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Water Conservation Techniques to Increase Crop Production in the Tail Reaches of Irrigation Networks

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Abstract

The lack of proper management, operation, maintenance, system efficiency, and illegal extraction in the irrigation system have remained major problems since the existence of the irrigation network that have resulted in inequitable and unreliable distribution, thus the poor tail-enders are always faced with shortage of water. Under prevailing warabandi (rotational) irrigation system, the distribution of water to the outlets is inequitable. The outlets at the head and middle reaches of distributaries draw more than the actual allocated share, whereas outlets at the tail reaches draw less than the actual allocated share. Outlets at the channel's head draw 3 to 6 times more share of total supplies than the tail outlets. Those who draw greater shares apply more water than the crop's water requirement resulting in excessive wet stresses to crops and excessive leaching of nutrients, whereas the tail ender apply less water than the crop's water requirement resulting in dry stresses to crops. Under both stresses, not only crop yields are affected but also low water use efficiency is achieved. Some tail-enders compensate the inadequate supply with poor quality groundwater are prone to secondary salinization due lack of proper knowledge of conjunctive use of such water.

The present paper describes various scientific approaches to manage the water available at the outlet. Various alternatives such as planting techniques, crop rotation, high yielding varieties with less water consumption, improvements in current traditional irrigation methods, conservation through advanced irrigation methods, use of small scale water storage ponds to harness off-season water, and conjunctive use of water has been discussed.

Introduction

Fresh water resources of Pakistan are being used to fulfill the food requirements and to improve the living standards of the population of Pakistan. But due to increasing onslaught of human population, these resources continue to dwindle and are becoming scare. The country once considered as a water surplus has emerged into a water deficit one. Despite having the world's largest contiguous irrigation system, it is facing the dilemma of water shortage and situation will even exacerbate in the near future.

The seepage losses in the irrigation network, mismanagement in distribution system and over application at farm level have created the problems of water logging and salinity. Thousands of hectares of farmland are lost annually due to rising water tables. It is an established fact that almost 20% of water is lost due to traditional surface irrigation methods at farmers' field. If this water is saved and consumptively used, additional arable and fertile lands essential for

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modern agriculture could be brought under cultivation which otherwise are lying barren due to water shortage.

Land, water and crop statistics

Land use inventory of Pakistan dictates that over 15.1 million hectares (Mha) of potential lands (i.e. about 9.5 Mha categorized as culturable waste and over 5.6 Mha of saline and waterlogged lands) have to come under cultivation for sustainable development of land resources of the country. The future water requirement and water availability reveals that irrigation requirements for the year 2013 and 2025 would increase to about 255 billion m^3 (BCM) and 343 BCM, respectively. Looking into the present available water resources, we have already slipped into shortage of irrigation water this deficit is projected to reach over 133 BCM and 187 BCM by the years 2013 and 2025, respectively (Mirjat and Chandio, 2000). This scenario had already red signaled that Pakistan had slide from water affluent country to water scare country, in the next 10 to 20 years situation will even aggravate.

The statistics on cropped area reveals that in 1951 the cropped area stood about 12.5 Mha for a population of 34 million. By 1981, the cropped area increased to 18.7 Mha while the population stood at 84 millions. At present, the cropped area stands about 20.7 Mha and the population has exceeded 140 millions. A simple calculation on the cropped area and population indicates that the per capita cropped area has significantly decreased. The figures reveal that the per capita cropped area that stood 0.37 during 1951, decreased to 0.22 hectares in 1981 and today it remains about 0.16 hectares per person. According to the projection of the planning commission the total food requirement stands about 105 million tones for a population of over 140 million as of today, while the available water resources can produce about 80 million tones with a shortage of 25 million tones. In the year 2015, the total food requirement for the projected population of 210 million is estimated to be 140 million tones and the estimated production would be about 90 million tones. This would result in a total shortage of 50 million tones. If we were to face the situation of such a dire food dearth in next 10 years, then we must start taking steps to increase crop production now. In order to achieve the comparable crop yields to that of other countries, to save land from water logging and salinity, to feed ever-increasing population of the country, and to bring agriculturally potential land under cultivation, the potential of limited water resources must be utilized to its full extent. Since, new sources of water supply are becoming scare and are unlikely to be constructed in the near future due to geo-political reasons, the emphasis must be given on the methods that can salvage the supplies already being lost within the present irrigation system. Though the existing water resources of the country are not sufficient to meet the crops' water requirement, yet they are not properly managed and efficiently used. The gap between the potential yields and actual yields could be narrowed down by the efficient use of available resources. In addition, alternative-cropping systems with the least dependence on irrigation should be adopted and the varieties giving highest crop yields with minimum irrigation requirements should be introduced. New irrigation scheduling approaches, not necessarily based on full crop's water requirement but aiming at increasing efficient use of allocated irrigation needs to be established.

Distribution system at outlet

The coordination between water users and the irrigation department has remained a major problem since the existence of irrigation network that has resulted mismanagement, poor maintenance, inequitable and unreliable distribution. Under prevailing rotational (warabandi) irrigation system, the distribution of water to the outlets is inequitable. The outlets located at the head and middle reaches of distributaries draw 3 to 6 times more than the actual allocated share, whereas outlets at the tail reaches draw less than the actual allocated share, hence, the poor tail-enders are always faced with shortage of water. Those who draw greater shares apply more water than the crop's water requirement resulting in excessive wet stresses to crops and excessive leaching of nutrients, whereas, the tail ender apply less water than the crop's water requirement resulting in dry stresses to crops. Under both stresses, not only crop yields exaggerate but the water use efficiency significantly reduces. Some tail-enders compensate the inadequate supply with poor quality groundwater and their fertile lands become prone to secondary salinization due lack of proper knowledge on conjunctive use of such water. All this suggests proper management and adoption of scientific approaches to utilize the water available at the outlet. This could be done at the farm level either by improving the present application methods or by introducing highly efficient irrigation methods.

Improvement in traditional methods

In fact, the farmers use traditional flood irrigation methods without consideration of land slope and soil texture. Thus, more than 20% water is lost at the field level through deep percolation. Similarly, furrows are prepared without proper knowledge on slope consideration. The farmers need proper training on the application of furrow, border and basin irrigation methods. These methods would still give high production if they are properly designed and applied according to soil and water conditions. One of the factors identified for inefficient use of irrigation water through these methods is poor leveling. The unleveled lands are characterized with non-uniform distribution of irrigation water and deep percolation which requires excessive application that in turn affects application efficiency. A properly leveled field with an appropriate layout and size reduces application losses, ensures uniform distribution, and increases crop yields.

In a field study, the model plots with various sizes (48 X 24 m), (48 X 12 m), (24 X 24 m) and (24 X 12 m) were irrigated using existing irrigation methods. These plot sizes and lay-outs were used to determine the optimum size that requires less irrigation time. The findings of this study suggest that the plots with 24 X 24 m provided the best results and took less time to irrigate one hectare as compared to other three plot sizes (Shah et. al., 1998). The water distribution pattern and application depth was significantly different under various sizes. Based on plot size and flow rate available, the plots were irrigated through one or two cuts it was observed that the number of cuts has no effect on application and perching depths thus plots could be irrigated either of one or two cuts.

In another study, the irrigation schedules based on farmers' practice, DRC scheduling, and crops' daily water requirements were tested to determine the best one for cotton crop. It was observed that irrigation with 75 mm depth applied at three week interval provided the best results in terms of yield and water saving (Mirjat et. al., 2001) hence this schedule could be adopted at the tail reaches where farmers experience water shortage. However, the farmers using tube well water can still use a different schedule that should strictly be based on crop's water requirement.

Potential of modern irrigation methods

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Efficient irrigation methods like trickle, sprinkler, pitcher, and sub-irrigation are required to be introduced at the tail reaches with water shortage problem. These methods are proven to be efficient in terms of water saving but are considered expensive thus farmers are reluctant to use them. However, the acceptance of these methods depends upon their success in terms of maximum yield returns associated with minimum water required. Since these techniques have potential to save lot of water, hence, more land could be brought under cultivation with small amounts of water available, particularly, at the tail reaches of the conveyance systems. The irrigation methods so introduced must be acceptable as well as economically affordable by the farmers; hence government should take initiative and install demonstration plots at farmers' fields to introduce them. Once, the farmers will realize the benefits of water saved and returns achieved, they will install such systems from their own resources.

Among the new methods mentioned, trickle irrigation has been reported one of the efficient methods of water application than any of the conventional surface irrigation methods. It provides prescribed amount of water, achieves high field application efficiency, offers better uniformity, saves water, and ensures better yields. Also, the water is applied to plants in a precise quantity thus their immediate water requirements are met. Studies reveal that, with this method, as high as 90 percent application and distribution efficiencies can be achieved (Mirjat et al. 2005; Soccol et al. 2002). The method has been reported more suitable for orchards and high value vegetables where 40-60% water could be saved. Other major economic benefits include yield increase per unit water and direct uniform application of fertilizer and pesticides with trickling water. In the tail reaches, if water is available in limited quantities it could be stored in the small ponds and supplied through mobile tanker systems. In case water is not available at the farm gate, it can directly be taken from the nearby minor or distributary using the tanker and supplied to distribution tanks located at the field.

Water storage ponds

The concept of water storage ponds at the farm level is quite new and needs research on how to make it economically and physically viable. Their use is a premeditated management tool to harvest water when it is in excess and utilize when needed. The storage capacity depends on the size of the pond and availability of water to be harnessed. For example, a 40 m long, 20 m wide, and 2 m deep pond will store 1600 m^3. If an irrigator applies 5 cm irrigation depth then the stored volume can irrigate at least 3.2 hectares. It is farmer's choice to properly manage and efficiently use the stored water as needed.

Storage options

1. The water supply in the Indus River system is variable; it is diminutive during winter and spring months and massive during irregular monsoon flooding seasons. The water availability in the canal system is more than the crop's water requirements during summer while it is less during winter. The canals are closed for cleaning/de-silting purpose during winter which further limits the water availability for crops. The storage ponds could be filled during flooding season and utilized at time of need.

2. The crops require less water near the harvesting thus the water might be available during this period that could be stored and used at later stage. For example, the water harvested at the end of cotton crop could be utilized for sowing the Rabi crops when the irrigation system is short to meet the pre-sowing and sowing irrigation requirements of

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wheat. The farmers may store surplus water of mid-kharif season and utilize the same either to replenish the deficit at critical growth stages or to supplement the sowing period of Rabi season.

3. During water shortage periods, the irrigation systems are operated on rotational basis. Some of the distributaries/minors in the distribution system are closed for few weeks while others remain operating. The stored water can properly be used during such forced closures.
4. The rain water in the desert areas could also be harvested during monsoon season and utilized as and when required. However, it requires efficient irrigation methods, such as trickle irrigation, that utilizes minimum amounts.
5. The delay action dams and small ponds could be constructed in the arid zone areas including Kohistan, Nangar Parker, Thar, Kharan, Quetta Valley to harness the rain water and utilize to irrigate the lands which otherwise remain barren in such areas.

Conjunctive use of water

The conjunctive use through blending waters of different qualities is not a popular option but becomes necessary in the tail reaches with water shortage. In this technique, the groundwater with marginal quality is blended with better quality canal water with an appropriate proportion. However, a better quality surface supply is always preferable whenever available; the poorer quality groundwater could be used whenever the surface supplies are insufficient. Amalgamation does not reduce the total salts load but allows more area to be cropped because of increased volumes due to dilution. However, the usability of the blended supply should be evaluated carefully to ensure that the total quantity of additional water needed for salinity control does not exceed the net gain in amount of blended water available and its quality can be found by using equation proposed by (Ayers and Westcot, 1985):

$$EC_{bw} = EC_{cw} \bullet a + EC_{ww} \bullet b$$

where,

EC_{bw} = concentration of blended water,
EC_{cw} = concentration of good quality canal water,
EC_{ww} = concentration of poor quality well water,
a and b = fractions of good quality canal and poor quality well water, respectively..

In the tail reaches where the good quality water is hardly available for blending with marginal quality water, application of gypsum and lime stone could be used as a management tool to use such water. The water with TDS $\leq$ 1700 ppm, and SAR as high as 5.0 has successfully been used without affecting the soil characteristics (Mirjat et. al., 1999). Results of several studies reported by Ghafoor et. al., (2004) also suggest that the improvements could be made in the quality of brackish water after passing through gypsum stone-lined water courses. According to them, a soil irrigated with a saline-sodic tube well water (EC 1.6 dS/m, SAR = 10.2, RSC = 7.1 mmol/L) passed through a 183 m long lined water course with gypsum stones of 5 to 30 kg. The amended water was applied to 3 wheat and 2 rice crops on sub soiled and/or gypsum treated @ 75% SGR soil. The reclamation efficiency was found in the order; sub soiling + gypsum > gypsum > sub soiling > control. In another study, a saline-sodic tube well water with TSS = 1600 ppm and SAR = 16 was passed over baffled gypsum stones of 5 to 20 kg in water

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course and it produced the dissolution rate of gypsum proportional to the square root of the velocity of water. Since gypsum is low cost and easily available in abundant supply in Pakistan thus its use is beneficial in areas underlain by poor quality water.

In many areas shallow aquifers with fresh water subsist or they are invariably underlain by native saline water in the areas near sea and gradually occupy deeper positions farther from the sea. Withdrawal of such water without scientific approach can undermine its quality and rapidly deteriorate the fresh aquifer. Thus, a scientific approach is required to extract such fresh waters without disturbing the underlying native saline water. One of the approaches practiced in the country is use of shallow skimming wells. These wells are installed in the zones of fresh groundwater with an appropriate cushion provided at the bottom of the well so that saline water intrusion is restricted. However, regular water quality measurements are required for safe use of such waters. If the water quality of discharging well deteriorates, its operational time could be reduced or it could be operated intermittently to allow the aquifer to recharge with good quality water.

Soil and crop management techniques

The soil management deals with physical techniques that improve soil hydro-physical and chemical properties such as infiltration, permeability, porosity, soil structure, density, and soil salinity etc. and they ultimately affect soil's production potential. They include deep plowing, sub-soiling, sand hauling, and horizon mixing. The techniques are aimed to increase soil permeability directly by mixing fine and coarse textured layers. Deep plowing consists the slackening of soil from about 40 to 150 cm depth and is beneficial in the stratified soils having impermeable layers. Sub-soiling consists of pulling vertical strips through the soil to shatter compact layer to improve soil permeability. It improves soil permeability and changes soil porosity, reduces compaction, and increases soil aeration and water holding capacity. Land leveling and shaping are the other useful practices which ensure proper water management and uniform application. To avoid major earth work, big fields should be divided into small parcels and leveled. The top soil layers should be carefully removed, otherwise one might end up loosing the rich fertile surface layers. Also drastic removal may expose the subsoil having C_aCO_3, and other undesirable materials which can pose difficulties in the reclamation and crop cultivation in the area.

The crop management includes; choice of crop, planting/sowing time, planting density, spacing, and cropping pattern which are the fundamentals for successful returns and play a decisive role especially in water scare areas with moderately saline water available. The proper and timely application of these factors would essentially increase crop production under limited water supplies. The farmers can grow more than one crop in a sowing season to harvest the maximum output from minimum water resources available. For example, onions are cultivated on ridges and until crop matures, wheat is grown in the same field. Many farmers grow sugarcane in combination with wheat and onion or both. The crop rotation is also dexterous to avoid salt accumulation. Inclusion of high water requirement crops in rotation is another better choice.

Salt tolerant crop species generally perform better under saline water and soil conditions thus are important for stabilization and reclamation of the soils. Cultivation of such crops provides reasonable income and control soil salinity level within acceptable limits. Plants are sensitive to soil and water salinity during germination hence, care should be taken during this stage. The application of saline water might affect the seed germination, thus it is important to keep EC in the seed bed as low as possible at planting time. The pre sowing irrigation with sweet water or dry sowing of crops is advisable that could help keep the EC low in the root zone at seed germination and seedling stages. To avoid the loss of young seedlings due to salinity, crops especially vegetables flowers and fruit trees, should be raised by transplanting their seedlings in a high-quality soil with better quality water. Further, younger plants are more sensitive to soil and water salinity and become better tolerant with age, relatively aged seedlings result in higher plant population and growth performance e.g. rice has been found to yield better if the age of nursery is increased from 40-50 to 55-60 days (Ghafoor et. al., 2004).

In the areas with water scarcity, the soils remain uncultivated and salt moves upward and accumulate at the surfaces; hence, should be brought under continuous cropping whenever possible. If crops are not possible to grow due water shortage, then soil must be ploughed frequently to break the capillaries through which soil solution moves upward. The levees must be provided to store rainwater that will help salt leaching and keep soil in good condition.

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