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Optimizing Deficit Irrigation Scheduling Under Shallow Groundwater Conditions in Lower Reaches of Amu Darya River Basin

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Abstract Water demand for irrigated agriculture is increasing against limited availability of fresh water resources in the lower reaches of the Amu Darya River e.g., Khorezm region of Uzbekistan. Future scenarios predict that Khorezm region will receive fewer water supplies due to climate change, transboundary conflicts and hence farmers have to achieve their yield targets with less water. We conducted a study and used AquaCrop model to develop the optimum and deficit irrigation schedule under shallow groundwater conditions (1.0–1.2 m) in the study region. Cotton being a strategic crop in the region was used for simulations. Capillary rise substantially contributes to crop-water requirements and is the key characteristic of the regional soils. However, AquaCrop does not simulate capillary rise contribution, thereby HYDRUS-1D model was used in this study for the quantification of capillary rise contribution. Alongside optimal irrigation schedule for cotton, deficit strategies were also derived in two ways: proportional reduction from each irrigation event (scenario-A) throughout the growth period as well as reduced water supply at specific crop growth stages (scenario-B). For scenario-A, 20, 40, 50 and 60 % of optimal water was deducted from each irrigation quota whereas for scenario-B irrigation events were knocked out at different crop growth stages (stage 1(emergence), stage 2 (vegetative), stage 3 (flowering) and stage 4 (yield formation and ripening)). For scenario-A, 0, 14, 30 and 48 % of yield reduction was observed respectively. During stress at the late crop development stage, a reduced water supply of 12 % resulted in a yield increase of 8 %. Conversely, during stress at the earlier crop development stage, yield loss was 17–18 %. During water stress at the late ripening stage, no yield loss was observed. Results of this study provide guidelines for policy makers to adopt irrigation schedule depending upon availability of irrigation water.

Keywords Khorezm · AquaCrop · HYDRUS-1D · Water scarcity

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1 Introduction

About 70 % of global withdrawals from freshwater resources are directed towards irrigated agriculture (Allouche 2011). Irrigation consuming around 2,663 km^3 of water annually (UNESCO 2009) is forecasted to be restricted in the near future to meet the global food production demand (Falkenmark 1998). Water withdrawals for domestic, industrial and livestock use are also projected to increase at least 50 % by 2025 (Rosegrant et al. 2002). This will strictly limit irrigation water withdrawal, which can increase only by 4 %, hindering food production in turn to fulfill the growing population demand (Rosegrant et al. 2002). With increasing demand from non-agricultural sectors and the uncertainties in water management brought about by climate change, the agricultural sector in many areas will face water shortage in the future (Bakkes et al. 2009). To cope with this situation, circumstances need to be shaped in order to allow global agricultural systems provide more food for increasing population in future. One of the options is to increase water productivity both in rainfed and irrigated systems as the main avenue to face the challenge (Fereres et al. 2011). To achieve higher water productivity, water management has to be improved through improved irrigation scheduling and increased irrigation efficiency. Greater attention in this case needs to be focused on managing surface and groundwater resources for conjunctive use (Barker et al. 2003).

Agriculture is a key role-player in Uzbekistan's economy by providing 28 % of the total Gross National Product. About 92.3 % of the Uzbek's water consumption goes to agricultural use (FAO 2011). The history of irrigation in the current Uzbekistan region is since 2,500 years (FAO/AQUASTAT 1997) in the country's seven natural oases. Between 1925 and 1985, the irrigated area in the Aral Sea Basin was substantially increased from 2 million ha to 7.2 million ha (Vlek et al. 2003). The drastic expansion of the irrigated area and inefficient irrigation in the region caused the Aral Sea dilemma (Fergus 1999; Micklin 1988) which according to Badescu and Schuiling (2010) can be restored by halting the cotton production in the region. Uzbekistan experienced water shortages due to droughts in the years 2000, 2001 (IWPR 2005; Wegerich 2002) and 2008 (Abdullayev et al. 2008). Heightened attention on the effects of global climate change scenarios has led to more stress on growing levels of water scarcity in Uzbekistan. With this trend, the surface water supplies will become limited in the region since competition for water use between different sectors has increased manifold (Wegerich 2002). Given that water resources are restricted, employing means of effective water use is the only way of managing increased demand pressure (FAO 2003).

Because of the inflexibility in the "norms" based irrigation system (norms is common term used in Khorezm for official irrigation quota and is fixed for different regions) and farmers' conventional practices in Uzbekistan, irrigation practices have not been changed substantially. The study region is known for its shallow groundwater levels and cotton cultivation. In the areas where groundwater is shallow, groundwater contribution to crop specific evapotranspiration cannot be ignored (Awan 2010; Farahani et al. 2009; Forkutsa 2006; Kahlown et al. 2005). Besides soil characteristics, the groundwater contribution is mainly driven by the groundwater depth, the shallower the water table depth is, higher is the groundwater contribution and vice versa (Kang et al. 2001). Capillary rise contribution thus is a significant component of the soil water balance (Yang et al. 2007). Soil salinity through the shallow groundwater levels is well manageable and documented by Kahlown et al. (2005).

Generally optimum irrigation is intended to maximize yield but this practice is not sustainable (Farahani et al. 2009) in future due to forecasted limited water supplies. Deficit irrigation has not so far, received adequate attention in research despite its high potential for improving water productivity (Fereres and Soriano 2007) but this requires a better understanding of crop response to various levels of water stress (Oweis et al. 2011) which is part of this study. There has been different research papers published about deficit irrigation (Conejero et al. 2011; Fernández et al. 2011; Tarara et al. 2011) but generally shallow groundwater contribution to the crop root zone is ignored in irrigation water scheduling/management (Hutmacher et al. 1996; Kite and Hanson 1984; Wallender et al. 1979). The objective of the study is to derive optimal and deficit irrigation schedules for cotton under shallow groundwater conditions in Khorezm region of Uzbekistan. The novelty of this study lies in the fact that capillary rise contribution due to shallow groundwater is incorporated with surface water supply for optimal and deficit irrigation scheduling (Fereres and Soriano 2007; English 1990) by using the AquaCrop model (Hsiao et al. 2009; Raes et al. 2009; Steduto et al. 2009).

2 Materials and Methods

2.1 Study Site Description

This study was carried out at the Cotton Research Institute (CRI), Khorezm, a region located in the lower part of the Amu Darya basin in the northwest of Uzbekistan (Fig. 1). The annual estimated potential evapotranspiration in the region is about 1,500 mm (Ibrakhimov et al. 2004). The amount of evapotranspiration far exceeds the annual precipitation which is around 92 mm (Awan 2010). The soil types, cropping pattern and shallow groundwater in CRI are representative for Khorezm region. Two cotton fields namely field 1 (7 ha) and field 2 (8.1 ha) with sandy loam and silt loam soils, respectively were selected for this study (Fig. 1).

A local cotton variety (Khorezm-127) was sown on 26th of April, 2010 on field 1 and on 12th April, 2010 on field 2.

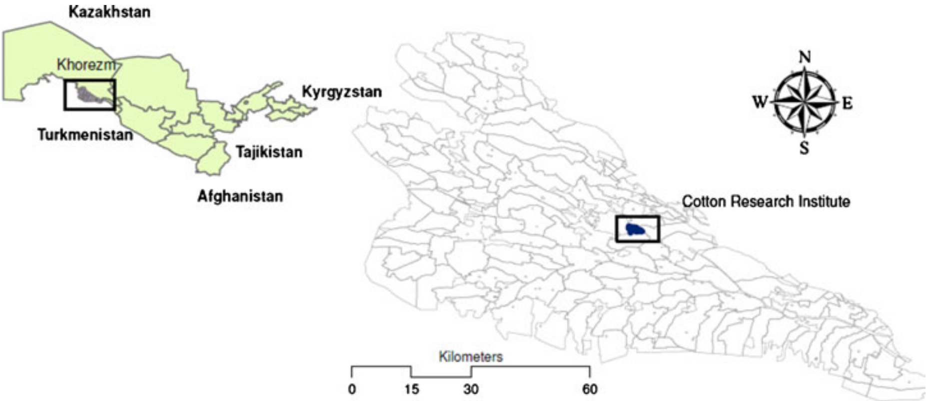

Fig. 1 Map of the study location in the Khorezm region of Uzbekistan

2.2 Field Data Collection

2.2.1 Irrigation and Yield Data

The irrigation water was managed by the local farmers in the CRI. The decision on quantity, frequency and time of irrigation water application came from the farmers' side. We only monitored the water applications in both the fields by using the area-velocity method. In area-velocity method, velocity is measured by propeller type current meter which is then multiplied by the cross-sectional area of the channel to determine discharge.

The cotton yield data was collected by identifying five sample plots each in field 1 and 2. The sample plots were selected close to the monitoring locations for soil moisture and groundwater levels. Soil moisture and groundwater levels are monitored from five different locations in the field. In order to know about the final yield, cotton bolls from the field 1 and 2 were picked 3 times, on 14 September, 2 October and 13 October, 2010. These bolls were weighed and then the yield was estimated for the whole fields. Irrigation amounts and yield data was then compared to simulated values.

2.2.2 Data for HYDRUS-1D Model

For the simulation of water flow, root water uptake and root growth, HYDRUS-1D model (Version 4.14) (Simunek et al. 2008) was used. This model numerically solves the Richards equation in combination with convection–dispersion type equations. The unknown parameters in the Richards equation are calculated by different sub-models introduced into HYDRUS-1D for which codes are provided by this model. The input parameters used in the HYDRUS-1D model were daily groundwater levels (cm), precipitation (cm day^{-1}), daily transpiration (cm day^{-1}) and daily evaporation values (cm day^{-1}) which were derived by using the FAO's (Food and Agriculture Organization) dual crop coefficient approach (Allen et al. 1998). The model for unsaturated soil hydraulic properties selected here was Van Genuchten model (1980) of soil hydraulic function and Mualem Model (1976) which predicts the hydraulic conductivity function of unsaturated porous media. We used "atmospheric boundary condition with surface layer" as the upper boundary condition. This boundary condition allows increase in water layer on the surface by precipitation or irrigation and decline in the surface water layer due to evaporation or infiltration. The lower boundary condition depends on the dynamics of the groundwater levels therefore "variable pressure head" was selected to describe the lower boundary of the soil profile. The root growth was simulated by using Hoffman and van Genuchten (1983) model for root distribution. For the determination of root water uptake, the method suggested by Feddes et al. (1978) was used.

The Penman-Monteith equation, recommended by FAO is well known for the estimation of evapotranspiration from uniform surfaces (Allen 1986; Monteith 1973). The procedure to define crop specific evapotranspiration (ET_c) by using the crop coefficients was adopted from the FAO-56 paper (Allen et al. 1998). To determine the reference evapotranspiration (ET_o) required for ET_c, the meteorological data (temperature, rainfall, humidity, wind speed and sunshine hours) was collected from the meteorological station based at the cotton research institute in Urgench, Khorezm. Evapotranspiration was split into evaporation (E) and transpiration (T) by using the FAO dual crop coefficient approach (Allen et al. 1998). As an input data requirement for HYDRUS-1D to estimate capillary rise contribution, E and T were separated using the dual crop coefficient approach, formulated as:

$$E = K_e \times ET_0 \tag{1}$$

$$T = K_{cb} \times ET_0 \tag{2}$$

where

E	Evaporation
K_e	Soil evaporation coefficient
ET_0	Reference Evapotranspiration
T	Transpiration and
K_{cb}	Basal crop coefficient

2.2.3 AquaCrop Model

For optimal and deficit irrigation scheduling, AquaCrop was used which is a water-driven simulation model for the simulation of yield response to water of major crops cultivated worldwide (Steduto et al. 2009). The relationship between evapotranspiration deficit $(1-(ET_a/ET_x))$ and yield decline $(1-(Y_a/Y_x))$ in AquaCrop model is given by FAO irrigation and drainage paper 33 (Doorenbos and Kassam 1979), with a slope, yield response factor (K_y):

$$\left(1 - \frac{Y_a}{Y_x}\right) = K_y\left(1 - \frac{ET_a}{ET_x}\right) \tag{3}$$

where Y_x and Y_a are the maximum and actual yield, ET_x and ET_a are the maximum/potential and actual evapotranspiration. AquaCrop (Steduto et al. 2009) advances from the K_y approach by: (i) dividing ET in soil evaporation (E) and crop transpiration (Tr), to avoid the effect of the non-productive consumptive use of water (E), (ii) obtaining biomass (B) from the product of water productivity (WP) and cumulated crop transpiration, the core of AquaCrop growth engine (Eq. 4) (iii) expressing the final yield (Y) as the product of B and Harvest Index (HI) (Eq. 5).

$$B = WP \times \sum Tr \tag{4}$$

$$Y = HI \times B \tag{5}$$

The Eqs. 4 and 5 are both water driven with a fundamental implication for the robustness of the model due to the conservative behavior of WP (Steduto et al. 2007). Irrigation schedule developed by AquaCrop model was based on moisture contents status in root zone. For the current study, irrigation event would occurre when soil moisture reached to depleted fraction. Depleted fraction values were taken from the FAO-56 paper (Allen et al. 1998).

2.3 Deficit Irrigation Scenarios Analysis

a) ***Deficit irrigation scenario with proportionally reduced water supply (Scenario-A)***

A proportional reduced water supply of 20, 40, 50 and 60 % was introduced into each irrigation event of the optimal irrigation schedule derived with AquaCrop model. After this the yield and biomass response (YBR) was simulated.

b) ***Deficit irrigation, stress introduction during a specific crop growth stage (Scenario-B)***

The main idea of stress introduction into specific crop growth stage is to identify and knock out those irrigation events which have the least impact on crop yield. Special irrigation events were expelled out of the optimal schedule at a special growth stage (early and late growth stages) by considering this as a natural occurring water shortage/stress.

3 Results

3.1 Capillary Rise Contribution for Cotton Crop Computed Using HYDRUS-1D Model

In field 1, the maximum capillary rise contribution was calculated in the month of July 2010 which was 139 mm against ETc of 156 mm in the same month (Table 1). Similarly, the maximum capillary rise contribution in field 2 was in the month of July 2010 which was around 62 mm against an ET_c of 166 mm in the same month (Table 2). Throughout the growth period of cotton, groundwater contribution to the root zone was 31.4 and 24 % by contributing 194 and 153 mm in field 1 and 2 respectively. This difference can be understood by the groundwater level depth which was 97 and 120 cm on average in field 1 and 2 respectively. Table 1 and Table 2 are not accounting for initial and existing soil moisture contents in the soil root zone.

3.2 Irrigation Scheduling

3.2.1 Optimal Irrigation Schedule by AquaCrop Versus Conventional Irrigation Practices by Farmers

The amount of capillary rise contribution in field 1 due to varying groundwater level directly impacts the irrigation quota recommended by AquaCrop in an optimal irrigation scheme. The optimal irrigation quota for cotton in shallow sandy loam soils is comparatively low that's why AquaCrop recommends 298 mm of net irrigation requirements (Table 3). In contrast, field 2 with an average medium groundwater level of 120 cm contributes 153 mm (24 % to the ET_c of cotton) (Table 2), comparatively less than in the aforesaid field. The difference in irrigation quota is strongly driven by the capillary rise that's why the net irrigation quota for medium silt loam cotton steps up to 356 mm (Table 4).

Compared to the simulated results (Tables 5 and 6), a considerable loss in yield has also been observed in both the cotton fields. The cotton yield losses were 42 and 45.8 %

Table 1 Water balance at field level (field 1)

Month	Gross Irrigation (mm)	Capillary Rise (mm)	Precipitation (mm)	ET_c (mm)
April	0	0	0	13
May	0	0	0	121
June	256	47	0	123
July	25	139	0.8	156
August	337	8	0	130
September	0	0	0	75
Total	618	194	0.8	617

Table 2 Water balance at field level (field 2)

Month	Gross Irrigation (mm)	Capillary Rise (mm)	Precipitation (mm)	ET_c (mm)
April	0	3	0	58
May	0	7	0	116
June	240	40	0	139
July	32	62	0.8	166
August	212	41	0	127
September	0	0	0	46
Total	484	153	0.8	651

respectively in fields 1 and 2. Simulated yield under current farmer's practices would be in the range of 2.4 to 2.5 tha^{-1} for field 1 and 2 respectively.

3.2.2 Optimization of the Deficit Irrigation

a) *Deficit irrigation optimization by proportionally reduced water supply (Scenario-A)*

Results from cotton fields (Tables 5 and 6) show that with a 20 % of deficit irrigation application, throughout the growth period, yield would increase by 2 % and biomass would reduce by 8–12 %. This would increase the water use efficiency from 0.89 to 0.95 kgm^{-3}. The yield increment with 20 % deficit supply can be result of two factors: 1) water stress with 20 % deficit irrigation would increase the harvest index from 37 % to 42 % on the average and 2) with 20 % proportional reduced water supply the water stress at the start of the season would result in reduced canopy growth, hence less transpiration and a better irrigation regime which would give higher yield.

Similarly a 40 % proportionally reduced water supply would result in a biomass reduction of 25–39 % as well as yield loss of 14 and 29 % in fields 1 and 2 respectively.

Table 3 Comparison of simulated optimal irrigation schedule with farmer's conventional irrigation schedule for cotton

Irrigation event	Optimum irrigation schedule (Field 1, Cotton)			Observed (farmers') irrigation schedule		
	DAS[a]	Irrigation quota (mm)	Simulated yield (t/ha)	DAS	Gross irrigation applied (mm)	Observed yield (t/ha)
1	21	26	4.7	62	256	2.7
2	43	30		94	181	
3	52	31		114	181	
4	58	33				
5	65	38				
6	104	48				
7	118	48				
8	133	45				
Total		298			618	

[a] Days after sowing

Table 4 Comparison of simulated optimal irrigation schedule with farmer's conventional irrigation schedule for cotton

Irrigation event	Optimum irrigation schedule (Fields 2, Cotton)			Observed (farmers') irrigation schedule		
	DAS	Irrigation quota (mm)	Simulated yield (t/ha)	DAS	Gross irrigation applied (mm)	Observed yield (t/ha)
1	25	32	4.8	75	240	2.6
2	46	38		109	114	
3	61	44		123	130	
4	69	46				
5	76	43				
6	85	46				
7	105	51				
8	134	56				
Total		356			485	

b) *Deficit irrigation, stress introduction during a specific crop growth stage (Scenario-B)*

The results from cotton fields show that water stress at the early crop development stage can be risky, at this stage a reduced water supply of 8 to 9 % would result in yield loss of 17 to 18 % in fields 1 and 2. During stress at this stage, biomass reduction would also be in the range of 13–15 % (Tables 7 and 8). AquaCrop simulation showed that stress at the late vegetative stage would result into 12 to 13 % water saving together with 7 to 8 % yield increase. Stress introduced during late vegetative and early boll formation stages in cotton would provide adequate and feasible irrigation options for water saving.

4 Discussion

Generally, in irrigation scheduling and management decisions, the groundwater contribution to crop water use due to shallow groundwater level is ignored (Hanson and Kite 1984; Wallender et al. 1979). If the groundwater level is in the range of 130 cm, the upward water movement would be in the range of 3.9 mm day^{-1} (Gardner and Fireman 1958). Similar results were found for maize and wheat in the semi-arid region (Northey et al. 2006; Kang et al. 2001) which attest the depth of groundwater level as the main driver in capillary contribution to crop root-zone in different soil types. Hoffman and Hall (1996) noticed cotton water uptake of 57, 38 and 28 % under a groundwater level of 90, 180 and 280 cm

Table 5 Yield and biomass response against a proportionally reduced water supply in cotton (Field 1)

	YBR (%) with 20 % RWS	YBR (%) with 40 % RWS	YBR (%) with 50 % RWS	YBR (%) with 60 % RWS
Biomass (t/ha)	−8	−25	−40	−56
Yield part (t/ha)	+2	−14	−30	−48

The −ve sign represents reduction and + ve sign represents increase

Table 6 Yield and biomass response against a proportionally reduced water supply in cotton (Fields 2)

	YBR (%) with 20 % RWS	YBR (%) with 40 % RWS	YBR (%) with 50 % RWS	YBR (%) with 60 % RWS
Biomass (t/ha)	−12	−39	−53	−64
Yield part (t/ha)	0	−29	−45	−59

The −ve sign represents reduction and + ve sign represents increase

respectively in sandy loam soils. Groundwater levels in Khorezm region are shallow. Capillary rise contribution to crop water requirements in Khorezm region has been documented by Forkutsa (2006) and Awan (2010). Forkutsa et al. (2009a) and (2009b) calibrated and validated this model for the region. Moreover the results of the capillary rise contribution are well in range of the results reported by the other authors. For example, for this study, the capillary rise contribution to ET_c of cotton ranged from 31 % in sandy loam to 24 % in silt loam soils in fields 1 and 2 respectively. Awan (2010) also reported 28, 23 and 16 % of capillary rise contribution in shallow (0–100 cm), medium (100–150 cm) and deep (>150 cm) silt loam soils respectively. In this study, the average groundwater level depth throughout the growth period of cotton in fields 1, 2 was respectively shallow (97 cm) and medium (120 cm). Experiments of Hutmacher et al. (1996) on cotton groundwater uptake show a groundwater contribution of about 30 to 42 % of seasonal total evapotranspiration (ET) in treatments with groundwater salinity ≤ 20 dSm^{-1} but declination to 12 to 19 % of total ET at higher salinity levels. Farmers in Khorezm are applying leaching (heavy irrigation to bare lands for removal of salts) before sowing cotton (January to March) to remove the salts from root zone. Current level of secondary soil salinity in the region is below the threshold value of cotton which is strategic crop in the Khorezm region (Forkutsa et al. 2009a, b). Current practices of leaching combined with well-maintained drainage infrastructure is reducing the adverse effect of shallow groundwater table and is viable strategy for farming community in LKhorezm (Awan 2010)

Compared to the optimal conditions, the observed yield losses in the conventional practices were 42 and 47 % in field-1 and field-2, respectively. The yield and biomass losses in the conventional practices are due to mismanagement practices (low field application efficiency) at the farm level. At farm level alongside other issues, water management problems are both improper timing and non-uniform irrigation distribution in the field which can be achieved without significant expense (Awan et al. 2011a). Farmers applied three irrigation events. Although the number of irrigation events are substantially lower than what recommended by AquaCrop, amount of water applied is too high. One of the reasons for high irrigation amounts is unreliability of canal water. Whenever the farmers get chance, they apply high irrigation amounts to avoid future stresses to their crops (Awan 2010).

Table 7 Yield and biomass response to water stress at different growth stages of cotton (field 1)

Irrigation treatment	RWS (%)	Biomass response (%)	Yield response (%)
Stress in early stage 2	8	−13	−17
Stress in late stage 2	12	−10	+8
Stress in early stage 4	16	−6	+2
Stress in late stage 4	15	0	0

The −ve sign represents reduction and + ve sign represents increase

Table 8 Yield and biomass response to water stress at different growth stages of cotton (field 2)

Irrigation treatment	RWS (%)	Biomass response (%)	Yield response (%)
Stress in early stage 2	9	−15	−18
Stress in late stage 2	13	−6	+7
Stress in early stage 4	14	−4	+2
Stress in late stage 4	16	−4	−5

The −ve sign represents reduction and + ve sign represents increase

Currently the irrigation application efficiency in Khorezm is in the range of 15 % to 43 %. One of the reasons for low field application efficiency is the high operational losses, which can be minimized by institutionalizing the farmers' involvement in water distribution planning (Awan et al. 2011b). Actually mismanagement of water in Central Asia has caused a series of problems that have direct and indirect social consequences in the region (Rahaman and Varis 2008). The results from cotton fields show that proportionally reduced water supply of 20 % resulted up-to 2 % yield increase while a reduced water supply of 40, 50 and 60 % resulted into 14–29, 30–45 and 48–59 % cotton yield reduction respectively. The results of Awan (2010) show a 10–18 % yield reduction against a 25 % proportional reduced water supply. Similarly in the case of Awan (2010) a 50 % proportional reduced water supply would bring a 22–30 % yield reduction. On the other side, results of Tekinel and Kanber (1979) show that a 30 % and 40 % (Yalcuk and Özkara 1984) proportional reduction in irrigation water application would not significantly reduce the cotton yield. These difference in yield reductions are due to different agro climatic conditions.

The yield response to water stress at a specific crop growth stage is needed to be evaluated (Salemi et al. 2011). During water stress at the very late crop development stage in field 1, a reduced water supply of 12 % resulted into a yield increase of 8 %. While during water stress at the earlier ripening stage, a 2 % yield increase was observed. The yield loss of 17–18 % respectively in field 1 and 2 during stress at the early crop development stage is supported by the statement of Prieto and Angueira (1999) that owing to the pre-seeding irrigation required, water deficit can be reached in the vegetative-bud formation stage and hence reduces the number of boll formation. The losses can be minimized if the stress is moved towards the late vegetative and late flowering and ripening stage. Similarly, yield increase during stress at the early ripening stage is because of the low crop water requirements at this stage and the deep crop rooting system has the capacity for extracting soil water from comparatively deeper soil depths (Prieto and Angueira 1999). Stress introduced during late flowering and boll formation stages in cotton provides feasible irrigation options for smallest yield reductions with limited supplies of irrigation water. Unlike Awan (2010) indicating that a 25 and 50 % proportional reduced water supply and equal stress introduction at some stages come up with the yield loss in the same range, the current study gives more details of stage specific stress and the relevant crop yield and biomass response. Contrary to the current study and the results of Kirda (2002) on cotton, Jalota et al. (2006) underlines the flowering to boll formation stage as the most sensitive stage to water stress.

The deficit irrigation practice is successful in increasing water productivity for different crops without causing severe yield reductions (Geerts and Raes 2009). Under conditions of water scarcity and drought, deficit irrigation is a tactical measure to reduce irrigation water use (Fereres and Soriano 2007). Deficit irrigation can lead to bigger economic returns but it requires an accurate understanding of crop reaction to water stress as stress tolerance differs considerably by species and crop growth stage (Geerts and Raes 2009). The crop response to drought stress is advised to be carefully studied (Hsiao 1973). Deficit irrigation can be useful when farmers have open access to irrigation water during sensitive crop growth stages which has to be applied at the time of need in order to avoid any serious yield loss. But this is not always possible especially in extremely dry regions where irrigation water is limited (Enfors and Gordon 2008). The reliability of water delivery has to be ensured which needs a high institutional capacity. In this case, decentralized storage capacities become important to adopt in order to reduce the impacts of future water shortage (Törnqvist and Jarsjö 2012; Zhang et al. 2010). In case the saved water (by deficit irrigation) could be used later in more sensitive periods, this would create an incentive to farmers to introduce deficit strategies especially when water availability is not reliable. Meanwhile within the field, uniformity of water applied (and as a consequence of soil moisture) should be high enough to be realized by appropriate leveling. Fereres and Soriano (2007), Kang et al. (2002) and Geerts and Raes (2009) suggest the guaranteeing of a minimum quantity of irrigation water availability for application.

5 Conclusions

Generally crop water-use and irrigation scheduling decisions ignore groundwater contribution (Ayars and Hutmacher 1994; Grismer et al. 1988; Hanson and Kite 1984). Results of the current study proved that optimum irrigation schedule under shallow groundwater conditions cannot be developed by ignoring the capillary rise contribution. Moreover there is not an integrated tool so far that simulates irrigation schedule and capillary rise contribution for developing the irrigation schedule. Through this study, for the first time optimum irrigation schedule was developed by using HYDRUS-1D model and AquaCrop model. Results from the AquaCrop model show that cotton yield can be raised from 2.7 tha^{-1} to 4.7–4.8 tha^{-1} by adopting the optimal irrigation schedule where the groundwater contribution has been incorporated as well.

After tentative diagnosis of two deficit irrigation strategies under shallow groundwater conditions, this study concludes that proportional reduction is comparatively easier and low-risk choice which would give minimal loss at 20 % proportionally reduced water supply. The deliberate stage specific deficit irrigation practice will be risky in case the temporal availability of irrigation water hasn't been made sure. The non-reliable water supply to the farms, in terms of quantity and application timing, can be overcome by small decentralized water storage facilities which can be utilized at the high crop-water demand stages. An alternative to storage would be to strengthen the Water Consumers Associations and water management organizations for a more reliable water distribution system.

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