HELPING MEASURES FOR FARMERS TO MITIGATE DROUGHT IN CANAL WATER SCARCE AREAS OF THE INDUS BASIN, PAKISTAN

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ABSTRACT: In the plains of Indus Basin of Pakistan, rainfall and canal water supplies are generally not sufficient to meet crop water requirement. Groundwater contributes significantly to fill this gap between demand and supply of water in the agriculture sector. The continuous dry spell of the past three years in the region has further marginalized the benefit of rainfall, forcing farmers to rely more on groundwater to overcome this drought situation. To extract groundwater, farmers are currently using skimming wells. The quality of skimmed groundwater is relatively fresh when compared with the quality of groundwater pumped by using conventional tubewells. However, it is relatively saline when compared to canal water. But, the quality of skimmed groundwater has also started deteriorating, simply due to less amount of recharge available under the prevailing drought. As a result, in areas irrigated with skimmed groundwater, two types of salinity hazards—transient salinity (short-term) and secondary salinity (long-term), may occur. Therefore, there is a need to find ways and means to meet the crop water requirement for good crop productivity while mitigating drought situations both at farm and field levels in the canal water scarce areas of the Indus Basin, and to control both types of salinity hazards in the root zone within crop salinity threshold levels during different stages of crop growth. In the given context, an outline is presented on the scope of different helping measures, which advocate smallholders irrigated agriculture by availing water and salinity control systems both at farm and field levels in the canal water scarce areas of the Indus Basin. Intermittent pumping is a farm level measure in which the daily operational hours for skimming wells are defined while estimating the potential recharge. While using saline water for irrigation, the selection of irrigation application method and the timing of irrigation are very important to save crop from the damaging effects of soil salinity resulting from water stress. At field level, the intermittent irrigation is scheduled to meet the crop water requirement with the minimum amount of irrigation water applied. In fact, this practice of irrigation is one way of making deficit irrigation more productive to mitigate drought in irrigation water scarce areas. The intermittent leaching is also a field level measure that helps in maximizing the leaching efficiency while minimizing the amount of irrigation water required to achieve the desired salinity in the root zone, and allows to leach salt in the root zone with each irrigation turn, rather than leaching at the end of the crop—a promising solution to control transient salinity in the root zone.

INTRODUCTION
Rainfall and canal water supplies in the Indus Basin of Pakistan are generally not sufficient to meet crop water requirement. Over the years, the cropping intensities and cropping patterns have changed for meeting the increasing demand of food and fiber. Although, rainfall in Pakistan is markedly variable in magnitude, time of occurrence and its spatial distribution (Khan and Muhammad, 2000), it contributes significantly to meet crop water requirement (Figure 1). Already, the recent dry spell in the region has marginalized this benefit of rainfall both in the kharif (summer) and rabi (winter) cropping seasons. Over the years, in both the cropping season, total rainfall showed decreasing trend, but the net crop water requirement has increased. On the other hand, lack of practices to use rainwater effectively: (i) to supplement crop water requirement, (ii) to leach salts from the root zone, and (iii) to recharge the depleting groundwater resource, are also the common feature of on-farm water and salinity control practices.

Presently, farmers are increasing their groundwater extractions to fill the gap between demand and supply of canal water, and to mitigate drought situation. Figure 2 shows the density of tubewells—number of tubewells per 1000 ha, in Punjab, Pakistan as affected by the quality of groundwater. Tubewell density is higher in areas that have fresh groundwater, and vise versa. In the north-central part of the Chaj Doab—area between Jhelum and Chenab Rivers in the Indus Basin, 138 public tubewells, having depth of 60-75 m, were installed during seventies to meet the irrigation water demand at farm level. But, most of them had to close at the request of farmers due to poor quality pumped groundwater. Then, in the vicinity of those abandoned public tubewells, farmers installed their own tubewells at the depth of 30-40 m depth. But, the quality of pumped groundwater started deteriorating with time from these tubewells too. Recently, farmers have started installing skimming wells that are multi-strainer tubewells and their pumped groundwater quality is much better than the previously installed tubewell technologies, still its quality remains relatively saline as compared to canal water.

Furthermore, the quality of pumped groundwater is directly related to the amount of recharge available from deep percolation of the conveyance and distribution system, as well as, irrigation and rainfall. Plate 1 shows a typical field situation where two farmers have installed their tubewells within 10 m radius. Such a field situation would

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Figure 1: Contribution of rainfall and canal water supplies to meet the crop water requirement in the command of Lower Jhelum Canal from Kharif 1997 till Rabi 1999-2000.

Figure 2: Effect of groundwater quality on the number of tubewells per 1000 ha in Punjab, Pakistan.
definitely result in deteriorating quality of both the wells, simply due to less amount of recharge available under recent drought situations. Figure 3 shows depth to water table behavior, distribution and amount of rainfall, and changes in pumped water quality from a farmers’ fractional skimming well. From October 2000 till July 2001, depth to water table behavior shows declining trend -less recharge available, and the pumped water quality shows deteriorating trend. But, the pumped water quality started improving after July 2001 due to excessive recharge resulting from the monsoon rainfalls.

Therefore, even if skimmed groundwater, extracted from unconfined aquifers underlain by saline groundwater, is used for irrigation purposes, two types of salinity hazards -transient salinity (short-term) and secondary salinity (long-term), may occur. Therefore, there is a need to find ways and means to meet the crop water requirement for good crop productivity while mitigating drought situations both at farm and field levels in the canal water scarce areas of the Indus Basin, and to control both types of salinity hazards in the root zone within crop salinity threshold levels during different stages of crop growth.

HELPING MEASURES FOR FARMERS
In the following, an outline is presented on the scope of different helping measures, which advocate smallholders irrigated agriculture by availing water and salinity control systems both at farm and field levels in the canal water scarce areas of the Indus Basin, Pakistan.

Intermittent Pumping
Figure 4 shows frequency distribution of daily operational hours, of the fractional skimming well installed at the Akram Farm, observed from June 2000 till December 2001. The farmer operated his fractional skimming well mostly for 2-8 h/d. The effect of daily operational hours on the pumped water quality and discharge is depicted in Figure 5. The discharge rate of this fractional skimming well during the first one hour was around 28 l/s. With the increase in daily operational hours from 2 to 12 h/d, the pumped water quality deteriorated three fold (i.e., it becomes 1.8 dS/m from 0.6 dS/m), and the percent reduction in discharge increases from 5% to 30%. The “Intermittent Pumping” is a farm level measure in which the daily operational hours for skimming wells are defined when there is less recharge available -from October 2000 till July 2001 as shown in Figure 3. Therefore, for this particular farm, and for farms having similar climatic and hydro-geological conditions, if farmer operates his fractional skimming well for 4-6 h/d, its pumped water quality will remain less than 1.0-1.2 dS/m with only 15-20% discharge reduction, thereby making his tubewell operation cost-effective, and application of pumped water will be less harmful to soil and crop.

Irrigation Application Methods and Practices While Using Poor Quality Waters
As the quality of pumped groundwater, even if it is pumped with fractional skimming well while using intermittent pumping practice, always remains relatively poor as compared to canal water. This situation calls farmers for using the limited quantities of non-saline waters (canal water) most judiciously in combination with the relatively poor quality waters. Farmers may adopt two practices for the combined use of relatively fresh water (skimmed groundwater -saline and/or sodic) and fresh water (canal water): (i) blending of different quality water supplies, and (ii) cyclic use of different quality waters. The strategy of cyclic use of different quality waters involves the use of canal water at the most sensitive crop growth stages and saline water is used at other stages so that the effects of low resultant soil salinity build up can be minimized. In most of the crops, the germination and vegetative periods have been identified as the most sensitive stage to salinity. A failure at these stages will lead to poor crop stand and considerable reduction in yields (Rhoades, 1987). Allen et al., (1998) presented an approximate function that predicts the reduction in the actual evapotranspiration (AET) caused by the stresses induced by soil salinity and soil water.

Plate 1: A typical field situation of closely installed farmers’ tubewells.
Figure 3: Depth to water table behavior, distribution and amount of rainfall, and changes in pumped water quality from a farmers' skimming well, observed at a farm near Bhabal, during 2000-2001.
Figure 4: Frequency distribution of daily operational hours observed from June 2000 till December 2001 at the Akram Farm near Bhalwal.

Figure 5: Effect of daily operational hours on the pumped water quality and discharge.
This function was derived by combining crop yield-AET equation from Doorenbos and Kassam (1979) with crop yield-salinity equation from Ayers and Westcot (1985). Thus, to achieve this, a prior information of the salinity threshold values of the crops to be grown in sequence and salt build up in the root zone with use of a given quality water during the cropping seasons is essential, which are not widely available under different agro-climatic and management conditions.

Although blending of saline water and canal water may not always be beneficial to crop production, as it does not reduce the total salt load (Gupta, 1990), the process, however, improves the stream size that would enhance the uniformity in irrigation by surface irrigation application systems and allows for more area to be planted (Gupta and Minhas, 1993). It may also lead to improvement in the quality of sodic waters (having high RSC and low calcium concentration), as the blending of canal water with the sodic groundwater would result in under-saturation with respect to calcite. Consequently, the blended water on irrigation will have greater tendency to pick up calcium through dissolution of native calcite from soils. There is, however, no direct evidence available at present to support this proposition. However, the blending of sodic water and canal water can dilute water to acceptable quality and can broaden the choice of crops. Therefore, it may be considered as an effective solution to the water quality problems if facilities for blending are available and the blending ratio is known.

Kruse (1995) described different factors that effect the selection of irrigation application methods for irrigating with saline water (Table 1). Conventional surface and improved surface irrigation application systems have higher water requirement for leaching. Sprinkler can apply small depths of water uniformly, keeping the seed bed adequately moist and salt-free. Therefore, sprinklers are sometimes used to germinate and establish salt-sensitive crops and surface irrigation can then be used to grow the established crop (Robinson and Mayberry, 1976).

**Timing of Irrigation**

The timing of irrigation needs special consideration while using saline water for irrigation, as soil water stress may occur more quickly and adds to the soil salinity stress that can cause immediate crop damage. Proper timing of irrigation can help to avoid low levels of soil moisture that cause salts in the soil solution to become highly concentrated. Frequent irrigation reduces soil water stress and soil salinity stress caused by the saline irrigation water. Frequent irrigation also keeps the salts moving through and away from the root zone. If irrigation is applied frequently, each irrigation turn must be light. Shalhevet (1994) reviewed the effect of frequency of saline water application on yield, and concluded that higher frequencies result in higher yield. Irrigation intervals of several days to allow for internal drainage are unnecessary because large soil volumes are not saturated. Light irrigation can seldom be applied as uniformly with surface irrigation application systems as with the sprinkler irrigation application systems. Irrigation should be scheduled during or after rainfall to leach the salts before they damage the crop (Somaani, 1993). IWMI has used a Class A Evaporation Pan for identifying timing of irrigation to corn crop sown at the Akram Farm near Bhalwal for two cropping seasons—in 2000 and 2001. However, a Marriott bottle was attached to the pan that maintains water level at 20 cm (Figure 6). In this modified evaporation pan, loss of water from the pan was monitored from the Marriott bottle (Plate 2).

Figure 7 shows evaporation pan data observed at the farm, which indicates daily changes in the actual evapotranspiration due to daily changes in weather conditions. Corn was sown, on sandy loam soil, in July and harvested in November each year. Corn is a drought and salt sensitive crop.

**Table 1: Factors affecting selection of irrigation application systems for irrigating with saline water (Kruse, 1995).**

<table>
<thead>
<tr>
<th>Systems</th>
<th>Crops</th>
<th>Salt distribution pattern</th>
<th>Leaching effectiveness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface</td>
<td>Most crops</td>
<td>Leaves salt in the root zone</td>
<td>Higher water requirement for leaching</td>
</tr>
<tr>
<td>Furrow (furrow-ridge and bed-and-furrow)</td>
<td>Row crops</td>
<td>High in beds between furrows</td>
<td>Similar to above</td>
</tr>
<tr>
<td>Corrugation (deep and shallow)</td>
<td>Close-growing crops</td>
<td>High in areas between corrugations unless entire field is inundated.</td>
<td>Similar to above</td>
</tr>
<tr>
<td>Sprinkler</td>
<td>Most crops</td>
<td>No salt concentrations in the root zone, if system designed and managed well</td>
<td>Uniform leaching, and can be used to leach salt accumulation left by other irrigation methods.</td>
</tr>
<tr>
<td>Drip/Trickle</td>
<td>High value crops</td>
<td>Salts concentrates at outer fringes of the soil profile wetted by each emitter.</td>
<td>Soil profile wetted by each emitter is well leached.</td>
</tr>
</tbody>
</table>
The management allowed deficit, for 0-30cm soil profile, was taken equal to 30%, which represents 36 mm evaporation loss from the evaporation pan. This management allowed deficit is an indicator for deciding the timing of irrigation. When evaporation pan showed 36 mm evaporation loss, then the soil moisture depletion in the top 30 cm soil profile was estimated (Figure 8). In the whole season, soil moisture depletion in the top 30 cm soil profile matched well with the pan evaporation estimates. This shows the effectiveness the modified Class A Evaporation Pan for identifying the timing of irrigation, which is simple to use and may help common farmers to plan irrigation.
**Intermittent Irrigation**

In case of a rainfall event that occurred within one day before canal irrigation turn, the area irrigated with that particular turn is always greater than the routine. Actually, the soil surface wetness, resulting from rainfall, increases the rate of advance of irrigation water in the field (cropped or non-cropped), and more area is irrigated. If the objective of surface wetness is achieved with rainfall simulators—like raingun sprinkler systems, then the area under canal water irrigation can be increased. This type of irrigation application practice is termed as "Intermittent Irrigation". In this practice, pressurized irrigation system helps in maximizing uniform distribution of irrigation water, and surface wetness due to sprinkling helps in minimizing the application of canal water, still can meet the crop water requirement. Simply, the intermittent irrigation is scheduled to meet the crop water requirement with the minimum amount of irrigation water applied at field level. The IWMI conducted preliminary field trails during Rabi 1997-98 in the command of Chishtian sub-division, southeastern Punjab, Pakistan, to assess the applicability and usefulness of intermittent irrigation. These trials were conducted at three different farms representing coarse, medium and fine texture soils. The decision of stopping irrigation applications was made based on the farmers' perceptions regarding pre-sowing (routi) irrigation in their respective fields. Plate 3 depicts application of intermittent irrigation to bare soil for seedbed preparation of wheat crop. Two plots, each of 0.05 ha area, were selected adjacent to each other at all the three locations. At each location, the same tubewell water was used while irrigating these two plots adopting conventional irrigation and intermittent irrigation application practices. Table 2 showed duration and amount of irrigation water applied to bare soil with intermittent and conventional irrigation application practices for coarse, medium and fine soils.
Plate 3: Intermittent irrigation is in progress to bare soil for seedbed preparation of wheat crop.

Table 2: Duration and amount of irrigation water applied to bare soil with intermittent and conventional irrigation application practices.

<table>
<thead>
<tr>
<th></th>
<th>Coarse</th>
<th>Medium</th>
<th>Fine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area (ha)</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
</tr>
<tr>
<td>Tubewell discharge (l/s)</td>
<td>32</td>
<td>24</td>
<td>28</td>
</tr>
<tr>
<td>Conventional irrigation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Duration of water application (min)</td>
<td>26</td>
<td>30</td>
<td>23</td>
</tr>
<tr>
<td>Depth of water applied (mm)</td>
<td>102</td>
<td>89</td>
<td>76</td>
</tr>
<tr>
<td>Intermittent irrigation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Duration of water application (min)</td>
<td>25</td>
<td>23</td>
<td>20</td>
</tr>
<tr>
<td>Depth of water applied (mm)</td>
<td>97</td>
<td>67</td>
<td>69</td>
</tr>
<tr>
<td>Possible increase in irrigated area due to intermittent irrigation (%)</td>
<td>5</td>
<td>33</td>
<td>11</td>
</tr>
</tbody>
</table>

Results showed that at all the three locations, intermittent irrigation took less time to irrigate the field as compared to conventional irrigation application practice. This saving in application time means that irrigated area can be increased to 5, 33, and 11% by adopting intermittent irrigation for coarse, medium and fine soils, respectively.

In the command of Chishitian sub-division, field monitoring on the performance of irrigation applications methods and practices under farmers management conditions was also carried out for three wheat seasons starting from Rabi 1996-97 till Rabi 1998-99. Majority of farmers applied four to five irrigations in a season. It was observed that farmers were over irrigating their fields in the first two irrigations, whereas the fields were generally under irrigated (i.e., deficit irrigation) in the last and second last irrigations. The irrigations in the middle of cropping season matched with the crop water requirement. Therefore, if over-irrigation during roni and first two irrigations is controlled, more area can be cropped and irrigated in a season, and intermittent irrigation can do effectively. Even under-irrigations can be covered with pressurized irrigation applications. In fact, this intermittent irrigation is one way of making deficit irrigation more productive to mitigate drought in irrigation water scarce areas. Intermittent irrigation application practice reduces cost of pumping and saves water that may be used to irrigate more area. But, the cost of installing, operational management, and maintenance of pressurized irrigation system poses significant constraints. As it involves less use of water, therefore, there is also a need to evaluate this practice for meeting crop water requirement during the whole cropping season. Presently, IWMI is undertaking another project, funded by the National Drainage Program (NDP), in collaboration with the Water Resources Research Institute (WRRI) and Mona Reclamation Experimental Project (MREP). The project entitles, Root Zone Salinity Management Using Fractional Skimming Wells with Pressurized Irrigation, and the project area constitutes a part of SCARP-II, and lies in the north-central part of the Chaj Doab. Under this project, efforts are being made to make this experience of intermittent irrigation practice into a practical reality as an on-farm water management practice in canal water scarce areas of the Indus Basin. The target farmers under this project are medium landholders that
have 2.5 to 5 ha landholdings. For these farmers, two alternatives were introduced to reduce the installation cost of intermittent irrigation systems:

1) pressurized irrigation system was installed on the 50 to 60% of the farm area, and
2) this system was connected directly to a small fractional skimming well designed to extract only 3 to 7 l/s of groundwater.

Total cost of installing such systems is rupees 45,000 to 60,000, which is comparable with installing the farmers’ groundwater extraction systems. Results of these trials will help in evaluating the efficiency of intermittent irrigation practice to save canal water and to minimize use of groundwater without affecting the crop growth.

Generally, when sprinkler uses saline water to grow the established crop, salt deposits on leaves may adversely affect some crops (Maas, 1985), especially deciduous fruit trees are susceptible (Hoffman et al., 1980). Susceptibility of plants to leaf injury from saline sprinkled water depends on: leaf characteristics affecting rate of absorption and is not generally correlated with tolerance to soil salinity (Rhoades et al., 1992). The degree of spray injury varies with weather conditions, and visible symptoms may appear suddenly following irrigations when the weather is hot and dry. Increased frequency of sprinkling, in addition to increased temperature and evaporation, leads to increase the salt concentration in the leaves, and results in leaf damage. However, irrigation at night (or any other low evaporation period) minimizes the salt concentration in the leaves due to adsorption (Krans, 1995).

Intermittent Leaching

Conventionally, there are two practices of leaching. One is continuous ponding and the second is through several light water applications. If continuous ponding is applied at the soil surface for leaching purposes, its leaching efficiency will be lower as compared to several light water applications. In order to achieve the same leaching efficiency, the amount of water needed in case of several light water applications is 25-35% lower than the amount needed for continuous ponding (Gupta and Gupta 1987). Actually, the practice of applying several light irrigations allows the salts accumulated in the soil micro pores to get properly dissolved and the following another light irrigation push the dissolved salts further down in the root zone. This light irrigation practice takes more time to clear the salts from the root zone as compared to continuous ponding practice.

In case of intermittent irrigation, an additional benefit would be the increased leaching efficiency. Pressurized irrigation applications will help in dissolving the salts accumulated in the micro pores of top 30 cm soil profile, and canal water application will push these dissolved salts down through the soil profile along with the solutes accumulated in the soil macro pores. This type of leaching practice is termed as “intermittent leaching”, which helps in maximizing the leaching efficiency while minimizing the amount of irrigation water required to achieve the desired salinity in the root zone. It will also allow to leach the salts down with each irrigation turn, rather than leaching at the end of the crop – a promising solution to control transient salinity in the root zone.

There should not be sole reliance on engineering solutions (shallow tubewell pumping, subsurface drainage, local evaporation basins, dry drainage, etc.) to solve secondary salinity problems. Where necessary, they must be used in combination with various on-farm land and water management measures. These include, among others, better matching of irrigation applications to crop water use requirements, laser land leveling to improve efficiency of water applications, and surface drainage of irrigated land. However, living with the problem may be necessary, especially in the short term, until more permanent controls can be developed. Growing crops that tolerate or avoid salinity exemplifies this approach. The usual sequence followed as their salinity problem persists is to convert corn to wheat, wheat to barley, barley to alfalfa, alfalfa to brome grass and brome to tall wheat grass.

CONCLUSIONS AND RECOMMENDATIONS

Daily operational hours affects significantly on the quality and quantity of pumped groundwater, and if fractional skimming well is operated for 4 h/day under drought conditions, then intermittent pumping would help in making its tubewell operation cost-effective, and application of pumped water would also be less harmful to soil and crop.

For sustainable irrigated agriculture under drought conditions, although the improved surface irrigation methods (like furrow–furrow–ridge and bed-and-furrow, and corrugation–deep and shallow) can help in minimizing the use of groundwater for irrigation purposes, they demand higher water requirement for leaching. Therefore, integrated use of the raingun pressurized irrigation method to germinate and establish salt-sensitive crops, and the surface–conventional and improved; irrigation methods can then be used to grow the established crop.

While using saline water for irrigation, timing of irrigation needs special consideration, as soil water stress may occur more quickly and add to the soil salinity stress that can cause immediate crop damage. The modified Class A Evaporation Pan, which is simple to use, can efficiently help for identifying the timing of irrigation, but additional fieldwork is needed to generalize its use for different crops grown under different agro-climatic conditions.

At field level, intermittent irrigation helps in meeting crop water requirement with minimum amount of irrigation water applied. In this practice, pressurized irrigation system helps in maximizing uniform distribution of irrigation water, and surface wetness due to sprinkling helps in minimizing the application of canal water, still can meet the crop water requirement. In fact, this practice of irrigation is one way of making deficit irrigation more
productive to mitigate drought in irrigation water scarce areas.

Intermittent leaching is also a field level measure that helps in maximizing the leaching efficiency while minimizing the amount of irrigation water required to achieve the desired salinity in the root zone. Pressurized irrigation applications will help in dissolving the salts accumulated in the micro pores of top 30 cm soil profile, and canal water application will push these dissolved salts down through the soil profile along with the salts accumulated in the soil macro pores. Therefore, it will also allow to leach the salts down with each irrigation turn, rather than leaching at the end of the crop—a promising solution to control transient salinity in the root zone.

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