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Effect of different pre-sowing water application depths on wheat yield under spate irrigation in Dera Ismael Khan District of Pakistan

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ABSTRACT

Spate irrigation is a method of flood water harvesting, practiced in Dera Ismael Khan (D.I. Khan), Pakistan for agricultural production for the last several hundred years in which during monsoon period flood water is used for irrigation before wheat sowing. A field study on the effect of different pre-sowing water application depths on the yield of wheat was conducted during 2006–2007. The spate irrigation command areas normally receive the flood water as a result of rainfall on the mountains during the months of July to September, which also carries a significant amount of sediment load. The flood water flows in different torrents and is diverted through earthen bunds to the fields for irrigation with depth of water application ranging from 21 to 73 cm and resulted in sediment deposition of 1.8–3.6 cm per irrigation. In this study, the effect on wheat yield of three different pre-sowing water application depths (D1 < 30 cm, D2 = 30–45 cm and D3 > 45 cm) were studied under field conditions. Fifteen fields with field sizes of about 2–3 ha were randomly selected, in each field five samples were collected for analysis of soil physical properties, yield and yield components. Five major soil texture classes (silty clay, clay loam, silty clay loam, silt loam and loam) were found in the area with water-holding capacity ranging from 23% to 36.3% (on a volume basis) and bulk density varied from 1.35 to 1.42 g cm^{-3}. About 36% more grain yield was obtained from loam soil fields, followed by silt loam (24%) as compared to wheat grown on silty clay soil condition. The maximum wheat grain yield of 3448 kg ha^{-1} was obtained from fields with water application depths of 30–45 cm and the lowest wheat yield was recorded in fields with water application depths greater than 45 cm. On-farm application efficiencies ranged from 22% to 93% with an overall average of about 49%. Due to large and uneven fields, a lot of water is lost. In general, the application efficiency decreased with increasing water application depth. Based on the results of this research, in arid to semi-arid environments, for optimum wheat yield under spate irrigation, the pre-sowing water application depth may be about 30–45 cm (September to July) and under or over irrigation should be avoided.

1. Introduction

Spate irrigation locally known as Rod–Kohi irrigation system is one of the old and major irrigation systems practiced in Dera Ismael Khan (D.I. Khan) for agricultural production. The largest area under this type of irrigation lies in the D.I. Khan and Tank districts of Pakistan. Rod means the main torrent bed and Kohi pertains to mountains. Rainfall in the upper catchments, which extend up to Baluchistan, Afghanistan, the Sulaiman range, Sherani hills and the Batani range results in runoff and water rushing into various torrents in the foothill plains of the D.I. Khan and Tank districts. Mostly the flood water flows in different torrents known as Zams and Rods in these districts. The flowing seasonal streams or Rods (Nullahs) are blocked with temporary diversion structures (small dams or earthen bunds) which are also called Sads, Gandi or Ghatti in the local language. The flood water is then diverted through field irrigation channels called Khulas and trail dikes (pal) prepared for this purpose for irrigation of fields. In districts of D.I. Khan and Tank a total of 0.69 mha of land is available for cultivation, out of which about 0.26 mha is under Rod–Kohi agriculture.

In these areas major problem in the flood water use is highly variable in quantity, distribution, time and space. Average annual rainfall is low, uncertain and cannot fulfill the crops' demand. The farming system can be categorized as substance agriculture which is faced with extreme events of flood and droughts. Besides, the

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subsistence agriculture livestock raising is the main source of income of the farming community in the area. Under the spate irrigation command area, due to the uncertainty in flood water availability, the field sizes are relatively large (1–5 ha), not leveled and most farmers do not invest on land leveling due to the limited return on investment. Farmers normally construct the embankment of the fields 1–2 m high. They irrigate their fields so that even the highest spot has water ponded at depths more than 30 cm. This practice results in over as well as under irrigation (uneven distribution of water). Once the fields receive flood water in July–September, wheat (*Triticum estivum* L.) and gram (*Cicer arietinum* L.) are sown on the residual moisture in the soil which is used to sustain the crop growth through the low rainfall period.

In Pakistan, a total of 15.32 million hectares have irrigation facilities out of a total cultivated area of 20.34 million hectares. Wheat is grown on an area of about 8.45 million hectares. The irrigated area under wheat is 75% of the total cultivated area in the country. In the North West Frontier Province (NWFP), wheat is grown on an area of about 0.72 million hectares which contributes 8.5% of the total wheat cultivated area in the country. In the NWFP, 61% of the area cultivated with wheat (0.5 million hectares) is irrigated (Pakistan Statistical Year Book, 2007).

Haile et al. (2002) studied water sharing in the spate irrigation system in the Sheeb, Eritrea. They found that the diversion structures are normally made of brushwood and stones which are often damaged by the flood. For repair and reconstruction of these floods diversion structures the farmers organized themselves in groups to coordinate collective labour and input. In general, the water is distributed according to rules but sometimes these rules are violated like construction of new structures.

Laghari et al. (1979) studied the effect of moisture levels on wheat (Pak-70) at the Malir Farm of the Sindh Agriculture University at Tandojam during 1975–1976 and 1976–1977. The crop was irrigated at 50%, 70% and 85% Management Allowable Depletion (MAD) during 1975–1976 and at 70%, 80% and 90% MAD during 1976–1977. The average water requirements of 66.6, 58.3 and 48.9 cm were obtained at 50%, 70% and 85% MAD while 54.1, 48.9 and 38.1 cm were obtained for 70%, 80% and 90% MAD, respectively. The maximum grain yield obtained was 2570 kg ha^{-1} at 85% MAD during 1975–1976 and 3130 kg ha^{-1} at 70% MAD during 1976–1977. The highest water use efficiency of 52.6 kg $(ha\ cm)^{-1}$ was estimated at 85% MAD during 1975–1976 and 60.3 kg $(ha\ cm)^{-1}$ at 90% MAD during 1976–1977.

Singh et al. (1979) conduced experiments for three crop years (1974–1975, 1975–1976 and 1976–1977) on dwarf wheat (Kalyan Sona) using four levels of irrigation i.e., no irrigation (I_0), one irrigation (I_1), two irrigations (I_2) and three irrigations (I_3), respectively. The results obtained showed that grain and straw yield increased with the number of irrigations in all years. Maximum response was obtained with the first irrigation which was as high as 2000 kg ha^{-1} in 1976–1977 as compared to no irrigation. This was consistent with earlier reports that an early input of water coinciding with crown-root initiation to jointing stages in wheat produces a maximum increase in yield. The rate of yield increase declined with the second irrigation while the difference in grain and straw yield was very small between the two and three irrigation treatments. The average grain yield of 3400, 4300, 4500 and 4600 kg ha^{-1}, respectively, was obtained with no irrigation (I_0), one irrigation (I_1), two irrigations (I_2) and three irrigations (I_3), respectively. Moreover, the apparent water use by wheat increased with the number of irrigations. Water use efficiency was maximum at one irrigation in 1976–1977 and with no irrigations in 1975–1976 due to the relatively high rainfall.

Tawfic and Tinsley (1984) reported that the irrigation application efficiency of farmers at the tail end of canals was found to be greater than those at the head of canals. They suggested that subsurface irrigation due to seepage from neighboring fields contributes substantially to crop water use. They concluded that the surface irrigation is possibly not the best way to irrigate and they suggested a gradual shift for adoption of high efficiency irrigation system to overcome the shortage of water in future.

Oweis and Hachum (2006) conducted a study on water harvesting and supplementary irrigation for improved water productivity of dry land farming and reported that water harvesting can improve agricultural productivity by efficient utilization of runoff and integrated farm resource management. With supplementary irrigation in low rainfall (300–500 mm) regions a significant increase in the yield of wheat and barley can be obtained with appropriate inputs (ICARDA, 2003; Oweis and Zhang, 1998).

Blair and Smerdon (1988) reported that under normal conditions, small applications of water produce high application efficiency, but a low uniformity coefficient and storage efficiency, conversely; large applications of water produce high uniformity coefficient and storage efficiency, but low application efficiency. They observed that none of these terms are unimodal functions of the volume of water applied.

Bhatnagar and Kundu (1990) reported that on a rainfed trial during the winter season at Almora (1250 m altitude) the total evapotranspiration during the growing season of wheat, barley, lentils and peas was 272.4, 235, 255.7 and 246.2 mm, respectively. The four crops gave grain/seed yields of 2.21, 1.52, 1.46 and 0.80 tons/ha and showed water use efficiencies of 8.10, 6.43, 5.70 and 3.25 kg grain or seeds $(ha\ mm)^{-1}$ water, respectively. Data on the water expense (rainfall during the growth period plus soil moisture in the soil profile at sowing and soil moisture storage at harvest), water expense efficiency (yield $(ha\ mm)^{-1}$ water) and percolation loss were also calculated.

Adequate control and management of irrigation water require some method(s) to evaluate irrigation practices from the time water leaves the point of diversion until it is utilized by crops. Irrigation efficiency is the basic criterion used to judge the adequacy of these practices. Overall irrigation efficiency has two important segments i.e. (i) water conveyance efficiency used for evaluating water conveyance and (ii) application efficiency used to judge the effectiveness of the water use at the farm. The knowledge of these segments of irrigation efficiency is essential to help improve the management of irrigation water.

The irrigation application efficiency for an irrigated area is the ratio, expressed in percent, of the volume of water beneficially used by the crop to the volume of water delivered to the area. Irrigation application efficiency depends on many factors i.e. soil topography, texture, structure, vegetative cover; degree of care exercised in leveling the area to be irrigated, the ability of the irrigator, frequency of irrigation, and depth of the root zone system.

Tesfai and Stroonsnijder (2000) studied the spate irrigation system in coastal zone of Eritrea and found over all spate irrigation system efficiency of about 20%. Another study by Tesfai and Sterk (2001) reported that on low lands of Sheeb valley in Eritrea the farmers produce crops without the use of fertilizers due to the incoming fertile sediment deposition during the spate irrigation. The sediment deposition rates ranged from 11.3 to 31.6 mm $year^{-1}$ with overall average sedimentation of 143 ton ha^{-1}. They also mentioned that in future to replenish the nutrients stock incorporation of crop residue and manure maybe necessary.

Spate irrigation deals with management of flood water which is unpredictable in timing and volume. Significant improvement can be brought in the performance of the system by strengthening the farmers' organizations and replacing the culverts with head regulator gates (Mehari et al., 2005). According to conservative estimates, significant (more than 50%) of flood water is allowed to