Chapter-10

Irrigation Scheduling Impact on Yield of Wheat, Pothowar Region, Pakistan

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Abstract

Wheat yields under rain-fed conditions are much less than under irrigated agriculture due to highly uncertain rains. Spatial and temporal distribution of rainfall is very uneven, often failing to meet crop water requirements when required. The use of high-efficiency irrigation systems to supplement crop water requirement in case of rain failure is a viable option.

An experiment was conducted and modelled to determine wheat yield with irrigation scheduling at different supplemental irrigation amounts under a center pivot irrigation system in the rain-fed Pothowar region. Model parameterization was performed using various first hand soil and water data sets, in addition to other available secondary data sets, such as published data. The treatments of the experiment were irrigations applied as 100%, 80%, 60% of crop water requirement and compared with a rain-fed treatment (control). Increases in wheat yield of 130 % over rain-fed yields were obtained by applying the full crop water requirement. By applying 20 % and 40 % less water than the crop water requirement, increases in wheat yields of 120 % and 69 % respectively over rain-fed were found. The APSIM model simulated yields, biomass and irrigation water applied in close agreement with the observed values.

Using the model for subsequent scenario analyses, it was shown that the risk of obtaining a grain yield less than 5000 kg ha^{-1} under rain-fed conditions was over 95 %. On the other hand, if 100 % irrigation was applied, the chance of achieving yields of 5000 kg/ha or more was more than 40 %.

However, in order to generalise the simulated results across different agro-ecological regions, different varieties and management practices, further modelling work is required. Growth and phenology of other widely grown wheat varieties need to be studied and incorporated into the model.

Description of the farming system modelled

Agriculture is the largest sector of Pakistan's economy contributing 21 percent to its GDP and 45 percent of the labor force employment (GoP, 2010). Wheat, being the leading food grain of Pakistan and the staple diet of the masses, is the most important crop. It is cultivated on the largest area in almost every part of the country with 23.864 million tonnes of production. The wheat yield on progressive farms in irrigated areas ranges from 6000 to 7000 kg ha^{-1}. However, wheat yield on rain-fed farms ranges from 500 to 1300 kg ha^{-1} depending upon the amount of rainfall. In irrigated areas wheat yield ranges from 2500 to 2800 kg ha^{-1} depending upon the irrigation water availability and other factors. That is roughly a 60 per cent yield gap in wheat, which needs to be narrowed. Food security in Pakistan would be ensured if this gap could be closed (Anonymous, 2000).

Montazar and Kosari (2001) have reported that globally-measured average water productivity values per unit water depletion are 1.09, 1.09, 0.65, 0.23 and 1.80 Kg m^{-3} for wheat, rice, cotton (seed), cotton (Lint), and maize respectively. Alam et al. (2005) has reported that yield per unit of water in Pakistan is the lowest in the world. Hussain et al. (2004) estimated the land and water productivity of Pothowar plateau and found that the wheat yield was 1451 kg ha^{-1} and that of groundnut was 864 kg ha^{-1}. In irrigated agriculture, wheat yield was 3084 kg ha^{-1} whereas groundnut was 1402 kg ha^{-1}. The Thematic group on rural development and food security of UN in Pakistan reported (UN-PAK/FAO/2000/1) that potential wheat yield in Pakistan is 6.4 tonnes ha^{-1} whereas national average yield is 2.2 tonnes ha^{-1} with a gap of 4.2 tonnes ha^{-1}. The international food policy research Institute (IFPRI) estimated that average water productivity of the cereals will increase from 0.56 to 0.94 kg/m^3 in developing countries and from 1-1.32 kg/m^3 in developed countries during the period 1995-2025. The UN-PAK/FAO/2000/1 report says that in Pakistan, low level productivity would indicate that the irrigation system (82 % of the agriculture land) is not working efficiently and effectively. Cai et al. (2001) has suggested that with growing water scarcity and increasing competition for available resources, water savings and more efficient use are needed for the best water resources management.

Approximately 10-12% of the wheat crop is planted under rain-fed conditions. Uncertain rainfall and frequent crop failures due to drought discourage input use. Crop husbandry in such rain-fed areas is primitive and yields are low. High efficiency irrigation systems are being successfully used to increase the water use efficiency and crop yield per unit of water. The self propelled sprinkling irrigation system is one of the interventions which meet the need of the time. Evan (2001) noted that these very adaptable water application methods have experienced tremendous popularity around the world due to their potential for highly efficient and uniform water application, and their high degree of labour reduction compared with most other irrigation methods. Application efficiency is as high as 80% dependant on management and properly designed installation for the site.

To meet the food requirements of the growing population, it is imperative to develop strategies for crop, land and water productivity improvement and resource conservation. In this scenario the improved crop productivity in less intensively cropped and land degraded rain-fed areas may play a vital role in meeting the ever increasing food demand of Pakistan's population. The Pothowar plateau has favourable climatic and agronomic conditions for agricultural production. The area is undulating with a creeping slope from the Northeast to the Southeast and rainfall ranges from 1000 mm in the Northeast to 350 mm in the Southeast area. Nearly 70 percent of this precipitation is received during the months of the monsoon (Bhutta et al,. 2002). The spatial and temporal distribution of rainfall is very uneven, failing to meet the crop water requirement at critical times. Rains in the Rabi season are very uncertain, regularly causing crop failure. The use of high efficiency irrigation systems to supplement crop water requirements and guard against rainfall failure may present a viable option.

Centre pivot sprinkler irrigation systems have been introduced during last two decades in Pakistan. According to the company information, 66 center pivot sprinkler irrigation systems have been installed in Pakistan up until now (Valley irrigation Pakistan, 2012). The center pivot sprinkler irrigation system (CPSIS) is a high efficiency irrigation system which is being introduced in the country. The crop productivity gaps can be minimized if effective water management using these systems is implemented. Therefore this study was conducted to determine crop water productivity at different water application amounts to supplement the crop water requirement in case of rainfall uncertainty and to bring the crops closer to potential yields. Irrigations were applied at 100%, 80%, 60% and rain-fed (control) of crop water requirement / crop evapotranspiration.

Experimental site description: The present study was conducted at the research fields of National Agricultural Research Centre (NARC), Islamabad, Pakistan. The site of the field experiments is located at latitude 33^0 43′ N, longitude 73^0 04′ E, and at an altitude of 490 m. It lies in the Pothowar rain-fed region. The soil belongs to the Nabipur soil series (coarse loamy, mixed, hyperthermic Udic Ustochrept). It is deep, well drained, and moderately calcareous, developed on level to nearly level deposition of the flood plain. It lies under sub-humid to humid and medium to high rainfall zone with annual rainfall ranging from 517 to 1550 mm. Rainfall is erratic, and 60 to 70 % of the total rain is received during the monsoon (Kharif season). The winter rains are more uncertain but often consist of gentle showers of long duration, thereby making them useful for crop production. More than half of the rain is received in the form of high intensity down-pours during July and August. Mean maximum temperature during summer ranges from 36 to 42 °C. The average low is 2 °C in January, while the average high is 40 °C in June. The highest temperature recorded was 48 °C in June, while the lowest temperature was −4 °C in January. Soil is alkaline (pH, 7.8), calcareous (CaCO3 equiv., 4.3 g/100g), low in organic matter (0.50 g/100g), and deficient in NO3-N (3.5 mg kg^{-1}), P (3.0 mg kg^{-1}), with K (80 mg kg^{-1}) and Zn (0.27 mg kg^{-1}). Maize and wheat are the major crops of region.

Datasets used

The experiment used for model parameterisation and validation was of one year's duration, with wheat sown in October 2011 and harvested in the first week of May 2012.

Experimental Description

Wheat was sown in three quadrants of the circle under a center pivot sprinkler irrigation system. Each Quadrant was divided into three equal parts for irrigation treatments namely I_1, I_2, I_3. Fourth irrigation treatment I_4 (rain fed) was selected in the adjacent field. Buffering of the treatment zones was done. Each treatment was subdivided into four replications namely R1, R2, R3 and R4 as shown in Figure10.1.

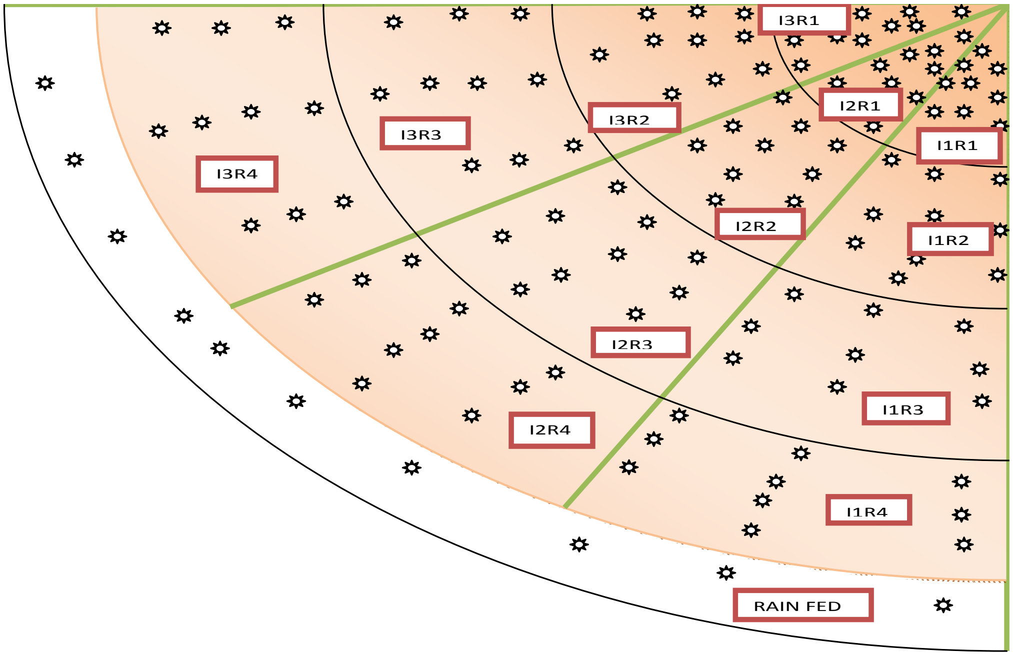

Figure 10.1. Experiment lay out of the study at WRRI, NARC field station

The experiment was a randomised split plot design with four experimental treatments and three replications. Wheat variety named *Chakwal-50* was sown in all plots on the 27th October, 2011 and harvested on the 5th May 2012. The size of the plots was one hectare. The treatments were:

I_1 Irrigation applied to 100% of crop water requirement

I_2 Irrigation applied to 80% of crop water requirement

I_3 Irrigation applied to 60% of crop water requirement

I_4 Rain-fed (control)

Irrigations were applied to re-fill the water deficit to the appropriate percentage for the given treatment. The centre pivot irrigation system previously described was used and weather, crop and soil data was collected as described below:

Weather data

The mean monthly meteorological data (1994-2012) of Water Resources Research Institute observatory was acquired with average humidity 63.4 % and wind speed 28.2 Km day^{-1} at the study site as shown in Table 10.1. Maximum/minimum temperatures and rainfall were available on daily basis. Sunshine hour data was acquired from Pakistan Meteorological Department observatory in Islamabad 15 km away from the experimental site. Daily incoming radiation (MJ m^{-2}, as required by the APSIM model) was calculated using sunshine hours and location specific information.

Table 10.1: Mean monthly meteorological data of Rabi season, WRRI field station, NARC, Islamabad (1985-2011)

Months	**Humidity (%)**	**Wind speed (Km day^{-1})**	**Total Pan Evaporation (mm)**	**Total. Rainfall (mm)**	**Maximum Temperature (^{o}C)**	**Minimum temperature (^{o}C)**
October	61.6	33.3	92.0	32.5	30.2	13.9
November	65.5	30.0	63.10	7.10	26.0	9.7
December	62.7	28.45	45.66	0.0	21.4	2.19
January	68.5	32.6	41.73	59.06	16.9	1.3
February	70.1	20.5	51.44	44.12	17.4	3.2
March	58.6	23.8	103.1	15.95	24.9	8.9
April	54.7	34.1	140.9	40.93	29.9	15.0
Total			445.9	167.2		
Average	63.4	28.2	74.3	27.9	22.8	6.7

Soil data

Soil samples were collected from the study site at depths 0-15 cm, 15-30 cm, 30-60 cm, 60-90 cm and 90-120 cm. The samples were analysed for soil bulk density, texture, pH, electricity conductivity (EC), organic matter, phosphorous and saturation moisture content (% volumetric) shown in table 10.2.

Table 10.2: Soil analysis of study site

Soil depths (cm)	**Soil PH (1:10)**	**Soil (EC) (1:10 dSm-^{1})**	**Organic matter (%)**	**Available Phosphorous (ppm)**	**Saturation moisture content (% vol)**	**Soil type**
0-15	7.7	0.90	1.01	2.2	42	Silt loam
15-30	7.7	0.60	0.65	3.2	46	Loam
30-60	7.8	0.37	0.49	2.6	48	Loam
60-90	7.9	0.45	0.44	1.6	54	Loam
90-120	7.9	0.37	0.33	1.0	50	Loam

The topsoil of the site has a dominating silt component and in the lower profile the dominant component is loam. The soil pH ranges from 7.7 to 7.9 which is considered as normal for the region. The soil EC ranges from 0.90 to 0.37 ds m^{-1} from top to bottom of the soil profile. Organic matter ranges from 1% to 0.33% which is a bit higher than normal soils in Pakistan which are considered deficient in organic matter.

Water Quality

Water samples were collected for determination of EC, (Ca^{2+} + Mg^{2+}), Na^+, Carbonate, Bicarbonate, Chloride, sodium adsorption ratio (SAR), residual soil carbon (RSC) and total dissolved solids (TDS). Electricity conductivity (Ec), carbonates, chlorides, SAR, RSC and TDS of water has no threats for extended use in irrigation of the study site (Table 10.3).

Table 10.3: Water quality analysis

EC (dSm^{-1})	(Ca^{++}+Mg^{++}) ($me\ l^{-1}$)	Na^+ ($me\ l^{-1}$)	Carbonate ($me\ l^{-1}$)	Bicarbonate ($me\ l^{-1}$)	Chloride ($me\ l^{-1}$)	SAR	RSC	TDS (ppm)
0.63	6.4	0.1	0.2	5.1	0.75	0.05	Nil	441

Crop data

Wheat crop variety Chakwal-50 was sown under the centre pivot irrigation system on October 27, 2011 and harvested on May 05, 2012. Total number of tillers (either spike-bearing or not) was counted from a randomly selected unit area from each replication in each treatment. Ten randomly selected spikes were threshed manually and their total number of grains were counted and averaged to record number of grains per spike. Plant height and spike lengths were measured. Three random samples of 1000 grains were counted from each seed lot, weighed and averaged to record 1000-grain weight. At harvest maturity, two central rows were harvested, sun-dried for three days, tied into bundles and weighed to record the biological yield and then converted into kg ha^{-1} by the unitary method. After that, wheat was threshed manually, grains were separated and weighed on an electric balance to calculate the grain yield and then converted into kg ha^{-1} by unitary method. To record straw yield, grain yield was subtracted from biological yield.

Table 10.4: Wheat Harvest data (2011-12)

Irrigation treatment	No of Plants/m^2	Plant Height (cm)	Spike Length (cm)	Grain Yield (kg ha^{-1})	Straw Yield (kg ha^{-1})
I1	59.00	104.86	10.00	5770.7	11458.5
I2	56.25	103.58	9.25	5557.3	10205.9
I3	61.00	91.81	8.94	4214.6	7428.9
I4	49.13	81.02	7.81	2492.0	4782.4

Soil Moisture Data

The soil moisture content over the profile at sowing was 16% (by volume), field capacity of the soil was 25% and wilting point was 11% by volume. Soil moisture contents in every treatment was measured before each irrigation at 0-15, 15-30, 30-60, 60-90 and 90-120 cm depths on volumetric basis to decide the next irrigation amount and water budgeting of cropping period.

Irrigation Application

First irrigation was applied on November 14, 2011, seventeen days after sowing of crop because of two rainfall events during this period. Soil moisture content was above 23 % and irrigation was applied for emergence and expansion of crop. Table 10.5 describes the irrigation applied (mm) at various crop phenological stages. Total crop water requirement was 331 mm. Irrigation applied at 100, 80 and 60 % of Evapo-transpiration (ET) came to be 198, 165 and 117 mm respectively. The highest irrigation was applied at tillering and maturity stages.

Table 10.5: Irrigation applied (mm) at various crop phenological stages

Crop Stages	Days since Sowing	I1 (mm)	I2 (mm)	I3 (mm)	ETc (mm)	Rainfall* (mm)
Emergence	0-20	18	18	18	33	7.1
Tillering	20-80	60	57	39	67	57.6
Anthesis	80-95	24	18	12	24	1.4
Grain Filling	95-130	24	18	12	74	49.6
Maturity	130-190	72	54	36	107	47
Total	**190**	**198**	**165**	**117**	**305**	**162.8**

* Rain received during the crop growing period

Results of model parameterisation, calibration, and validation

Data collected from the field experiment and from literature were used for the parameterisation of the APSIM model (Keating et al., 2003; Gaydon et al., 2012a, 2012b). Phenological development of various stages especially maturity and harvest date were calibrated. Secondary data was used for calibration of various stages as observed growth data were unavailable. Secondary wheat biomass data at various crop stages was used as observed data was taken only at harvest. Likewise secondary data on soil bulk density, texture of the soil, field capacity and wilting point was used for model calibration.

Wheat yield (kg ha^{-1}) was simulated under various irrigation treatments as shown in Figure 10.2. The model showed good agreement for I3 and I4 treatments, but slightly underestimated the I2 scenario. In the I1 treatment slight underestimation was observed. The model underestimated wheat yields by 568 kg ha^{-1}, 506 kg ha^{-1} and 78 kg ha^{-1} for I1, I2 and I3 treatments respectively, however all discrepancies between simulated and measured yields were within the bounds of experimental variability (see the error bars in Figure 10.2.). Hence overall the model showed good agreement with the observed wheat yield with coefficient of determination (R^2) of 0.96, and was considered to be acceptable for use in subsequent scenario analyses. Comparison of treatments results showed that by applying full irrigation 3279 kg ha^{-1} more wheat yield was achieved from control (rain-fed). Similarly by applying 20 and 40 percent less irrigation than the required, 3056 kg ha^{-1} and 1725 kg ha^{-1} more wheat yield was attained than rain-fed. Enhanced wheat yield of 130 % over rain-fed yields was attained by applying full crop water requirement. When 20 % less water than crop water requirement was applied, increase in wheat yield of 120 % over rain-fed was obtained. Under limited water situations, when 40 % less irrigation was applied than full crop water requirement, a higher wheat yield of 69 % over rain-fed yields was obtained.

Figure 10.3 expressed biomass simulation at harvest stage. The biomass results were in line with wheat yield but with large differences. Model showed under estimation for I1, I2 treatments and overestimation for I3 and I4 treatments in case of biomass results. This is often the case, as field experiments rarely measure dropped or dead leaves, and these are included in the APSIM simulated biomass figures.

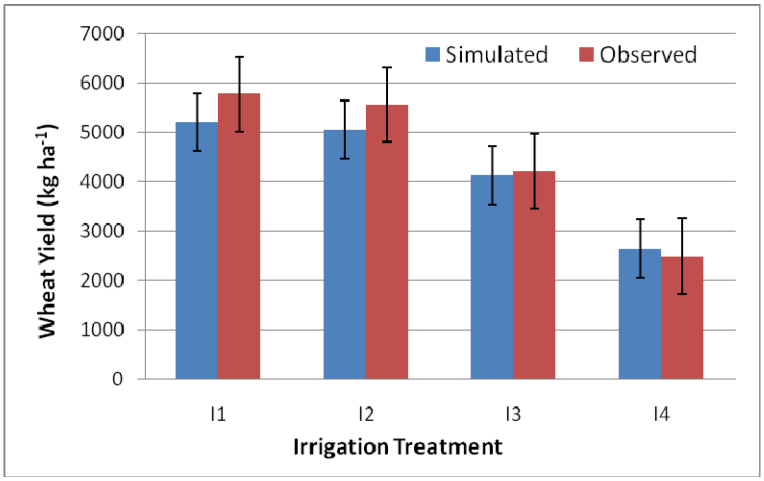

Figure 10.2: Simulated and observed grain yield of wheat under different amounts of irrigation application. The error bars represent the standard error over all treatments for both the simulated and observed data.

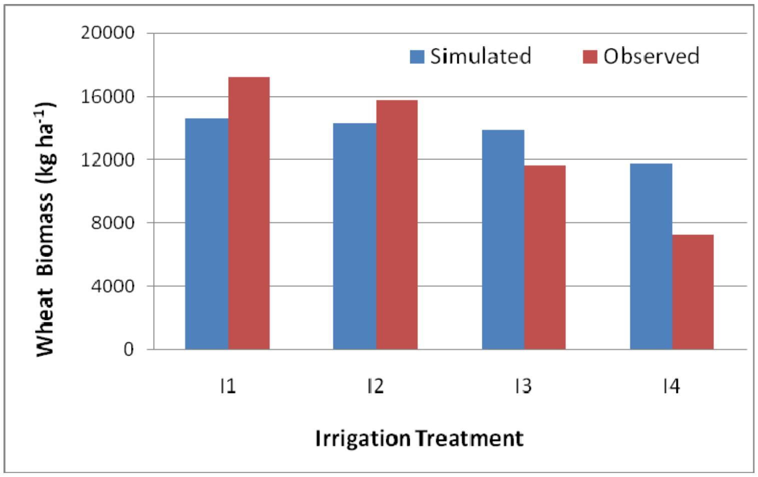

Figure 10.3: Simulated and observed biomass of wheat under different amounts of irrigation application

Amount of irrigation applied under I1, I2 and I3 treatments came to be 198 mm, 165 mm and 117 mm and 139 mm, 123 mm and 114 mm respectively under model simulation. There was significant variation of irrigation amounts applied under I1 and I2 treatments as shown in Figure 10.4. Field irrigation applications were found much higher than the modelled.

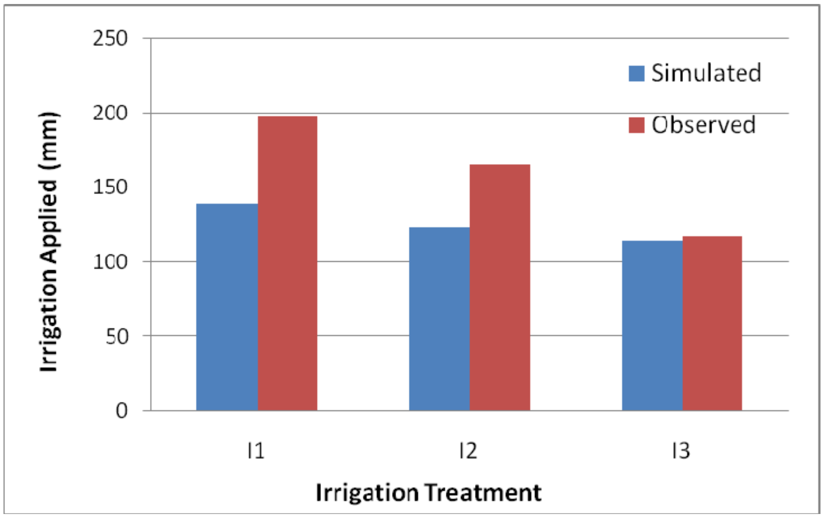

Figure 10.4: Irrigation applications (mm) under modelling and field conditions

Definition of scenarios modeled

Irrigation Management Scenarios

Measured irrigation water was applied to the crop on critical stages through the center pivot sprinkler irrigation system. Irrigation scheduling was planned for four irrigation management strategies. Under I1 strategy, irrigation water was applied to the crop as per crop water requirement. In I2 treatment, irrigation of 80 % of crop water requirement was applied at various crop stages. Under I3 scenario, 60 % of required irrigation was applied. I4 represented the crop under rain-fed conditions. Eighteen years mean monthly meteorological data (1994-2012) was now applied to the validated APSIM model for these scenarios.

Result of scenario analysis

Multi-year APSIM model scenario runs were used to create cumulative distribution functions (CDF’s) which give a representation of risk and probability of yields and WUE in the system for each of the scenarios simulated. The long-term climate files provide a measure of likely seasonal risk in the system.

The APSIM scenario simulations produced 18 wheat yields per treatment – one for each climatic year simulated (1994-2012). Based on the assumption that these 18 years gave a representative sample of the likely climatic variability at the site, the yields for each treatment were ranked and used to produce cumulative distribution functions (CDF’s) for the purposes of representing the probability of achieving a given wheat yield at the site.

The risk of obtaining a grain yield less than 5000 kg ha^{-1} under rain-fed conditions was over 95 % without the application of irrigation in case of rain failure (Figure 10.5). This means that opportunity of getting good yields under rain-fed was very low. On the other hand, if 100 percent irrigation was applied as per crop water requirement, the probability of getting yields of 5000 kg/ha or more was more than 40 %.

The risk of obtaining a grain yield less than 4000 kg ha^{-1} under rain-fed conditions is more than 50%. These risks reduced to 22%, 29%, and 35% with the application of 100%, 80% and 60 % irrigation water for the yield threshold of 4000 kg ha^{-1}.

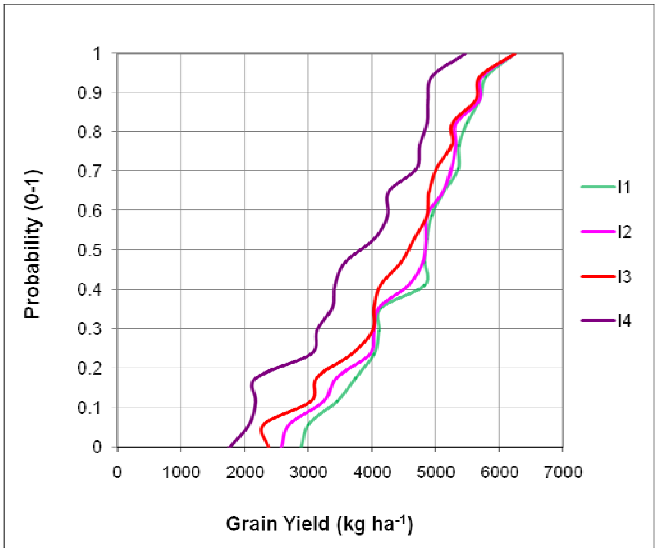

Figure 10.5: Cumulative probability distributions of the simulated wheat yield under different amounts irrigation (for 16 years of climate data)

Discussion of results

For the model parameterisation, various data sets were collected from NARC. Weather data was also available for the same site for eighteen years. Irrigation at various stress levels was applied to wheat crops. Wheat yields at this site for various levels of irrigation were simulated. Simulated grain yield, after parameterisation, was in acceptable agreement with the observed ones for the year 2011-12, hence the model was considered to be validated. The model has shown good agreement for I2 and I3 treatments and underestimation for I1 and overestimation for I4 (rain-fed) treatments for wheat yield, but these were all within the bounds of experimental error. The biomass production at harvest stage was in line with yield but with greater variations. There were significant variation of Irrigation amounts applied under I1 and I2 treatments. Field irrigation applications were much higher than those modelled. This may be due to the insufficient characterization of sub-surface soil and water dynamics.

The Pothowar area receives good rains but these are highly uncertain. Temporal distribution of rain is highly uneven. It may not rain when crop requires water, causing crop damage. Farmers are never sure of getting rain and good crop yields under rain-fed conditions. Substantial increases in yields can be achieved if supplemental irrigation is applied in case of rain failure with proper irrigation scheduling.

However, in order to generalise the simulated results across different agro-ecological regions, different varieties, and management practices, further simulations and field validation are required. Growth and phenology of other widely grown wheat varieties need to be studied and incorporated into the APSIM model. This site has been reserved for organic farming where various types of organic fertilizers are applied. Possible changes in crop phenology and growth, and soil characteristics in response to the changed fertiliser application and organic matter addition should be included into the model. Once model (re)parameterisation and validation were carried out with this information, simulations could be done across a wide range of phenomenon and interpretations and recommendations to farmers would be possible.

Wheat yield could be increased to that of 6000 kg per ha with application of supplemental irrigation when rainfall did not meet crop water requirement. Substantially increased yield can be attained with irrigation application at critical crop development stages. Therefore, irrigation application reduced the risk for farmers both in good (when total rainfall is high but its distribution is not good) and bad years (less rain). The results support and demand introduction of water resources development and supplemental irrigation schemes in the area. Due to the highly heterogeneous terrain, only sprinkler/drip irrigation is possible. These highly-efficient irrigation systems are costly and beyond the reach of the majority of farmers. For agricultural development and livelihood generation, people-supported subsidized schemes must be launched.

Conclusions

- Irrigation at critical growing stages can increase average grain yields substantially.
- Good yields in low rainfall seasons can be obtained under full, 80%, and 60% irrigation levels.
- The risk of obtaining a grain yield less than 5000 kg ha^{-1} under rain-fed conditions was over 95 %. On the other hand, if 100 percent irrigation was applied, the chance of getting yields of 5000 kg/ha or more was more than 40 %.
- Crop failures/damages due to unreliable and non-uniform rains can be avoided through supplemental irrigation.

References

Alam, M.M., M.N. Bhutta and A.H. Azhar, 2005. The use and limitations of sprinkler and drip irrigation systems in Pakistan. Pakistan Engineering Congress 70th annual session proceedings: paper No. 661.

Anonymous, 2000. United Nations Statement on Food Security in Pakistan 2000, United Nations System in Pakistan, Islamabad, Publication No. UN PAK/FAO/2000/1.

Bhutta, M. N., Chaudhry, M. R., Siddu, M., 2002. Rain water harvesting impact on agriculture in Pakistan. Proceedings of the national seminar on drought and water resources in Pakistan.

Burt, C.M., Clemens, A.J., Strelk , T.S., Solomon ,H. K.H., Bliesner, R.D., Hardy , L.A., Howell , T.A., 1997. Irrigation performance measures efficiency and uniformity. Journal of Irrigation and Drainage Engineering, 123(1): 423-442.

Cai, X., and Rosegrant, M., 2003. World water productivity: Current situation and future options. In: Kijne, J.W.,Barker, R. and Molden, D. (Eds.) Water Productivity in Agriculture: Limits and opportunities for Improvement. CABI Wallingford, pp 163-178.

Evans, R.G., 2001. Center pivot irrigation. www.ars.usda.gov/Site.

Gaydon, D.S., Probert, M.E., Buresh, R.J., Meinke, H., Suriadi, A., Dobermann, A., Bouman, B.A.M., Timsina, J., 2012a. Rice in cropping systems – modelling transitions between flooded and non-flooded soil environments. European Journal of Agronomy 39, pp 9-24.

Gaydon, D.S., Probert, M.E., Buresh, R.J., Meinke, H., Timsina, J., 2012b. Capturing the role of algae in rice crop production and soil organic carbon maintenance, European Journal of Agronomy 39, pp35-43.

Government of Pakistan, 2010. Economic Survey 2009-10. Islamabad: Finance Division.

Hussain M., 2004. Impact of small irrigation schemes on poverty alleviation in marginal areas of Punjab, Pakistan. Mphil Thesis University of Agriculture Faisalabad Pakistan

Keating, B.A., Carberry, P.S., Hammer, G.L., Probert, M.E., Robertson, M.J., Holzworth, D., Huth, N.I., Hargreaves, J.N.G., Meinke, H., Hochman, Z., McLean, G., Verburg, K., Snow, V., Dimes, J.P., Silburn, M., Wang, E., Brown, S., Bristow, K.L., Asseng, S., Chapman, S., McCown, R.L., Freebairn, D.M., Smith, C.J., 2003. An overview of APSIM, a model designed for farming systems simulation. European Journal of Agronomy 18, pp 267-288.

Montazar. A. and Kosari, H., 2001. Water productivity analysis of some irrigated crops in Iran. Irrigation and Drainage Engg. University of Tehran: 109-120.

U.N- Pak./FAO/2000/1., 2000. United Nations statement on food security in Pakistan.

Valley irrigation Pakistan, 2012. http://www.valleyirrigationpakistan.com/