Yield Gap Analysis of Wheat Production in Central Asia

ANNUAL REPORT

April 2016 – December 2016

Submitted on December 25, 2016

Kazakhstan Kyrgyzstan Tajikistan Uzbekistan

САС ЦАК

ICARDA
Science for Better Livelihoods in Dry Areas

Funded by

ECFS

About the Project

Implemented by:
Uzbek Cotton Research Institute (Uzbekistan)
Gallaral Branch of Research Institute of Cereals (Uzbekistan),
South-west Research Institute of Livestock and Plant production (Kazakhstan),
Research Institute of Farming (Kyrgyzstan),
Tajik Academy of Agricultural Science (Tajikistan)
ICARDA

Funded by:
Russian Funding.

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Date of submission: December 2016

About ICARDA

The International Center for Agricultural Research in the Dry Areas (ICARDA) is the global agricultural research center working with countries in the world's dry and marginal areas, supporting them for sustainable agriculture development to help increase their productivity, raise incomes for smallholder farmer families, improve rural nutrition and strengthen national food security. With partners in more than 40 countries, ICARDA produces science based-solutions that include new crop varieties (barley, wheat, durum wheat, lentil, faba bean, kabuli chickpea, pasture and forage legumes); improved practices for farming and natural resources management; and socio-economic and policy options to enable and empower countries to improve their food security. ICARDA works closely with national agricultural research programs and other partners worldwide in Central Asia, South Asia, West Asia, North Africa, and Sub-Saharan Africa.

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2016

Yield Gap Analysis of Wheat Production in Central Asia

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Implementing Country	: Kazakhstan, Kyrgyzstan, Tajikistan, Uzbekistan
National partner	: Uzbek Cotton Research Institute, Gallaral Branch of Research Institute of Cereals (Uzbekistan), South-west Research Institute of Livestock and Plant production (Kazakhstan), Research Institute of Farming (Kyrgyzstan), Tajik Academy of Agricultural Science (Tajikistan)
Data collection site	: Irrigated and rainfed basins of Kazakhstan, Kyrgyzstan, Tajikistan ar Uzbekistan

Justification:

Most calories and protein in human diets in Central Asia come from plant sources. According to FAOSTATS, wheat provides between 37 percent and 60 percent of the dietary caloric intake in Central Asian countries, and is thus the major source of calories by a considerable margin.

In 2013, Central Asia region has about 16 million ha sown to wheat (FAOSTAT 2013). However, productivity of wheat in general is low and as around 1.0 t/ha in rainfed areas and 4.0 t/ha in the irrigated areas, on the average. Wheat production in the region increased from 18 Mt in 2000 to 26 Mt in 2010, which is a quite high increase based on improved management practices combined with the use of improved varieties and irrigation. Yet, most of the region is a net importer of wheat and agricultural growth for wheat needs to be kept over or at least the same level as the population growth to meet the increasing demand at the same level until 2025.

Water scarcity, irrigation induced salinity, increasing land degradation and climate variability causing extreme events of heat, drought, and frost pose significant threats in achieving improved wheat productivity in the region. Thus, there is a need for the use of improved production practices together with improved cultivars to address these challenges and meet the increasing demand for food. Research at the International Center for Agricultural Research in the Dry Areas (ICARDA), and at other regional and national research institutes, has led to the development of appropriate technologies and management options for increased water use efficiency, including crop and soil management practices, improved germplasm and on-farm water management options. A considerable gap between awareness and adoption of new technology has been observed at the farm level. This can be attributed to a number of constraints, including technical, socioeconomic and policy factors, but most

Importantly the lack of community participation in the development and implementation of improved technologies.

As a result, there exists a gap between the potential yield and actual yield of wheat in Central Asia. An attempt has, therefore, been made to estimate yield gap in wheat and find out reasons for such a gap.

Methodology for assessing potential yields and yield gap

Current project used the existing multiyear/multi treatment data collected by "Adaptation to Climate Change in Central Asia and People's Republic of China" project funded by ADB.

In 2016, ICARDA in partnership with scientists from the national agricultural research system of Kazakhstan, Kyrgyzstan, Uzbekistan, and Tajikistan launched a new multi-disciplinary project on the "Yield Gap Analysis of Wheat Production in Central Asia" funded by the Russian Government.

The overall objective of the project thus was to increase knowledge in the field of estimate yield gap in wheat and find out reasons for such a gap and propose farming practices to reduce this gap.

The following workflow was pursued:

1) In close collaboration with partners from the national research institutes in Kazakhstan, Uzbekistan, Kyrgyzstan and Tajikistan available (historic) data sets on the field testing of various wheat varieties located in all major agro-ecological zones of Central Asia were collected. Available results (grain yield, straw yield, N-uptake, phenological characteristics, etc.) as well as accompanying soil characteristics were screened and structured. Data sets from altogether 18 sites for 14 different bread wheat cultivars were collected to calibrate and validate CropSyst Model in order to estimate yield gap.
2) Major biophysical model parameters of the daily time step crop-soil simulation model, CropSyst (Stöckle *et al.* 2003), were calibrated to the available data sets.
3) ICARDA's GIS-unit provided regionally downscaled climate change (CC) maps for Central Asia derived from a range of Global Climate Models (GCMs). De Pauw *et al.* (see separate report) distinguished three future periods, namely *immediate-future* (year 2011-2040), *mid-term future* (2041-2070) and *long-term future* (2071-2100).
4) The CropSyst model calibration was done on the basis of experimental data obtained from 18 sites within different agro-ecological zones. Information on currently used farmer's management practices, including Nitrogen fertilizers application and irrigation for the selected agro-ecosystems obtained from the results of survey carried out by local NARES were fed into the model.

The present report provides an in-depth description of the study.

1 Methodology

1.1 Agro-ecological Zoning

One of the main criteria of selecting suitable sites for this study was their representativeness. This was assured by matching site locations with major agro-ecological zones (AEZ) of Central Asia, which are most suitable for cultivation of wheat and as had been identified by ICARDA's GIS-unit (de Pauw and co-workers; De Pauw 2010; and **Error! Reference source not found.**).

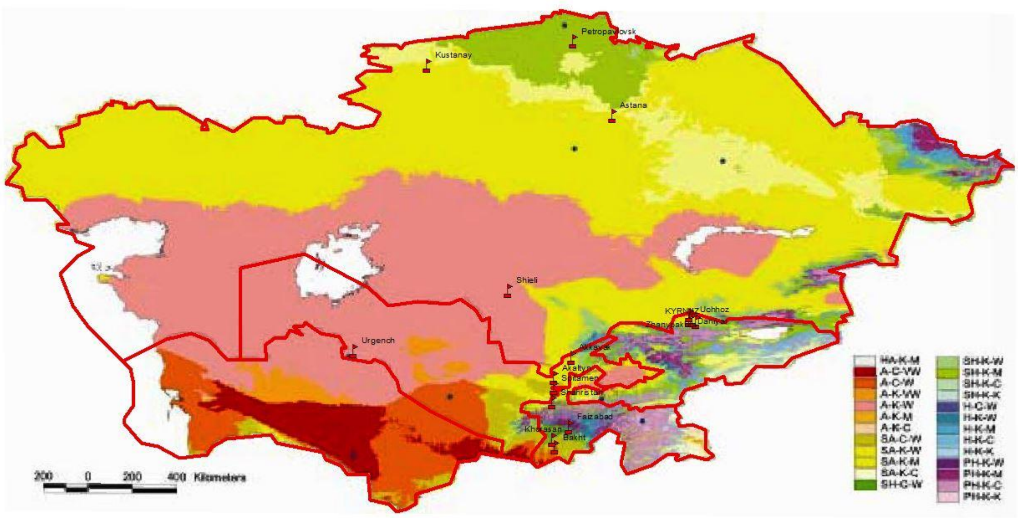

Figure 1: Agro-ecological zones suitable for cultivation of wheat in Central Asia (de Pauw, 2010), and sites selected for the study

Table 1: Description of agro-ecological zones of Central Asia selected for this study

Country	Province	Site name	AEZ	Agro Cilmat Explanation	Salinity_D
Kazakhstan	Kyzylordinskaya	Shieli	A-k-W	Arid, cold winter, warm summer	Irrigated -Low salinity
Kazakhstan	Kustanayskaya	Kustanay	SA-K-W	Semi-arid, cold winter, warm summer	Rainfed-Low salinity
Kazakhstan	Sever-Kazakhstanskay	Astana	SA-K-W	Semi-arid, cold winter, warm summer	Rainfed-Medium Salinity
Kazakhstan	Sever-Kazakhstanskay	Petropavlovsk	SA-K-W	Semi-arid, cold winter, warm summer	Rainfed-Low Salinity
Kazakhstan	Atyrauskaya	Makat	A-K-W	Arid, cold winter, warm summer	Rainfed - Medium Salinity
Kazakhstan	Jambylslkaya	Sarysu	A-K-W	Arid, cold winter, warm summer	Rainfed - High Salinity
Kazakhstan	Yujno-kazachstanskaya	Suzak	A-K-W	Arid, cold winter, warm summer	Rainfed - Low Salinity
Kazakhstan	Vostochno-kazachstanskaya	Zaysan	SA-K-W	Semi-arid, cold winter, warm summer	Rainfed - Low Salinity
Kazakhstan	Zapadno-kazachstanskaya	Zelyenov	SA-K-W	Semi-arid, cold winter, warm summer	Rainfed - High Salinity
Kazakhstan	Severo-kazachstanskaya	Bulayev	SH-K-M	Sub-humid, cold winter, warm summer	Rainfed- Medium Salinity

Kazakhstan	Almatinskaya	Raimbek	SH-K-M	Sub-humid, cold winter, warm summer	Rainfed - High Salinity
Kyrgyzstan	Bishkek province (Chiu Valley)	Daniyar	SA-K-W	Semi-arid, cold winter, warm summer	Irrigated - High Salinity
Tajikistan	Bokhtar	Bakht	SA-C-W	Sub-humid, cold winter, warm summer	Rainfed-High Salinity
Uzbekistan	Syrdarya province	Akaltyn	A-K-W	Arid, cold winter, warm summer	Irrigated-High Salinity
Uzbekistan	Khorezm province	Urgench	SA-K-W	Semi-arid, cold winter, warm summer	Irrigated-Medium Salinity
Uzbekistan	Karakalpakstan	Chimbay district	A-K-W	Arid, cold winter, warm summer	Irrigated - Medium Salinity
Uzbekistan	Bukhara	Peshku district	A-C-W	Arid, cool winter, warm summer	Irrigated - Low Salinity
Uzbekistan	Bukhara	Karakul district	A-C-W	Arid, cool winter, warm summer	Irrigated-High Salinity

The selected sites cover whole Central Asia and are located in the most of the above-mentioned AEZs.

1.2 CropSyst model description

The CropSyst crop model (Stöckle *et al.* 2003) was used to simulate wheat productivity in Central Asia under the different interventions for each of the 18 sites. Therefore, major biophysical model parameters were calibrated to the available data sets.

CropSyst has been explained in length in some other publications (Stöckle *et al.* 2003; Sommer *et al.* 2007 and 2008; Giannakopoulos *et al.* 2009; Djumaniyazova *et al.* 2010) and therefore only a very brief overview is provided here:

We used CropSyst version 4.19.06, which is a multi-year, multi-crop, daily time-step crop-soil model that simulates crop canopy development, root growth, crop biomass production and yield, the water, salt and nitrogen (N) budget, the soil-plant nitrogen budget, as well as residue and organic matter inputs and soil organic matter decomposition. The model allows the user to specify management parameters and to enable or disable different sub-routines.

In CropSyst crop development is a function of accumulated growing degree days (GDDs). Daily potential biomass accumulation is governed by either daily potential transpiration-dependent biomass accumulation or daily radiation-dependent growth, whichever is lower. We applied the new Transpiration Use Efficiency (TUE) model implemented in CropSyst since version 4.13.04, which uses a regression based approach to determine TUE under given conditions of atmospheric vapor pressure deficit (VPD). TUE depends on the TUE (g Biomass/kg H_2O) when VPD is 1 kPa and the scaling coefficient for the TUE regression power function as detailed in Kemanian *et al.* (2005) and Stöckle *et al.* (2009). We kept the scaling coefficient for the TUE regression at its default value of 0.45. The TUE at VPD equal 1 kPa was calibrated manually.

We used the Leaf Area Index (LAI) based growth sub-model of CropSyst, enabled the nitrogen (i.e. the simulation of all N-related dynamics including crop N-stress and nitrate leaching), soil freezing and snow accumulation subroutines.

The calculation of daily potential evapotranspiration follows the crop coefficients approach (analogous to Allen *et al.*, 1998) and uses either the Penman-Monteith or the Priestley-Taylor method. We selected the Penman-Monteith method, as this is the most suitable method to assess reference evapotranspiration under conditions of high VPD in arid environments, as they are characteristic for the lowlands of Central Asia.

For simulating soil water dynamics, the finite difference method of CropSyst was applied that builds on the Richards equation and the Campbell (1985) model to describe soil water retention and hydraulic conductivity. Corresponding soil physical parameters were derived by application of the pedo-transfer functions of Saxton and Willey (2006). If applicable, shallow groundwater as well as saline soil and groundwater (salinity subroutine) conditions were considered in the simulations.

Simulations also took into account the increase in atmospheric CO_2 concentrations in a CC future (see **Error! Reference source not found.**). Higher CO_2 concentrations affect crop growth in various ways (see Tubiello *et al.* 2000), overall leading to a so-called carbon fertilization effect, i.e. improved plant growth.

Most of CropSyst's model parameters were kept at the recommended default values. The following major model parameters were subject of careful calibration using field observation of crop growth, yield, water and N-dynamics, as far as these were available for the different experiments:

Thermal times, photoperiod:

- Base temperature
- Cutoff temperature
- Accumulated growing degree days from seeding to
  - emergence
  - reach maximum rooting depth
  - end of vegetative growth
  - flowering
  - beginning grain filling
  - maturity
- Leaf area duration
- Leaf area duration sensitivity to water stress

Transpiration, canopy growth:

- Maximum expected LAI
- Specific leaf area, SLA
- Leaf/stem partition coefficient, SLP

Physiological growth, harvest:

- Transpiration use efficiency when VPD is 1 kPa
- Unstressed harvest index
- Sensitivity to water and N stress during flowering
- Sensitivity to water and N stress during grain filling
- Duration of unstressed grain filling period
- Sensitivity to temperature stress during flowering

Root, nitrogen

- Maximum rooting depth
- Nitrogen demand adjustment
- Max N concentration of chaff and stubble

- Standard root N concentration
- Residual soil N not available for uptake
- Soil N at which uptake starts decreasing

Hardiness

- Temperature that begins to damage plant
- Temperature which is lethal to plant
- Number of days before maturity to salvage yield

Results of the model calibration are presented in chapter 1.3.

1.3 Calibration results

During the calibration process, some of the model parameters related to crop transpiration, canopy growth, were kept at model defaults. Others were modified to improve model accuracy (**Table 2-Tabe 4**). Measured aboveground biomass (AGB) and grain yield of wheat of the eight entries of winter/spring wheat planted in Central Asian countries were compared with the simulated results.

For the varieties Saratovskaya 29, Almaly, Polovchanka, Kupava, Jagger, Intensivnaya and Jagger the RMSE between observed and simulated grain yields were 246, 467, 306, 844, 984, 667 and 571 Mg ha^{-1} and between observed and simulated AGB were 689, 1870, 853, 1617, 2271, 1839 and 1733 Mg ha^{-1} (Figure 2), respectively. The corresponding RRMSE was 16, 23, 12, 18, 22, 20 and 18 % for grain yield, and 22, 26, 14, 14, 22, 19 and 17 % for AGB.

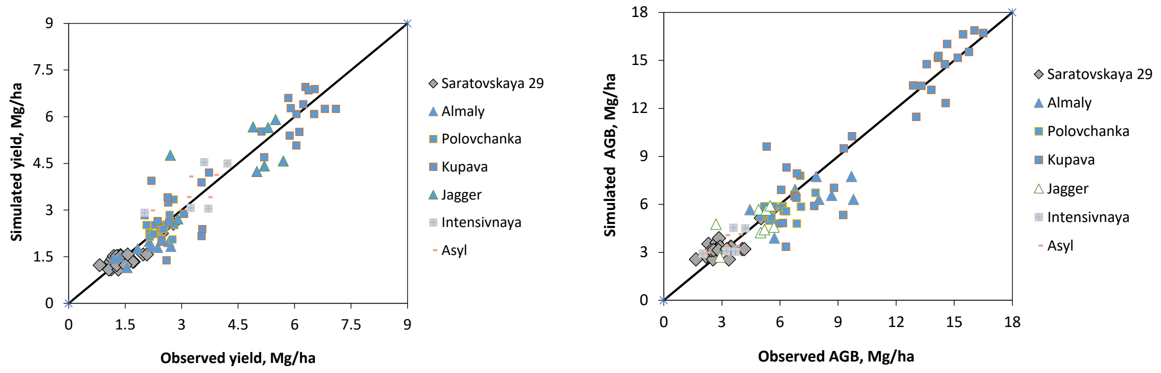

Figure 2: Simulated vs. observed grain yield (left) and aboveground biomass (right) for the 7 varieties of wheat grown at CAC countries

The RMSE between observed and simulated grain yield was 0.62 Mg ha^{-1} (RMSE =20.2%) (Figure3) and that between observed and simulated aboveground biomass was 1.44 Mg ha^{-1} (RMSE= 18.5%) (**Figure 4**) for all experimental sites in Central Asia.

Results of validation of CropSyst parameters for Dustlik, Saratovskaya 55, Karlygash, Steklovidnya 24, Arna, Saratovskaya 42, Akmola 2, Kroshka and Kupava indicate that RMSE between observed and simulated grain yield was 0.60 Mg ha^{-1} (RMSE =24%) (**Table 5)**

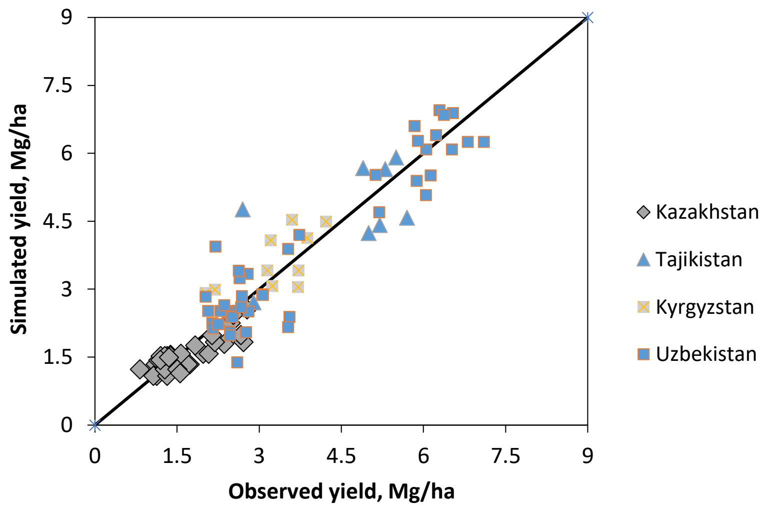

Figure 3: Simulated vs. observed grain yield at all Central Asian sites

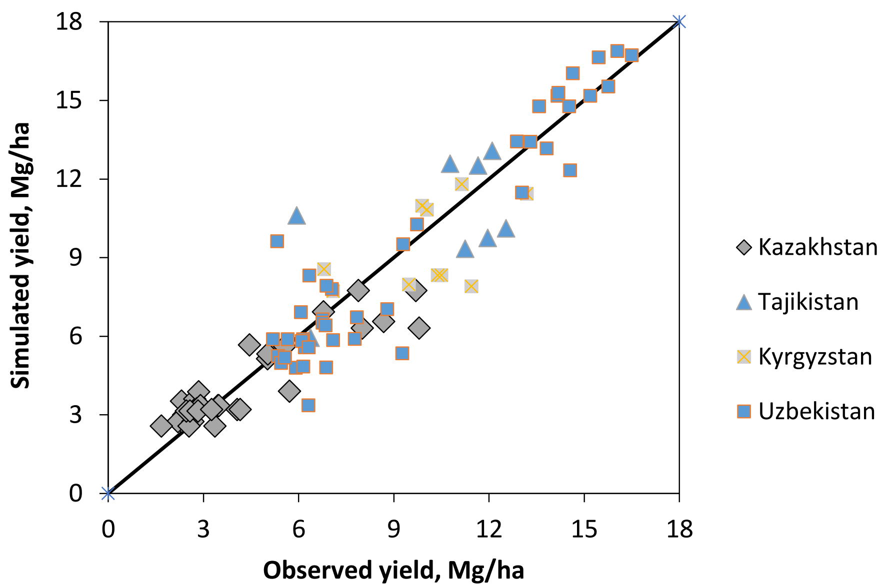

Figure 4: Simulated vs. observed aboveground biomass (AGB) at all Central Asian sites

Table 2 Summary of CropSyst model settings for the wheat varieties Polovchanka*, Almali, Kupava and Saratovskaya 29* grown in Uzbekistan and Kazakstan; C = calibrated; D = default; O = observed; Lit = literature values

Location	Akaltyn		Shieli		Urgench		Kustanay		Astana		Petropavlovsk	
Variety	**Polovchanka**		**Almali**		**Kupava**		**Saratovskaya 29**		**Saratovskaya 29**		**Saratovskaya 29**	
Parameters	Value	Source	Value	Source	Value	Source	Value	Source	Value	Source	Value	Source
Thermal times, Photoperiod												
Base temperature (°C)	2	C	2	C	3	C	0	C	0	C	0	C
Cutoff temperature (°C)	22	C	23	C	25	C	22	C	22	C	22	C
Accumulated growing degree days from seeding to												
emergence (°C day)	182	O	155	O	94	O	365	O	270	O	280	O
reach maximum rooting depth (°C day)	490	C	550	C	440	C	925	C	875	C	950	C
end of vegetative growth	500	O	583	O	510	O	928	O	900	O	980	O
flowering (°C day)	500	O	583	O	507	O	928	O	900	O	980	O
beginning grain filling (°C day)	620	O	638	O	590	O	1000	O	975	O	1035	O
maturity (°C day)	1218	O	1300	O	1040	O	1452	O	1412	O	1360	O
Adjustment factor for phenological response to stress (0-1)	1.0	D	1.0	D	1.0	D	1.0	D	1.0	D	1.0	D
Leaf area duration (°C day)	600	O	630	O	600	O	900	O	900	O	900	O
Leaf area duration sensitivity to water stress (0-3)	1	C	1	C	1	C	1	C	1	C	1	C
Transpiration, Canopy growth												
Initial green LAI (fraction)	0.011	O	0.011	O	0.011	O	0.011	O	0.011	O	0.011	O
Min green LAI for regrowth (fraction)	0.011	O	0.011	O	0.011	O	0.011	O	0.011	O	0.011	O
Maximum expected LAI (m2/m2)	6.0	O	7.0	O	7.0	O	7.0	O	7.0	O	7.0	O
Specific LAI at optimum temperature (m2/kg)	18.0	C	18.0	C	25.0	C	20.0	C	13.0	C	22.0	C
Fraction of max LAI at physiological maturity	0.8	C	0.8	C	0.8	C	0.8	C	0.8	C	0.8	C
Stem/Leaf portioning coefficient	1.6	C	1.8	C	2.0	C	1.8	C	1.8	C	1.8	C
Leaf water potential for reduction of canopy expansion ($J\ kg^{-1}$)	-800	D	-800	D	-1400	D	-800	D	-800	D	-800	D
Leaf water potential that stops canopy expansion ($J\ kg^{-1}$)	-1200	D	-1200	D	-2000	D	-1200	D	-1200	D	-1200	D
Canopy extinction coefficient (0-1)	0.57	C	0.57	C	0.40	C	0.57	C	0.57	C	0.57	C
Evapotranspiration crop coefficient at fully canopy	1.15	D	1.1	D	1.15	D	1.10	D	1.10	D	1.10	D

Location	Akaltyn		Shieli		Urgench		Kustanay		Astana		Petropavlovsk	
Variety	**Polovchanka**		**Almali**		**Kupava**		**Saratovskaya 29**		**Saratovskaya 29**		**Saratovskaya 29**	
Parameters	Value	Source	Value	Source	Value	Source	Value	Source	Value	Source	Value	Source
Maximum water uptake (mm d^{-1})	10	D	10	D	10	D	10	D	10	D	10	D
Leaf water potential at the onset of stomatal closure (J kg^{-1})	-700	D	-700	D	-1330	D	-700	D	-700	D	-700	D
Wilting leaf water potential (J kg^{-1})	-1600	D	-1800	D	-2000	D	-1800	D	-1500	D	-1600	D
Physiological growth, Harvest												
Transpiration use efficiency when VPD is 1 kPa (g BM/kg H_20)	5.0	C	5.15	C	6.0	C	5.0	C	5.2	C	5.0	C
Scaling coefficient of TUE regression (power function)	0.45	C/D	0.45	C/D	0.45	C/D	0.45	C/D	0.45	C/D	0.45	C/D
PAR use efficiency (g MJ^{-1})	3.0	C/D	3.0	C/D	3.5	C/D	2.8	C/D	3.0	C/D	3.0	C/D
Mean daily temperature that limits early growth (°C)	10	D	10	D	10	D	10	D	10	D	10	D
Unstressed harvest index (HI)	0.43	O	0.48	O	0.48	O	0.49	O	0.49	O	0.49	O
Root, Nitrogen, Salinity												
Maximum rooting depth (m)	1.2	C	0.8	C	1.1	C	0.9	C	0.9	C	1.3	C
Root/shoot (mass) ratio at emergence	2.0	D	2	D	2	D	2	D	2	D	2	D
Root/shoot (mass) ratio at full extent	0.1	D	0.1	D	0.1	D	0.1	D	0.1	D	0.1	D
Max. surface root density at full rooting depth (cm cm^{-3})	6	D	5	D	4	D	6	D	4	D	6	D
Curvature of root density distribution (0.0001-6)	1	C	0.5	C	0.01	C	0.1	C	0.01	C	0.5	C
Root sensitivity to water stress	0	C	1	C	1	C	0	C	1	C	0	C
Soil solution osmotic potential to 50% yield reduction (kPa)	-504	Lit.	-504	Lit.	-504	Lit.	-504	Lit.	-504	Lit.	-504	Lit.
Salinity tolerance exponent (Van-Genuchten) (1-5)	3.0	D	3.00	D	3.00	D	3.0	D	3.0	D	3.0	D
Nitrogen demand adjustment (0-1)	0.9	C	0.8	C			0.8	C	0.8	C	0.8	C
Biomass to start dilution of maximum N concentration (tn/ha)	5.0	C	1.5	C	5.0	C	1.5	C	5.0	C	1.5	C
Critical N concentration at emergence (kgN kg^{-1} DM)					0.013	C			0.007	C		
Maximum N concentration at emergence (kgN kg^{-1} DM)					0.013	C			0.024	C		
Max above ground concentration at maturity (kgN kg^{-1} DM)	0.023	C	0.023	C	0.018	C	0.023	C	0.018	C	0.023	C
Max N concentration of chaff and stubble (kg kg^{-1} DM)	0.007	C	0.007	C	0.006	C	0.007	C	0.007	C	0.007	C
Standard root N concentration (kg kg^{-1} DM)	0.007	C	0.007	C	0.002	C	0.007	C	0.002	C	0.007	C
Concentration curve slope (0-1)	0.5	C	0.25	C	0.10	C	0.562	C	0.100	C	0.562	C

	Location	Akaltyn		Shieli		Urgench		Kustanay		Astana		Petropavlovsk	
	Variety	Polovchanka		Almali		Kupava		Saratovskaya 29		Saratovskaya 29		Saratovskaya 29	
	Parameters	Value	Source	Value	Source	Value	Source	Value	Source	Value	Source	Value	Source
	End dilution curve (°C-days)	1000	C	0	C	1000	C	0	C	975	C	0	C
	Maximum N uptake during rapid linear growth (kg ha^{-1} d^{-1})	5	D	5	D	4	D	5	D	5	D	5	D
	Residual soil N not available for uptake (mg kg^{-1})	2	C	5	C	3	C	3	C	5	C	3	C
	Soil N at which uptake starts decreasing (mg kg^{-1})	12	C	20	C	14	C	20	C	15	C	10	C
	Plant avail. water at which N uptake start decreasing (0-1)	0.5	D	0.7	D	0.7	D	0.7	D	0.7	D	0.5	D
Hardiness													
	Temperature that begins to damage plant (°C)	-8	C	-5	C	-17	C	-5	C	-15	C	-5	C
	Temperature which is lethal to plant (°C)	-20	C	-35	C	-38	C	-20	C	-40	C	-20	C
	Thermal time at which grain filling may continue after lethal frost (°C days)	1200	C	1200	C	1200	C	1200	C	1200	C	1200	C

Table 3 Summary of CropSyst model settings for the wheat varieties Polovchanka, Almali, Dustlik, Saratovskaya 55, Karlygash, Steklovidnaya 24 grown in Tajikistan, Kyrgystan and Kazakhstan ; C = calibrated; D = default; O = observed; Lit = literature values

	Location	Bokhtar		Daniyar		Chimbay		Makat		Sarysu		Suzak	
	Variety	Polovchanka		Almali		Dustlik		Saratovskaya 55		Karlygash		Steklovidnaya 24	
	Parameters	Value	Source	Value	Source	Value	Source	Value	Source	Value	Source	Value	Source
Thermal times, Photoperiod													
	Base temperature (°C)	1	C	2	C	3	C	0	C	0	C	0	C
	Cutoff temperature (°C)	21	C	23	C	25	C	22	C	22	C	22	C
	Accumulated growing degree days from seeding to												
	emergence (°C day)	145	O	115	O	94	O	325	O	220	O	325	O
	reach maximum rooting depth (°C day)	450	C	425	C	440	C	925	C	875	C	925	C
	end of vegetative growth	460	O	430	O	510	O	1158	O	850	O	958	O
	flowering (°C day)	460	O	430	O	507	O	1158	O	850	O	958	O
	beginning grain filling (°C day)	570	O	490	O	590	O	1220	O	975	O	1020	O

Location	**Bokhtar**		**Daniyar**		**Chimbay**		**Makat**		**Sarysu**		**Suzak**	
Variety	**Polovchanka**		**Almali**		**Dustlik**		**Saratovskaya 55**		**Karlygash**		**Steklovidnaya 24**	
Parameters	Value	Source	Value	Source	Value	Source	Value	Source	Value	Source	Value	Source
maturity (°C day)	1112	O	1300	O	1040	O	1500	O	1412	O	1412	O
Adjustment factor for phenological response to stress (0-1)	1.0	D	1.0	D	1.0	D	1.0	D	1.0	D	1.0	D
Leaf area duration (°C day)	650	O	630	O	600	O	900	O	900	O	900	O
Leaf area duration sensitivity to water stress (0-3)	1	C	1	C	1	C	1	C	1	C	1	C
Transpiration, Canopy growth												
Initial green LAI (fraction)	0.011	O	0.011	O	0.011	O	0.011	O	0.011	O	0.011	O
Min green LAI for regrowth (fraction)	0.011	O	0.011	O	0.011	O	0.011	O	0.011	O	0.011	O
Maximum expected LAI (m2/m2)	7.0	O	7.0	O	7.0	O	7.0	O	7.0	O	7.0	O
Specific LAI at optimum temperature (m2/kg)	20.0	C	22.0	C	25.0	C	12.8	C	13.0	C	12.8	C
Fraction of max LAI at physiological maturity	0.8	C	0.8	C	0.8	C	0.8	C	0.8	C	0.8	C
Stem/Leaf portioning coefficient	1.8	C	1.8	C	2.0	C	1.8	C	1.8	C	1.8	C
Leaf water potential for reduction of canopy expansion (J kg^{-1})	-800	D	-800	D	-1400	D	-800	D	-800	D	-800	D
Leaf water potential that stops canopy expansion (J kg^{-1})	-1200	D	-1200	D	-2000	D	-1200	D	-1200	D	-1200	D
Canopy extinction coefficient (0-1)	0.57	C	0.57	C	0.40	C	0.57	C	0.57	C	0.57	C
Evapotranspiration crop coefficient at fully canopy	1.15	D	1.15	D	1.15	D	1.10	D	1.10	D	1.10	D
Maximum water uptake (mm d^{-1})	10	D	10	D	10	D	10	D	10	D	10	D
Leaf water potential at the onset of stomatal closure (J kg^{-1})	-700	D	-700	D	-1330	D	-700	D	-700	D	-700	D
Wilting leaf water potential (J kg^{-1})	-1600	D	-1600	D	-2000	D	-1500	D	-1500	D	-1500	D
Physiological growth, Harvest												
Transpiration use efficiency when VPD is 1 kPa (g BM/kg H_20)	6.5	C	7.0	C	6.0	C	6.0	C	5.2	C	5.0	C
Scaling coefficient of TUE regression (power function)	0.40	C/D	0.45	C/D	0.45	C/D	0.45	C/D	0.45	C/D	0.48	C/D
PAR use efficiency (g MJ^{-1})	3.4	C/D	3.0	C/D	3.5	C/D	3.0	C/D	3.0	C/D	3.0	C/D
Mean daily temperature that limits early growth (°C)	10	D	10	D	10	D	10	D	10	D	10	D
Unstressed harvest index (HI)	0.46	O	0.46	O	0.42	O	0.48	O	0.49	O	0.49	O
Root, Nitrogen, Salinity												
Maximum rooting depth (m)	1.5	C	1.0	C	1.1	C	0.9	C	1,0	C	1.5	C

Location	Bokhtar		Daniyar		Chimbay		Makat		Sarysu		Suzak	
Variety	**Polovchanka**		**Almali**		**Dustlik**		**Saratovskaya 55**		**Karlygash**		**Steklovidnaya 24**	
Parameters	Value	Source	Value	Source	Value	Source	Value	Source	Value	Source	Value	Source
Root/shoot (mass) ratio at emergence	2.0	D	2	D	2	D	2	D	2	D	2	D
Root/shoot (mass) ratio at full extent	0.1	D	0.1	D	0.1	D	0.1	D	0.1	D	0.1	D
Max. surface root density at full rooting depth (cm cm^{-3})	6	D	6	D	4	D	6	D	4	D	6	D
Curvature of root density distribution (0.0001-6)	0.1	C	0.1	C	0.01	C	0.1	C	0.01	C	0.1	C
Root sensitivity to water stress	0	C	0	C	1	C	0	C	1	C	0	C
Soil solution osmotic potential to 50% yield reduction (kPa)	-504	Lit.	-504	Lit.	-504	Lit.	-504	Lit.	-504	Lit.	-504	Lit.
Salinity tolerance exponent (Van-Genuchten) (1-5)	3.0	D	3.00	D	3.00	D	3.0	D	3.0	D	3.0	D
Nitrogen demand adjustment (0-1)	0.85	C	0.8	C					0.8	C	0.8	C
Biomass to start dilution of maximum N concentration (tn/ha)	3.0	C	1.5	C	5.0	C	3.0	C	5.0	C	3.0	C
Critical N concentration at emergence (kgN kg^{-1} DM)					0.007	C	0.005	C	0.007	C	0.005	C
Maximum N concentration at emergence (kgN kg^{-1} DM)					0.024	C	0.010	C	0.024	C	0.010	C
Max above ground concentration at maturity (kgN kg^{-1} DM)	0.023	C	0.023	C	0.018	C	0.023	C	0.018	C	0.023	C
Max N concentration of chaff and stubble (kg kg^{-1} DM)	0.007	C	0.006	C	0.006	C	0.007	C	0.007	C	0.007	C
Standard root N concentration (kg kg^{-1} DM)	0.007	C	0.006	C	0.002	C	0.007	C	0.002	C	0.007	C
Concentration curve slope (0-1)	0.5	C	0.562	C	0.10	C	0.500	C	0.100	C	0.500	C
End dilution curve (°C-days)	1000	C	0	C	1000	C	1000	C	975	C	1000	C
Maximum N uptake during rapid linear growth (kg ha^{-1} d^{-1})	5	D	5	D	5	D	5	D	5	D	5	D
Residual soil N not available for uptake (mg kg^{-1})	2	C	2	C	3	C	0.5	C	5	C	0.5	C
Soil N at which uptake starts decreasing (mg kg^{-1})	10	C	10	C	10	C	10	C	15	C	10	C
Plant avail. water at which N uptake start decreasing (0-1)	0.5	D	0.5	D	0.7	D	0.7	D	0.7	D	0.7	D
Hardiness												
Temperature that begins to damage plant (°C)	-20	C	-15	C	-30	C	-5	C	-15	C	-5	C
Temperature which is lethal to plant (°C)	-30	C	-35	C	-45	C	-20	C	-40	C	-20	C
Thermal time at which grain filling may continue after lethal frost (°C days)	1200	C	1200	C	1200	C	1200	C	1200	C	1200	C

Table 4 Summary of CropSyst model settings for the wheat varieties Arna, Saratovskaya 42, Akmola, Kroshka and Kupava grown in Kazakhstan and Uzbekistan; C = calibrated; D = default; O = observed; Lit = literature values

Location	Zaysan		Zeleyonov		Bulayev		Raimbek		Peshku		Karakul	
Variety	Arna		Saratovskaya 42		Akmola 2		Arna		Kroshka		Kupava	
Parameters	Value	Source	Value	Source	Value	Source	Value	Source	Value	Source	Value	Source
Thermal times, Photoperiod												
Base temperature (°C)	0	C	0	C	0	C	0	C	2	C	2	C
Cutoff temperature (°C)	22	C	22	C	22	C	22	C	22	C	22	C
Accumulated growing degree days from seeding to												
emergence (°C day)	325	O	325	O	325	O	325	O	102	O	102	O
reach maximum rooting depth (°C day)	925	C	925	C	925	C	925	C	520	C	520	C
end of vegetative growth	1158	O	1158	O	1158	O	1158	O	600	O	600	O
flowering (°C day)	1158	O	1158	O	1158	O	1158	O	500	O	500	O
beginning grain filling (°C day)	1220	O	1220	O	1220	O	1220	O	540	O	540	O
maturity (°C day)	1450	O	1500	O	1500	O	1450	O	1218	O	1218	O
Adjustment factor for phenological response to stress (0-1)	1.0	D	1.0	D	1.0	D	1.0	D	1.0	D	1.0	D
Leaf area duration (°C day)	800	O	900	O	900	O	800	O	1100	O	1100	O
Leaf area duration sensitivity to water stress (0-3)	0.5	C	1	C	1	C	0.5	C	1	C	1	C
Transpiration, Canopy growth												
Initial green LAI (fraction)	0.011	O	0.011	O	0.011	O	0.011	O	0.011	O	0.011	O
Min green LAI for regrowth (fraction)	0.011	O	0.011	O	0.011	O	0.011	O	0.011	O	0.011	O
Maximum expected LAI (m2/m2)	7.0	O	7.0	O	7.0	O	7.0	O	6.0	O	6.0	O
Specific LAI at optimum temperature (m2/kg)	12.8	C	12.8	C	12.8	C	12.8	C	22.0	C	22.0	C
Fraction of max LAI at physiological maturity	0.8	C	0.8	C	0.8	C	0.8	C	0.8	C	0.8	C
Stem/Leaf portioning coefficient	1.8	C	1.8	C	1.8	C	1.8	C	1.6	C	1.6	C
Leaf water potential for reduction of canopy expansion (J kg^{-1})	-800	D	-800	D	-800	D	-800	D	-800	D	-800	D
Leaf water potential that stops canopy expansion (J kg^{-1})	-1200	D	-1200	D	-1200	D	-1200	D	-1200	D	-1200	D
Canopy extinction coefficient (0-1)	0.57	C	0.57	C	0.57	C	0.57	C	0.57	C	0.57	C
Evapotranspiration crop coefficient at fully canopy	1.00	D	1.10	D	1.10	D	1.00	D	1.15	D	1.15	D

Location	Zaysan		Zeleyonov		Bulayev		Raimbek		Peshku		Karakul	
Variety	**Arna**		**Saratovskaya 42**		**Akmola 2**		**Arna**		**Kroshka**		**Kupava**	
Parameters	Value	Source	Value	Source	Value	Source	Value	Source	Value	Source	Value	Source
Maximum water uptake (mm d^{-1})	10	D	10	D	10	D	10	D	10	D	10	D
Leaf water potential at the onset of stomatal closure (J kg^{-1})	-700	D	-700	D	-700	D	-700	D	-700	D	-700	D
Wilting leaf water potential (J kg^{-1})	-1500	D	-1500	D	-1500	D	-1500	D	-1600	D	-1600	D
Physiological growth, Harvest												
Transpiration use efficiency when VPD is 1 kPa (g BM/kg $H_2$0)	5.0	C	5.0	C	6.0	C	5.0	C	5.0	C	7.0	C
Scaling coefficient of TUE regression (power function)	0.45	C/D	0.45	C/D	0.45	C/D	0.45	C/D	0.45	C/D	0.45	C/D
PAR use efficiency (g MJ^{-1})	3.0	C/D	3.0	C/D	3.0	C/D	3.0	C/D	3.0	C/D	3.0	C/D
Mean daily temperature that limits early growth (°C)	10	D	10	D	10	D	10	D	10	D	10	D
Unstressed harvest index (HI)	0.48	O	0.48	O	0.48	O	0.48	O	0.43	O	0.43	O
Root, Nitrogen, Salinity												
Maximum rooting depth (m)	1.0	C	1.3	C	1.5	C	1.0	C	1.0	C	1.0	C
Root/shoot (mass) ratio at emergence	2.0	D	2	D	2	D	2	D	2	D	2	D
Root/shoot (mass) ratio at full extent	0.1	D	0.1	D	0.1	D	0.1	D	0.1	D	0.1	D
Max. surface root density at full rooting depth (cm cm^{-3})	6	D	6	D	6	D	6	D	6	D	6	D
Curvature of root density distribution (0.0001-6)	0.1	C	0.1	C	0.1	C	0.1	C	1.0	C	1.0	C
Root sensitivity to water stress	0.5	C	0	C	0	C	0.5	C	0	C	0	C
Soil solution osmotic potential to 50% yield reduction (kPa)	-504	Lit.	-504	Lit.	-504	Lit.	-504	Lit.	-504	Lit.	-504	Lit.
Salinity tolerance exponent (Van-Genuchten) (1-5)	3.0	D	3.00	D	3.00	D	3.00	D	3.0	D	3.0	D
Nitrogen demand adjustment (0-1)									0.9	C	0.9	C
Biomass to start dilution of maximum N concentration (tn/ha)	3.0	C	3.0	C	3.0	C	3.0	C	5.0	C	5.0	C
Critical N concentration at emergence (kgN kg^{-1} DM)	0.005	C	0.005	C	0.005	C	0.005	C				
Maximum N concentration at emergence (kgN kg^{-1} DM)	0.010	C	0.010	C	0.010	C	0.010	C				
Max above ground concentration at maturity (kgN kg^{-1} DM)	0.023	C	0.023	C	0.023	C	0.023	C	0.023	C	0.023	C
Max N concentration of chaff and stubble (kg kg^{-1} DM)	0.007	C	0.007	C	0.007	C	0.007	C	0.007	C	0.007	C
Standard root N concentration (kg kg^{-1} DM)	0.007	C	0.007	C	0.007	C	0.007	C	0.007	C	0.007	C
Concentration curve slope (0-1)	0.5	C	0.5	C	0.5	C	0.5	C	0.5	C	0.5	C

	Location	Zaysan		Zeleyonov		Bulayev		Raimbek		Peshku		Karakul	
	Variety	**Arna**		**Saratovskaya 42**		**Akmola 2**		**Arna**		**Kroshka**		**Kupava**	
	Parameters	Value	Source	Value	Source	Value	Source	Value	Source	Value	Source	Value	Source
	End dilution curve (°C-days)	1000	C	1000	C	1000	C	1000	C	1000	C	1000	C
	Maximum N uptake during rapid linear growth (kg ha^{-1} d^{-1})	5	D	5	D	5	D	5	D	5	D	5	D
	Residual soil N not available for uptake (mg kg^{-1})	0.5	C	0.5	C	0.5	C	0.5	C	2	C	2	C
	Soil N at which uptake starts decreasing (mg kg^{-1})	10	C	10	C	10	C	10	C	12	C	12	C
	Plant avail. water at which N uptake start decreasing (0-1)	0.7	D	0.7	D	0.7	D	0.7	D	0.5	D	0.5	D
Hardiness													
	Temperature that begins to damage plant (°C)	-5	C	-5	C	-5	C	-5	C	-25	C	-25	C
	Temperature which is lethal to plant (°C)	-20	C	-20	C	-20	C	-20	C	-40	C	-40	C
	Thermal time at which grain filling may continue after lethal frost (°C days)	1200	C	1200	C	1200	C	1200	C	1000	C	1000	C

Table 5: Validation results of CropSyst model for 10 experimental sites in Kazakhstan and Uzbekistan.

Country	Site	Wheat variety	Year	Yield obs (kg ha^{-1})	Yield sim (kg ha^{-1})	RMSE yield (kg ha^{-1})	RRMSE yield (%)
Kazakhstan	Chimbay	Dustlik	2004-05	2180	1799	602	24
		Dustlik	2005-06	2800	2820		
		Dustlik	2006-07	3020	2805		
	Makat	Saratovskaya 55	1999	1300	1769		
		Saratovskaya 55	2000	1830	1646		
		Saratovskaya 55	2001	1290	893		
	Sarysu	Karlygash	1984-85	840	909		
		Karlygash	1985-86	1670	1378		
		Karlygash	1986-87	1980	1880		
	Suzak	Steklovidnaya 24	2005-06	1480	1717		
		Steklovidnaya 24	2006-07	1820	2567		
	Zaysan	Arna	2000-01	960	1961		
		Arna	2001-02	1820	2085		
		Arna	2002-03	1270	1964		
	Zelyonov	Saratovskaya 42	1989	1110	1143		
		Saratovskaya 42	1990	1490	1472		
		Saratovskaya 42	1991	710	422		
	Bulayev	Akmola 2	2000	1320	1987		
		Akmola 2	2001	2180	1819		
		Akmola 2	2002	2700	2197		
	Raimbek	Arna	2000	850	1959		
		Arna	2001	1680	2377		
		Arna	2002	1130	1814		
Uzbekistan	Bukhara	Kroshka	2007-08	6050	6055		
		Kroshka	2008-09	5220	6470		
		Kroshka	2009-10	7350	7611		
	Karakul	Kupava	2004-05	5100	4277		
		Kupava	2005-06	5650	5157		

2 Major constrains and opportunities for bridging the yield gaps

The potential yields were estimated using a crop simulation approach and review of research station experimental data. The yields estimated coupled with the research station yields were used to estimate the yield gaps for wheat (Singh, P et al, 2009). Following successful calibration and validation of the Model different management practices were considered: early planting, supplemental pre-sowing irrigation, optimum irrigation and Nitrogen management in bridging the yield gap. We used CropSyst model to simulate potential yields of wheat at 18 Central Asian sites with different climatic and soil conditions. As mentioned above this model required weather data (daily, solar radiation, maximum and minimum temperature and rainfall data, soil profile data and cultivar specific parameters to simulate crop growth, yield and resource use by the crops. Multi-year simulation of the rainfed and irrigated wheat crop was carried out for all 18 locations and averaged over time and space to estimate the irrigated and potential yields (**Table 6** and **Table 7**) . Farmers yields were determined from the area and production data of a crop from closest farmers where experimental station data were collected (**Appendix 1**).

Table 6 Potential, research and farmers' yields at rainfed sites in Kazakhstan and Tajikistan

Country	Province name	Site name	Agroclimatic zone	Salinity	Farmers Yield (Kg/ha)	Research Results (Kg/ha)	Potential Yield (Kg/ha)	Years
Kazakhstan	Vostochno-kazachstanskaya	Zaysan	SA-K-W	Rainfed - Low Salinity	1052	1350 (+28%)	2252 (+114%)	2001-2003
Kazakhstan	Kustanayskaya	Kustanay	SA-K-W	Rainfed-Low salinity	897	1286 (+43%)	1523 (+70%)	1988-1990
Kazakhstan	Sever-Kazakhstanskay	Petropavlovsk	SA-K-W	Rainfed-Low Salinity	924	1391 (+51%)	1784 (+93%)	1988-1989
Kazakhstan	Yujno-kazachstanskaya	Suzak	A-K-W	Rainfed - Low Salinity	1420	1650 (+16%)	2391 (+68%)	2005-2007
Kazakhstan	Sever-Kazakhstanskay	Astana	SA-K-W	Rainfed-Medium Salinity	753	1454 (+93%)	1680 (+132%)	1982-1984
Kazakhstan	Atyrauskaya	Makat	A-K-W	Rainfed - Medium Salinity	960	1473 (+53%)	2224 (+132%)	1999- 2001
Kazakhstan	Severo-kazachstanskaya	Bulayev	SH-K-M	Rainfed- Medium Salinity	1116	2066 (+85%)	3345 (+200%)	2000-2002
Tajikistan	Bokhtar	Khatlon provinve	SA-C-W	Rainfed-High Salinity	2215	4650 (+110%)	5579 (+152%)	2007-2009
Kazakhstan	Jambylslkaya	Sarysu	A-K-W	Rainfed - High Salinity	1460	1496 (+2%)	2078 (+42%)	1984-1987
Kazakhstan	Zapadno-kazachstanskaya	Zelyenov	SA-K-W	Rainfed - High Salinity	950	1103 (+16%)	1788 (+88%)	1989-1991
Kazakhstan	Almatinskaya	Raimbek	SH-K-M	Rainfed - High Salinity	1053	1220 (+16%)	2189 (+108%)	2000-2002

Figures in brackets indicates % increase of yields obtained in research station and potential yield over farmers yields

Table 7 Potential, research and farmers' yields at irrigated sites in Kazakhstan, Kyrgyzstan and Uzbekistan

Country	Province name	Site name	Agroclimatic zone	Salinity	Farmers Yield (Kg/ha)	Research Results (Kg/ha)	Potential Yield (Kg/ha)	Years
Kazakhstan	Kyzylordinskaya	Shieli	A-k-W	Irrigated -Low salinity	1386	2001 (+44%)	2562 (+85%)	2003--2006
Uzbekistan	Bukhara	Peshku district	A-C-W	Irrigated - Low Salinity	5213	6206 (+19%)	6767 (+30%)	2007-2010
Uzbekistan	Khorezm province	Urgench	SA-K-W	Irrigated-Medium Salinity	4396	4745 (+8%)	6130 (+39%)	2005--2008
Uzbekistan	Karakalpakstan	Chimbay district	A-K-W	Irrigated -Medium Salinity	2531	2666 (+5%)	5951 (+135%)	2004--2007
Uzbekistan	Syrdarya province	Akaltyn	A-K-W	Irrigated-High Salinity	2238	2493 (+11%)	3180 (+42%)	2003--2006
Kyrgyzstan	Bishkek province (Chiu Valley)	Daniyar	SA-K-W	Irrigated - High Salinity	2350	3450 (+47%)	6622 (+182%)	2007-2009
Uzbekistan	Bukhara	Karakul district	A-C-W	Irrigated-High Salinity	4576	5306 (+16%)	6222 (+36%)	2004-2007

Figures in brackets indicates % increase of yields obtained in research station and potential yield over farmers yields

As indicated in above table main interventions (early sowing, pre-sowing irrigation (50 mm) and optimum Nitrogen Management) applied for rainfed Kazakstan and Tajikistan sites might increase farmer’s yields from 42 to 200% while increase of experimental station yields over farmers yields ranged from 16 to 110%.

Mean yield gap between simulated rainfed potential yield and farmer yield was 1276 kg/ha. The lowest gap (618 kg/ha) was described for Zelenov site while the maximum gap (3364 kg/ha) was for Sarysu site . At the experimental station level the gap was also highest for Zelenov site (2435 kg/ha). The mean gap at this scale was 576 kg/ha.

In irrigated sites main interventions (salinity management, optimum irrigation and optimum Nitrogen Management) applied for irrigated sites in Central Asia might increase farmer’s yields by 36 to 182% while increase of experimental station yields over farmers yields ranged from 5 to 47%.

Mean yield gap between simulated irrigated potential yield and farmer yield was 2106 kg/ha. The lowest gap (942 kg/ha) was described for Akaltyn site while the maximum gap (4272 kg/ha) was for Daniyar site . At the experimental station level the gap was also highest for Daniyar site (1100 kg/ha) and minimum for Chimbay site (135 kg/ha). The mean gap at this scale was 597 kg/ha.

Conclusion

Eighteen sites were considered in this study. These reflected all major agro-ecological zones of Central Asia suitable for wheat cultivation; rainfed (spring) wheat production predominating in the north of Kazakhstan and irrigated cropping in the more arid south of Central Asia.

CropSyst model tools showed higher efficiency as a tool to simulate crop yields both for research station, identify reasons for such gap and estimate yield gap by applying different management practices.

Thus in the main rainfed and irrigated areas in Central Asia there is sufficient gap that can be possible bridged by improved irrigation, nitrogen and salinity management in the future. Preliminary research indicated that (early sowing, pre-sowing irrigation (50 mm) and optimum Nitrogen Management) applied for rainfed sites and optimum irrigation and optimum Nitrogen Management for irrigated sites can significantly reduce this yield gap.

We considered that irrigation water would be available at least before sowing in order to get normal germination in Kazakhstan sites. Since water, deficit issues already exist in the region, targeted crop breeding towards draught and temperature tolerance in combination with improved agronomic management (shifting planting dates) may be able to tackle the issue. The current situation of excessive irrigation and subsequent secondary soil salinization being a constant threat to agricultural demands for improved irrigation and drainage management. Therefore, further research should address issues for improved irrigation management under high salinity conditions. These might include residue retention, crop rotation with alfalfa, and development of optimum leaching rates, optimum Nitrogen and Phosphorous management, crop rotation and improved varieties.

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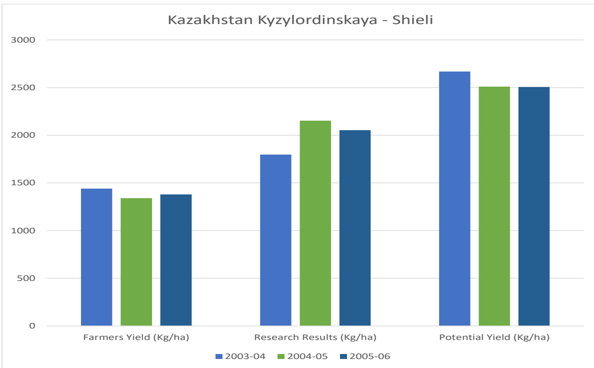
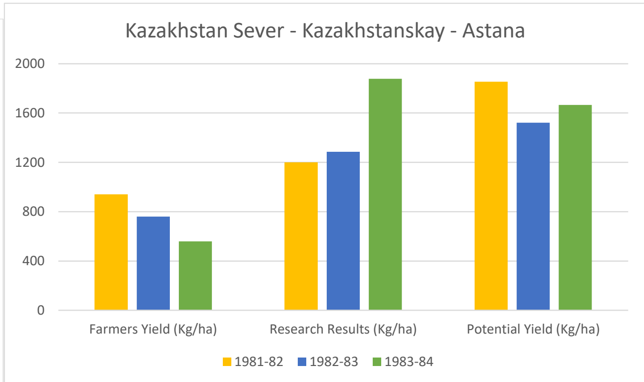
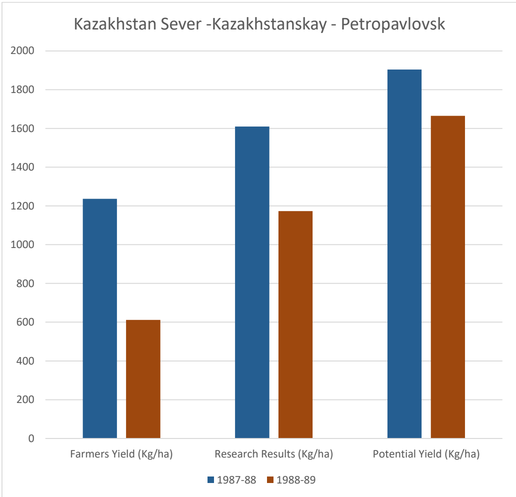
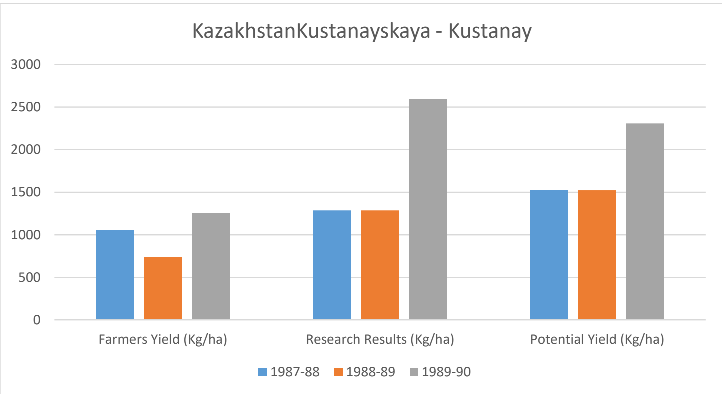
Appendix 1

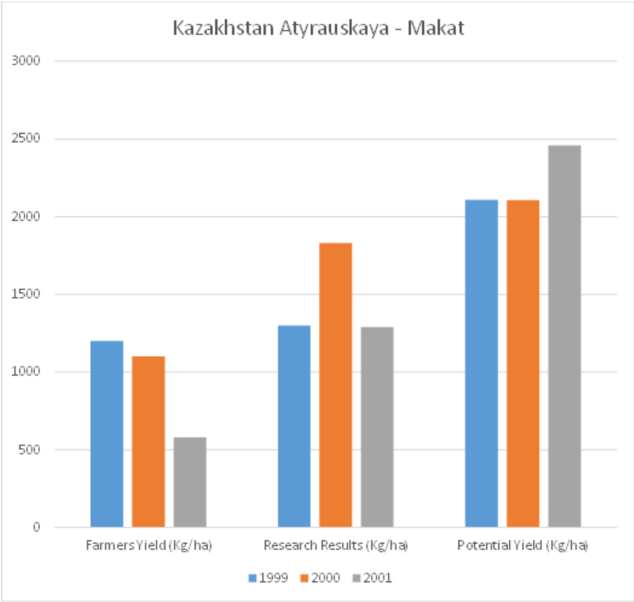
Farmers yield, research results and potential yields for 18 experimental sites in Kazakhstan, Kyrgyzstan, Tajikistan and Uzbekistan

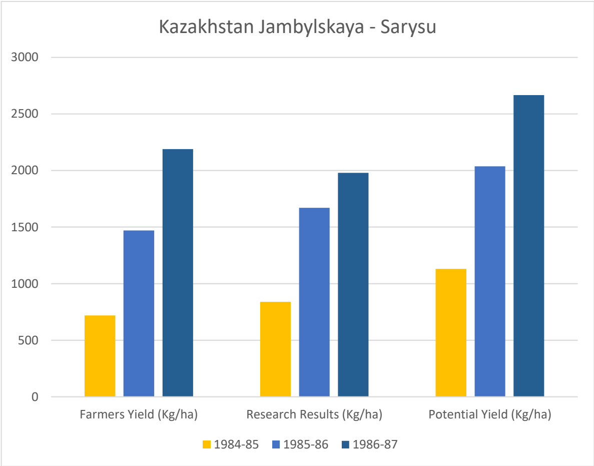


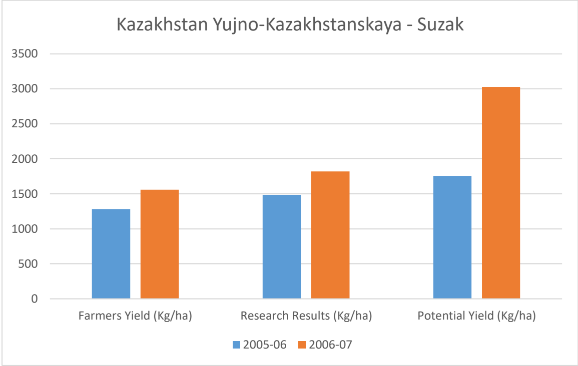


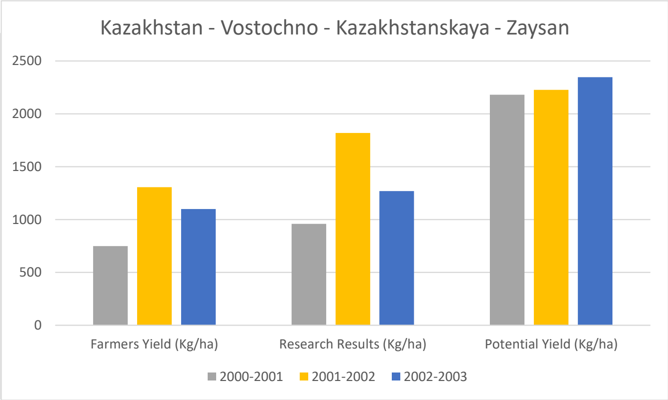


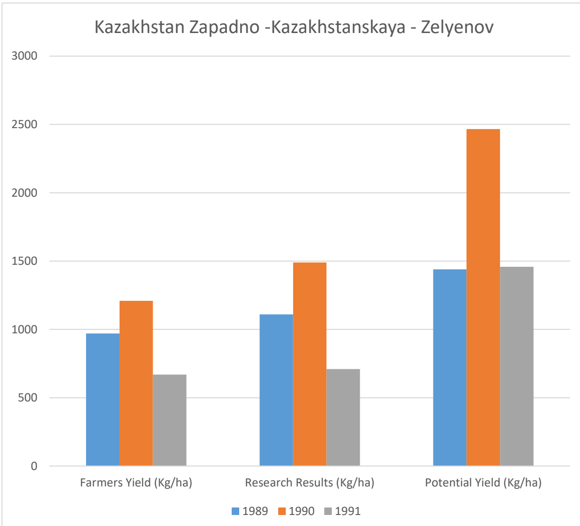


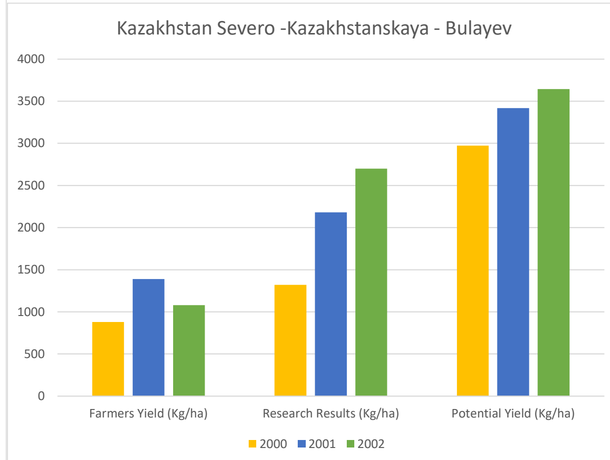

Kazakhstan Atyrauskaya - Makat
3000
2500
2000
1500
1000
500
0
Farmers Yield (Kg/ha)
Research Results (Kg/ha)
Potential Yield (Kg/ha)
1999
2000
2001

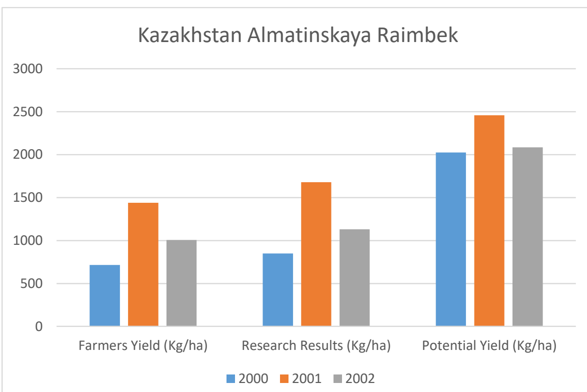

Kazakhstan Jambylskaya - Sarysu
3000
2500
2000
1500
1000
500
0
Farmers Yield (Kg/ha)
Research Results (Kg/ha)
Potential Yield (Kg/ha)
1984-85
1985-86
1986-87

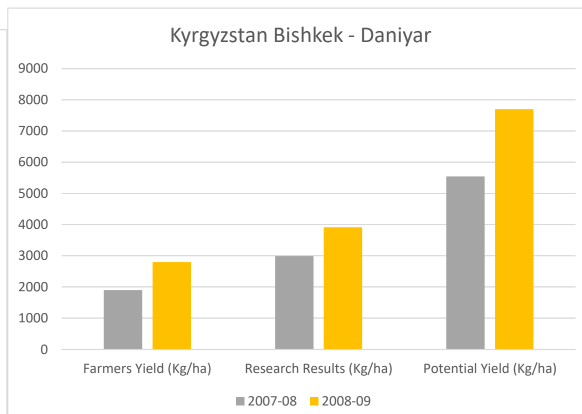

Kazakhstan Yujno-Kazakhstanskaya - Suzak
3500
3000
2500
2000
1500
1000
500
0
Farmers Yield (Kg/ha)
Research Results (Kg/ha)
Potential Yield (Kg/ha)
2005-06
2006-07

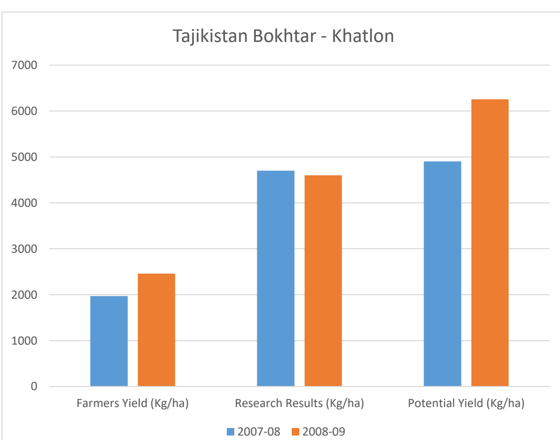

Kazakhstan - Vostochno - Kazakhstanskaya - Zaysan
2500
2000
1500
1000
500
0
Farmers Yield (Kg/ha)
Research Results (Kg/ha)
Potential Yield (Kg/ha)
2000-2001
2001-2002
2002-2003

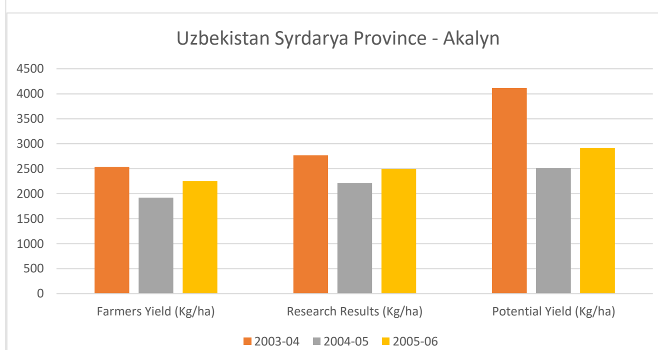

Kazakhstan Zapadno -Kazakhstanskaya - Zelyenov
3000
2500
2000
1500
1000
500
0
Farmers Yield (Kg/ha)
Research Results (Kg/ha)
Potential Yield (Kg/ha)
1989
1990
1991

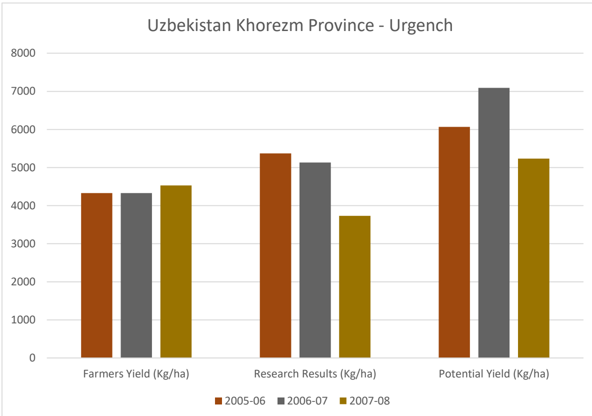

Kazakhstan Severo -Kazakhstanskaya - Bulayev
4000
3500
3000
2500
2000
1500
1000
500
0
Farmers Yield (Kg/ha)
Research Results (Kg/ha)
Potential Yield (Kg/ha)
2000
2001
2002

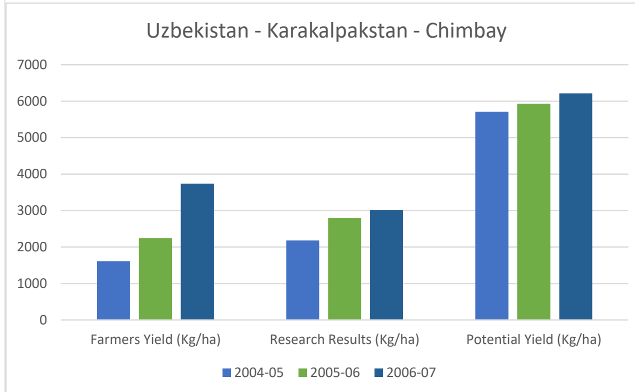

Kazakhstan Almatinskaya Raimbek
3000
2500
2000
1500
1000
500
0
Farmers Yield (Kg/ha)
Research Results (Kg/ha)
Potential Yield (Kg/ha)
2000
2001
2002

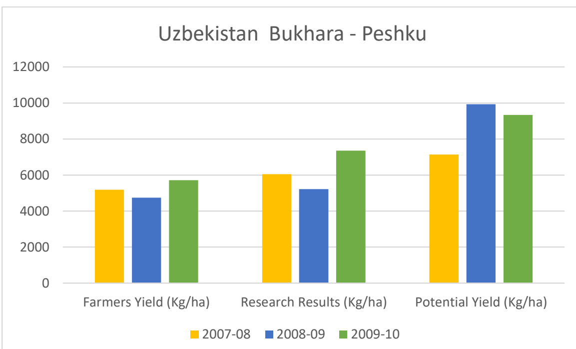

Kyrgyzstan Bishkek - Daniyar
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Farmers Yield (Kg/ha)
Research Results (Kg/ha)
Potential Yield (Kg/ha)
2007-08
2008-09

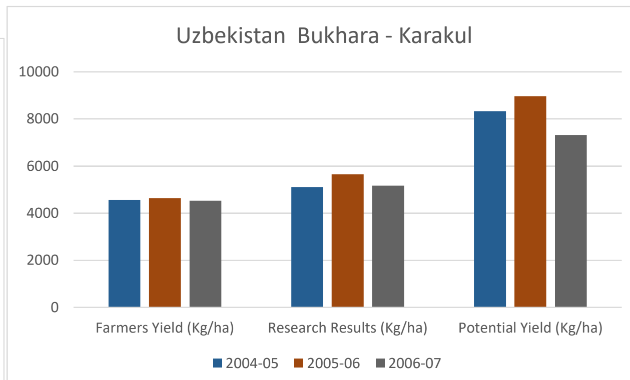

Tajikistan Bokhtar - Khatlon
7000
6000
5000
4000
3000
2000
1000
0
Farmers Yield (Kg/ha)
Research Results (Kg/ha)
Potential Yield (Kg/ha)
2007-08
2008-09


Uzbekistan Syrdarya Province - Akalyn
4500
4000
3500
3000
2500
2000
1500
1000
500
0
Farmers Yield (Kg/ha)
Research Results (Kg/ha)
Potential Yield (Kg/ha)
2003-04
2004-05
2005-06


Uzbekistan Khorezm Province - Urgench
8000
7000
6000
5000
4000
3000
2000
1000
0
Farmers Yield (Kg/ha)
Research Results (Kg/ha)
Potential Yield (Kg/ha)
2005-06
2006-07
2007-08


Uzbekistan - Karakalpakstan - Chimbay
7000
6000
5000
4000
3000
2000
1000
0
Farmers Yield (Kg/ha)
Research Results (Kg/ha)
Potential Yield (Kg/ha)
2004-05
2005-06
2006-07


Uzbekistan Bukhara - Peshku
12000
10000
8000
6000
4000
2000
0
Farmers Yield (Kg/ha)
Research Results (Kg/ha)
Potential Yield (Kg/ha)
2007-08
2008-09
2009-10


Uzbekistan Bukhara - Karakul
10000
8000
6000
4000
2000
0
Farmers Yield (Kg/ha)
Research Results (Kg/ha)
Potential Yield (Kg/ha)
2004-05
2005-06
2006-07