fungi associated with root rots under non-limiting moisture conditions was low, being 2% for take-all (G. graminis) and 3% for Pythium spp. (see International Scientific Journals, publication 6).

New evidence from Turkey clearly indicates that:

a. The Fusarium crown rot species F. culmorum is one of the more aggressive species of Fusarium as a greater degree of pathogenicity is found under aseptic greenhouse conditions. This confirms that, at least for Turkey, this is the most important species for damage to winter wheat.

b. As with studies in other parts of the world (Canada and Australia), the Fusarium Head Scab fungus (F. graminearum) can also cause the symptoms of crown rot.
Source: Tunali et al., Plant Pathology Journal 2006

5. Cyst Nematode confirmed to be important in China
During the 2nd International Course on Soil Borne Pathogens held in May in Henan province it was evident that CCN was found in many farmers’ fields. A very limited survey was made during one of the weekends (25 fields) showing a widespread distribution in Shandong, Anhwui, Hebei, Henan provinces but not Gansu. The Chinese colleagues were very excited by this finding and collaborative work has begun with CIMMYT, China and Australia on conducting yield loss studies and assessing potential sources of resistance.

Objective # 3
Investigate other integrated management practices to control cereal nematodes with emphasis on rotation and crop management practices (10% time allocation).

1. Long-term rotation trials monitored in Haymana experiment station
Since 1970, the Haymana experimental station has conducted cereal rotation experiments. In the first year cereal is sown and then the following year a range of rotational regimes is used, including chickpea, fallow, safflower, spring lentil, sunflower, wheat, vetch/barley mix, winter lentil and winter vetch. A high level of Cyst and Lesion nematode is found in the trial area.

After two years of monitoring the trial for cereal nematodes, the wheat/fallow rotation was found to show no difference for cyst nematodes when compared to the wheat/wheat rotation, inferring that fallowing does not significantly reduce cyst populations. Over the two years, the rotation regimes showed a hosting ability for cyst nematodes (in decreasing order) of vetch/barley, wheat, fallow, chickpea, sunflower, spring lentil, winter lentil, winter vetch, safflower. For lesion nematodes,
hosting ability decreased in the order winter lentil, spring lentil, wheat, vetch/barley, winter vetch, chickpea, safflower, sunflower, fallow. From this study, fallowing is considered an effective method of reducing lesion but not cyst populations and safflower is the most useful crop rotation for both types of nematodes. Barley should be avoided under cyst populations and lentil where lesion nematode populations are high.

2. Long-term wheat stubble management trial on Eskisehir experimental station

This trial is only 4 years old and is considering the effect of different treatments including:
1. bed-planting,
2. stubble burning,
3. stubble retention,
4. direct drill and
5. conventional plough.
On this site there is a high natural population of both Cyst and Lesion Nematodes.

Data from two years of monitoring have revealed that the Lesion Nematode population is significantly reduced with treatments 1-3, whilst Cyst Nematodes appeared to be lower (though not significantly) in all treatments except conventional (5). These preliminary data infer that the effect of plant parasitic nematodes may be reduced when conservation agriculture is practiced (bed-planting, stubble burning or retention). More work is being conducted to establish the relationship of other nematodes (non-plant pathogenic) as they may explain this finding, as these resource conserving technologies should improve soil health, and hence improve the microbial balance between pathogens and beneficial microbes in the soil.

Objective # 4
Seek funding initiatives to support root disease related research/training on cereals and other research/training activities to support the IWWIP (International Winter Wheat Improvement Program) (14% time allocation)

1. Seeking funding for the promotion of new research methods, crop management practices and varieties through training, demonstration and participatory on-farm trials on the CAP of Turkey

A tripartite project was successfully funded and executed in 2005 with funding from the Embassies of Canada, Australia and The Netherlands (US$ 35,000). This allowed three regional Turkish National Programs to conduct coordinated research to improve zero-till planting techniques and conduct a variety of demonstration trials on farmers fields in more than 9 locations across the Plateau in Turkey. The project was very successful and since then a PPO/PPA EU project was prepared with the Dutch government on zero-till with the Turkish Ministry. Although the project was successfully funded (350,000 Euro), it will not be implemented presently. The major reason for this is the coordination and funding allocation aspects of the project between the EU and the various Turkish Ministries which are involved in the project. Although on this occasion the project was not successful, the Ministry is eager to finding other funds to conduct such projects. In another positive step, for the first time, in October the Ministry held a National meeting with agronomists on Conservation Agriculture.
Funding for this course was successfully obtained from The ATSE Crawford Fund, ACIAR, CIMMYT and several Chinese foundations (including CAAS and private companies) to conduct the very successful course.

3. Partnerships and networks solidified on work relating to Soil Borne Pathogens
   a. NARs in the region: this year particularly China, India, Iran, Morocco and Tunisia have joined various aspects of the SBP research activities carried out by CIMMYT and TURKEY. China (see Objective 2, point 5) has started active research on Cereal Cyst Nematodes and is very keen to work with both CIMMYT/TURKEY and Australia. Iran is actively preparing National projects on both Cereal Root Rots and Nematodes with CIMMYT assistance. India has returned screening data for germplasm sent in 2003, where they have confirmed resistances and selected several materials. Several key pathologists and breeders have been identified with K. Ammar (CIMMYT Durum breeder) to work on aspects of Root Rot research. These collaborators have received materials and are currently actively screening them in close collaboration with CIMMYT/TURKEY.

   b. New Turkish Initiatives to work on SBP: the joint CIMMYT/Turkish National research program in Root Rots came to a close this year and efforts are underway to establish either a new large national collaborative project with TUBITAK (national funds), or several smaller related projects. Currently the Turkish coordination of the project is not clear and a strong University partner needs to be identified. The CIMMYT/Turkey National Cereal Nematode project is going well and has 2 years to run; however a new TUBITAK project was submitted in 2005 in collaboration with the Turkish Ministry of Agriculture, CIMMYT and Cukurova University to further boost the efforts and resources for this work. The outcome of this should be known in early 2006.

   c. USAID/Pacific North West partnership: with a USAID seed grant a successful meeting was held in June in Portland USA with USA, CIMMYT, Turkey and ICARDA scientists to develop a joint program of proposed research. A final concept note has been developed and the US counterparts (Prof Jim Cook, Dr Kim Campbell and Dr Tim Paulitz are pursuing donors).

   d. CSIRO/CIMMYT Fusarium Head Scab (FHS)/Crown Rot (CR) research: a joint meeting (attended by Dr Ban and Dr Nicol) was held in March 2005 at CSIRO Brisbane to establish the opportunity to work in this area together. A clearly developed work plan was made and currently the MOU for this workplan is still waiting to be finalized by CIMMYT management to enable this to move forward (issues exist about IPR and germplasm). Both CIMMYT and CSIRO scientists believe there is a high level of synergy and complementarity in this area and the partnership scientifically is very strong and fruitful. An ACIAR project is currently being developed to submit early next year (MOU pending).

   e. ICARDA: as with previous years seed has been sent to ICARDA Syria to jointly screen for cereal nematodes and root rots, however the coordination of this work needs to improve. The USAID initiative included Dr Amor Yahyoui as ICARDA representative. Also International Conference Paper (3), and International Scientific Journal (2) were published this year with ICARDA. Efforts are underway to enable Ms Elif Sahin (CIMMYT Technical officer in Turkey) to obtain
a fellowship under the GCP to work in ICARDA Syria for 4 months to enable a stronger integration of related SBP activities with CIMMYT and ICARDA.

f. International Global Root Disease Resistance (GRDR) Nursery: this is a nursery which is being prepared as part of the CIMMYT/GRDC strategic alliance project (Component 4). Based on feedback from both NARs partners and ARIs it is anticipated that more than 20 collaborators will take part in screening this nursery for various SBP and other biotic constraints in 2006.

Publications List

International Scientific Journal Articles reviewed ( )
2003 (4), 2004 (4) & 2005 (6)

Books and Chapters

International Scientific Journals

Short Note Publications
International Conference Papers


OTHER POINTS

a) Research, Training and networking highlights

Research
- More than 40 lines with one or more SBP resistance were identified belonging to both winter and spring wheat groups. These spring wheat lines represent 16% of the entries coming out of the SAWYT this year – a major achievement. Many of these lines have marker confirmed resistances from Mexico which have been field/greenhouse validated in Turkey.
- More than 300 targetted WW crosses have been made in the last 3 years incorporating SBP resistance into WW.
- The chromosomal region of Pratylenchus thornei resistance in 2 important sources has been clarified and some of the pyramided lines showing immunity
- Clear indication of the widespread distribution of Cyst (Heterodera spp.) and Lesion (Pratylenchus thornei, and P. neglectus) Nematodes in Turkey and Syria. The most prevalent species is H. filipjevi in Turkey and Iran, whilst in Syria it appears to be H. latipons followed by H. filipjevi. In Turkey very clear associations have been proven for sandy soil type with higher CCN populations, also indicating more damage potential.
• Enhanced understanding of distribution of Root Rots of importance in Turkey (40% of soil/crown samples have one or more common Root Rotting fungi) and their widespread distribution. Also clear evidence to indicate that the head scab Fusarium can cause crown rot under aseptic seedling greenhouse screening conditions.

• More than 20 sources of bread wheat have been confirmed to hold a high level of resistance to Crown Rot (CR) and also Fusarium Head Scab (FHS) from Mexico.

• Several reselections of F7 winter wheat with GS50a spring wheat P. thornei resistance in their pedigree have confirmed a level of resistance equivalent to Gs50a and also more than 5 of these sister lines have high Zinc efficiency.

**Training and Networking Highlights**

1. **2nd International Training Course on SBP of Cereals, Henan Province, China 5-20th May 2005.**
   This course was very successful being conducted in the Henan Province of China with 21 participants from more than 12 Chinese provinces. Dr Maarten Ryder (CSIRO Australia) and Dr Nicol were co-editors and co-coordinators of the course. The key teaching experts were from CIMMYT (Dr Julie Nicol, Dr Tomohiro Ban, Dr He), USA, China and Australia. Funding was obtained from a number of Chinese (CAAS and private companies) and Australian sources (The ATSE Crawford Fund, ACIAR) and CIMMYT. The course (like the first one conducted for the WANA region in Turkey in 2003) was deemed highly successful and the Australian donors and teaching experts have committed to another course potentially in Morocco in 2007 with CIMMYT. There is also a very high probability that a short CCN workshop will take place in China in 2006 to follow up on the initiatives taken after the course last year. Another highlight is that ACIAR have agreed with CIMMYT to help support the publishing of two manuals on Soil Borne Pathogens – one for theory and the other practical use.

2. **Soil Borne Disease Network solidified**
   A Specific Disease Nursery for SBP has been distributed to Iran, Syria (ICARDA) Tunisia, Morocco, China, Spain, Australia and CIMMYT Mexico with respective traits relating to SBP provided.

   Clear research programs to work in SBP are being established in the region with the assistance of CIMMYT: Iran (Nem and RR), China (Nem) and Morocco (RR).

   This year the first International Global Root Disease Resistance Nursery will be distributed. This nursery is part of the CIMMYT/GRDC strategic alliance project (Component 4). Based on feedback from both NARs partners and ARls it is anticipated more than 20 collaborators will take part in screening this nursery for various SBP and other biotic constraints in 2006.

1. **Assistance with supervision of students towards PhD, Masters in SBP.**
   Presently 2 PhD students (Mr Halil Toktay and Ms Elif Sahin) and 1 Masters student (Mr Adnan Tulek) are being supervised for their research in various aspects of Cereal Nematology. Mr Toktay's project has been very successful, with part of his
training being conducted in Australia as part of a GRDC project (CIM12). He is presently writing his thesis and eager to continue aspects of the work both with CIMMYT, Australia and TUBITAK. Ms Elif Sahin has completed the 1st year of her PhD study and is doing extremely well. It is anticipated she will receive further ARI training either in ICARDA, Australia or Belgium (depending on funding opportunities). Mr Adnan Tulek Masters thesis should be completed by end of 2006. His work has revealed the first Winter Wheat accessions with Root Lesion Nemaotode (P. thornei) resistance and Zinc efficiency, a very good outcome.

A new PhD student has been identified (Mr Fatih Ozdemir) to work on various relationships and aspects of Crown Rot and Fusarium Head Scab in wheat germplasm. It is anticipated he will start his study next year and hopefully can receive some training in Australia with CSIRO (as part of the joint research initiative to work in this area).

b) New Ideas/Projects Initiated

Unfortunately SBP is a difficult area of research to gain support for. The key country working in the area particularly of genetic resistance is Australia which has been an avid supporter of this work for more than 8 years.

As Peter Ninnes clearly indicated 'Support from Europe for soil health work has come in the form of collaboration with France and funding through Germany. France is pretty much 'missing in action' in the CG at the moment and priorities for Germany have taken a different turn as we have recently seen. Denmark only has funding at the country desk level (Africa). The Netherlands (Wagenigen) may be a possibility, especially in a systems context'

Efforts have been made in the past with Germany, which have proved unsuccessful on all attempts, although the chances of success were quite high. It is hoped that with the development of a clear concept note, a clear CIMMYT institutional structure, and good future relations with ICARDA, given targeted efforts this area could attract funding. It is certainly clear that the projects will need to be packaged for donors and their priorities to a large degree (for example we could talk about CR/FHS relations, Climate Change, Nematodes as quarantine pests etc.)

The projects which were submitted in 2005 included;
1. ADB proposal prepared January 2004 – unsuccessful
2. USAID concept note prepared in collaboration with Pacific North West researchers. US colleagues are presently looking to identify donors. (USAID seed grant 25K). This concept note can be used to find funds from US related donors and can also serve as a good base document to seek funds elsewhere.
3. ACIAR funding obtained to develop published manuals for both theory and laboratory methods to work with Soil Borne Pathogens (a joint CIMMYT/ACIAR publication). (approx 20K)
4. ATSE Crawford Funding obtained to send Turkish student to Australian in 2006 (4K)
5. Embassy funds (Canada, Australia and Netherlands) to sponsor Turkish National Programs to conduct 0-till research and variety demonstration trials in 3 regional areas of the Central Anatolian Plateau (35K)
6. ACIAR, The ATSE Crawford Fund support to sponsor the 2nd International Soil Borne Pathogen Course on Cereals conducted this May in China.
7. Pre-committal support from the ATSE Crawford Fund to part sponsor the 3rd International Soil Borne Pathogen Course on Cereals in Morocco 2007.
8. ACIAR draft proposal for joint research on Fusarium Head Scab and Crown Rot with CSIRO and CIMMYT Turkey and Mexico.

c) Problems and concerns
1. Decreasing scientific capacity of National Program of Turkey – this is an ongoing discussion; however, it will be a major issue affecting both the quality and quantity of the research we are able to execute with SBP (and the greater IWWIP program) in Turkey. The national program is weakening in terms of trained scientists, the level of English, clear coordination of activities and leadership. This is certainly a problem with the National CIMMYT/Turkey root rot program whose project has now finished, and the future is lacking clear leadership and scientific capacity from the National Program. This is also a major problem with respect to writing scientific articles for International Journals as the National capacity is extremely limited.
2. Finding Special Project Funding to support his work on SBP (see paragraph above)
3. CSIRO/GRDC MOU – In the stages of being finalized.
4. Post-Doc – as raised with the last 2 reviews, the work profile being addressed in Turkey and the greater region with SBP has grown substantially since my placement here (2001) and requires more scientific support from CIMMYT. Although this opinion was indicated by the review panel last year, it appears unlikely that a post-doc appointment will be possible in 2006. As a result, it will be necessary to reprioritize key work objectives for the short-term.
5. Publications – there must be at least 12 publications which could be written and published in 2006 if time permitted in doing so, however this is a key problem given the current workload. Furthermore as raised in point 1., most of the key writing is done solely by myself as Turkish NARs have very limited capacity in doing so.
6. Role of SBP research with new GRDC initiatives – in the past one of the major donors for SBP research work at CIMMYT has been GRDC. The present project (Component 4 of the CIMMYT/GRDC strategic alliance) will be terminating in 2006. It is important that new initiatives be formed with GRDC to continue support of this work.
7. ICARDA relations – ICARDA and CIMMYT have yet to capture potential synergies and complementation in the area of SBP research. It is hoped that, with the new partnership between the 2 centres, a very strong and cohesive program can be initiated in 2006. I am very supportive of the potential of this joint venture.

d) Key Alliances/Partnerships