Growing Wheat under Spate Irrigation In Dera Ismail Khan (2006 – 07)

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Summary

Spate irrigation is a several hundred year old method of flood water harvesting, practiced in Dera Ismael Khan (DIKhan), district of Pakistan. The practice is meant basically for agricultural production and it utilizes the monsoonal flood water for irrigation before the sowing of crops, in this case wheat. A field study on the effect of different pre-sowing water application depths on the yield of wheat was conducted during 2006–2007 with Agriculture University, Peshawar (AUP), PLI and Colorado State University. The spate irrigation command areas normally receive the flood water as a result of rainfall on the mountains during the monsoon months of July to September. The rainwater also carries a significant amount of sediments. The flood water flows in different torrents and is diverted through earthen bunds to the fields for irrigation. Water application depths vary, ranging from 21 to 73 cm, resulting 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 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. Context

Spate irrigation locally known as *Rudh Kohi* irrigation system is one of the oldest and major irrigation systems practiced in DIKhan for agricultural production. Rudh Kohi is the combination of two words, where *Rudh* means the main torrent bed and *Kohi* pertains to mountains. Rainfall in the upper catchments, which extend up to Baluchistan, the Sulaiman range, Sherani hills and the Batani range results in runoff and water rushing into various torrents in the foothill plains of the DIKhan district. Mostly the flood water flows in different torrents bed known as *Rudhs*. The flowing seasonal streams or *Rudhs* (*Nullahs*) are blocked with temporary diversion structures (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 irrigation of fields. In DIKhan and Tank districts a total of 690,000 ha of land are available for cultivation, out of which about 260,000 ha is under Rudh Kohi agriculture. The most important crop grown in the area of spate irrigation is wheat.

How it works

Spate irrigation is a type of water management that makes use of water from “spates”, short duration floods. Spates – lasting from a few hours to a few days – are diverted from normally dry riverbeds and spread gently over agricultural land. After the land is inundated crops are sometimes sown immediately. Often the moisture is stored in the soil profile and used later. The spate irrigation systems support low economic value farming systems, usually cereals (sorghum, wheat, barley), oilseeds (mustard, castor, rapeseed), pulses (chickpea, cluster bean), but also cotton, cucurbits and even vegetables. Besides providing irrigation, spates recharge shallow groundwater (especially in river bed), they fill (cattle) ponds and they are used to spread water for pasture or forest land in some places.

Lisa Magazine 25.1 March 2009

2. Problem/objective

A major problem in the flood water irrigation (Rudh Kohi) areas is the high variability 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 subsistence agriculture which is faced with extreme events of flood and droughts. Besides the subsistence agriculture, livestock keeping 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) and are not leveled. Most farmers do not invest on land leveling due to the limited return on investment. They normally construct the embankment of the fields 1–2 m high and irrigate such that even the highest spot has water ponded at depths of 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 aestivum* 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.

Spate irrigation deals with management of flood water which is unpredictable in timing and volume. According to conservative estimates, significant amount (more than 50%) of flood water is allowed to escape and fall into river Indus. Of the remaining water more than 2/3 is wasted and not properly used for irrigation. Farmers try to store the maximum amount of water in their fields (*Bandras*) for moisture conservation used for agricultural production. Some time the farmers stored extra water in the fields which they drained out before sowing. The farming communities in Rudh Kohi areas of the DIKhan are very poor. The farming of the local community mostly depends on Rudh Kohi irrigation system. Very little is known about the effect of different pre-sowing water application depths on wheat yield under spate irrigation systems.

The objectives of the study is to find the optimal water application depth for better wheat yield as well as to explore the possibility of water saving that could be used for irrigation of downstream command area. The study was a mutual team work between the AUP, PLI and Colorado State University in 2006-2007. The study also included the analysis of soil physical properties and on-farm application efficiency.

3. Study area and Methodology

Draban and Chodwan Zams[2] are situated at latitude of 31°33' to 31°37' and longitude of 70°19' to 70°24' with an elevation that ranges from 224 to 264 m. The study area receives small amounts (less than 1m^3 s^{-1}) of perennial water in the upper reaches of the system and irrigates small percentage (about 5%) of the cultivated land. Most of the area is irrigated by the flood water generated by the rainfall in the upper catchments during July to September. The flood water is then diverted to fields for irrigation. A total of 15 fields were randomly selected in Draban and Chodwan Zams to determine the effect of different pre-sowing water application depths on wheat yields. In general, the farmers applied more depths of water to their fields in early flood period (July) as compared to late flood season (August and September) before the sowing of winter wheat in October/November.
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 methods and materials used for the study comprised:

Experimental layout:

[2] Zam means an out let of the hill torrents and it is also denote a place where permanent water springs exist.

The experiment consisted of applying three water depth levels, and replicating them five times. D1 = 15–30 cm; D2 = 31–45 cm and D3 _ 45 cm. In treatment D3 pre-sowing depths of water application ranged from 46 to 79 cm. A total of 15 experimental fields (*Bandras*) were randomly selected at Draban and Chodwan zams which were irrigated during July 2006 at the head, middle and tail of the spate irrigation system. In each field the exact pre-sowing depths of water application were measured at five locations with the help of pre-installed graduated gauges. With the help of GPS the positions of all the gauges in term of their latitude, longitude and altitude within each field were recorded. Later, the pre-sowing depths of water application in these locations were related to grain yields obtained from the same position from an area of $1m^2$ and statistical analysis was performed on the data.

Data was collected utilizing the following means

Measurement of rainfall: Rain gauges were installed in the project area and rainfall data was collected during the wheat-growing season (2006–2007). Beside that long term (1970–2007) rainfall was obtained from the Pakistan meteorological department to find the probability of annual rainfall.

Installation of gauges**:** For the application of the desired water depths, calibrated wooden gauges at five locations in each field were installed before the arrival of irrigation water and the coordinates of each gauge were determined with a GPS unit.

Depth and time of water application: Depth and time of water application were recorded during the irrigation of the field. Depth, date and time of water application at each location were noted along with the number of days of standing water in each field. All the experimental fields were irrigated during the month of August 2006 and wheat was sown in October. The depth of water application depends on the height of the fields' embankment (0.8–1.5 m) and the depth of water application ranged from 32 to 87 cm. On an average the depth of water stands for about 8–10 days in the field after irrigation and 4–5 cm of water is lost by evaporation due to high air temperature that ranged from 40 to 50 °C and low infiltration rate that varied from 0.5 to 2 mm h^{-1}.

Soil physical properties*:* Soil samples were collected from 15 fields at three different depths (0–30, 30–60 and 60–100 cm) as well as three locations before flooding, during wheat sowing (November, 2006) and at the end of the wheat harvest (April, 2007). Soil samples were analyzed to determine the soil moisture, soil texture, bulk density and water holding capacity.

Application efficiency (Ea)*:* Application efficiency refers to the ratio of depth of water stored (DWS) in the root zone of 1 m and to the depth of water applied (DWA) to the field. The application efficiency was determined by the following formula:

$$Ea = (DWS \div DWA) \times 100$$

Yield data: At three locations in each of the 15 experimental fields the wheat grain yield from an area of 1 m^2 was collected during the month of April 2007 and analyzed to determine the effect of pre-sowing water application depths and soil texture.

Topographic survey: A topographic grid survey of the selected fields (*Bandras*) was carried out to determine the levelness of each of the experimental fields.

4. Results and Discussion

Water rights and distribution system

The local distribution system of Rudh Kohi irrigation in DIKhan was constituted called Riwajat & Kuliyat-e- Abapashi during the last decade of 19th century and later updated during 1904–1905 and 1967–1968. As per water rights the users at the head of the flood streams get to irrigate their cultivated land (certain fixed amount of land with water rights) up to the embankments of the fields. After irrigation it is the duty of the irrigators to cut the earthen diversion bunds and allow the waters to pass on to next downstream users. As per rule, the users cannot construct the earthen diversion bund again during the same flood season and they have to wait for the next flood season to be allowed to construct it again. The earthen bunds for diversion are constructed ranging in length from 87 to 754 m, bottom width 5–15 m and height 1.2–3.4 m. In general, few large earthen diversion structures are constructed at the reaches with dam height exceeding 3.0 m. In total 175 earthen diversion bunds were observed in the project area. On an average the area served by earthen diversion bund ranged from 13.5 to 538 ha. For construction of flood diversion bunds the farmers organize themselves into small groups for collection of labour and input locally called Kamara. From the diversion bunds the water is channeled through canal system and used for irrigation of big fields that ranged from 3.5 to 5.0 ha with depth of water application ranged from 0.32 to 0.87 m and resulted sediment deposition that varied from 1.8 to 3.6 cm per irrigation.

The implementation of rules and monitoring of the Rudh–Kohi irrigation system is the responsibility of government agency. But enforcement of rules is a constant source of problems for the inhabitants especially for the powerless and poor farmers. It has been found that flood channels with fewer earthen diversion bunds for irrigation perform better than with too many weak diversion earthen bunds which are normally washed away by flash floods.

Rainfall: The actual monthly rainfall measured during the period 2006–2007 and average rainfall obtained from long-term data (1970–2007) is shown in Fig. 1. The figure shows that the maximum normal rainfall occurs during the month of July (61 mm), followed by August and March of about 58 and 35 mm, respectively. About half of the rainfall is received during the months of July, August and March. Normally during the months of June, October, November, December, January and February the rainfall is relatively small (less than 19 mm per month). During the study period (2006 –2007) 43, 143, and 115 mm of rain falls were received in November, February and March which were substantially higher than normal rainfalls.

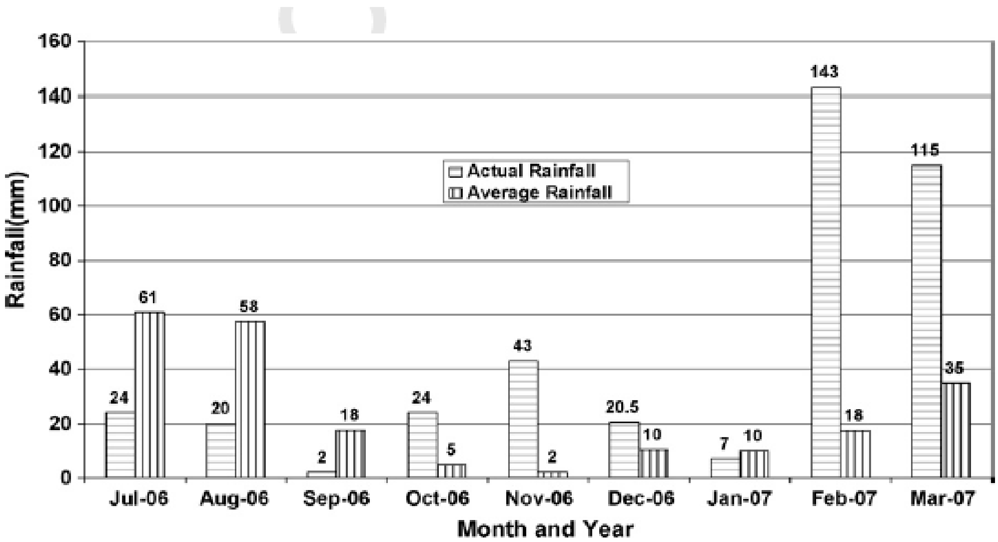
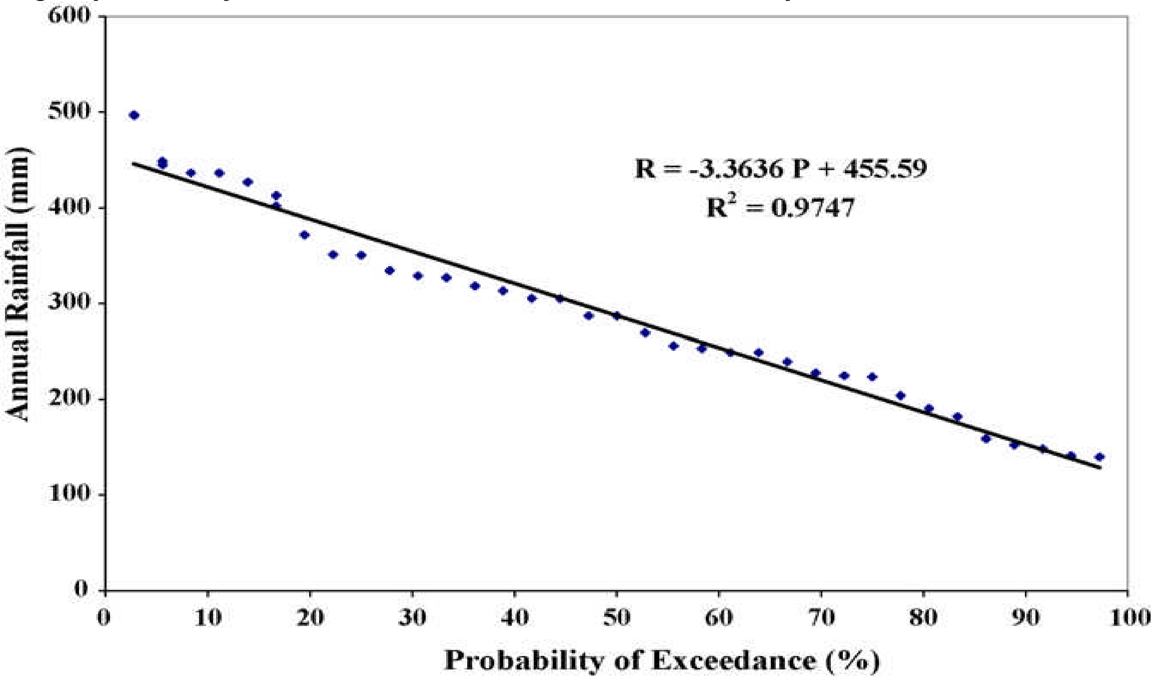


Fig-1: Actual and normal monthly rainfall in DIKhan

The probability of annual rainfall for the period 1970–2007 is shown in Fig. 2. The probabilities of exceedance of 20%, 50% and 80% rainfalls were 388, 287 and 187 mm accordingly. During the year 2006, below normal annual rainfall of 204 mm was received, while for the year 2007 it was above normal (449 mm).

Fig-2: probability of exceedance of annual rainfall for the period 1970-2007



Water holding capacity and bulk density: The volumetric water holding capacity of the soils of the experimental fields ranged from 23.0% to 36.3% (Table 1) and bulk density varied from 1.36 to 1.42 g cm3 (Table 2).

Table-1: Water holding capacity of the experimental fields

Treatment #	**Replication #** **Water holding capacity on volume basis (%)**					**Mean**
	R1	R2	R3	R4	R5	
D1 (< 30 cm)	31.1	29.7	28.3	26.7	28.7	28.7
D2 (31 to 45 cm)	23.0	30.7	36.0	27.7	30.5	29.6
D3 (>45 cm)	33.9	36.3	32.5	29.0	29.1	32.2
Average	29.0	32.2	32.3	27.8	29.8	

Table-2: Average bulk density up to soil depth of 1 m during wheat sowing period

Treatment #	**Replication #** **Water holding capacity on volume basis (%)**					**Mean**
	R1	R2	R3	R4	R5	
D1 (< 30 cm)	1.42	1.39	1.38	1.41	1.41	1.40
D2 (31 to 45 cm)	1.39	1.37	1.40	1.38	1.42	1.39
D3 (>45 cm)	1.38	1.36	1.40	1.38	1.35	1.37
Average	1.40	1.37	1.39	1.39	1.39	

Topography: Based on the grid survey, the coefficient of variations in relative elevations of the grids of the fields ranged from 3.59% to 17.56% with overall average of 8.18%.

Soil moisture before flood, at wheat sowing and harvest:
During 2006 the soil moisture content on volume basis was determined before the pre-sowing irrigation at five locations and three depths in each field up to a soil depth of 1 m and it ranged from 4.95% to 9.24% with overall average of 7.5% (Table 3). A significant difference in the initial soil moisture content was found among the different textural soil classes at a 5% probability level; therefore these soils were divided into two distinct groups (clay and loam type). Soil moisture contents were also determined up to a soil depth of 1 m during the wheat sowing period and at harvest. At sowing the soils moisture content ranged from 21.7% to 26.3% (Table 3). No statistical significant difference was found among the treatments.

Table -3 Average soil moisture contents before flood, during wheat sowing and at harvest

Treatment #	**Replication # Soil moisture in 1m root zone on volume basis (%)**		
	Before flood	Wheat sowing	Wheat harvesting
D1 (< 30 cm)	7.5	21.7	12.4
D2 (31 to 45 cm)	7.5	24.1	12.9
D3 (>45 cm)	7.5	26.3	14.1
Average	7.5	24.0	13.1

Pre-sowing depths of water application on wheat and straw yields: On the basis of statistical analyses, no significant differences in wheat grain and straw yields were found among the treatments. But it is also clear that greater pre-sowing depths of water application did not increase the wheat and straw yields hence the excess water can be saved for irrigation of downstream command areas. The effect of different pre-sowing water application depths on wheat and straw yields is shown in Tables 4 and 5. Maximum wheat grain (3448 kg ha^{-1}) and straw (6880 kg ha^{-1}) yields were obtained from pre-sowing depth of water application of D2 (31–45 cm) as compared to other treatments. It can be seen from Table 4 that 10% more yield was obtained from treatment D2 as compared to D3. Although treatment D3 (46–79 cm) consumed about 64% more water as compared to D2 and still produced relatively lower wheat grain yield.

Table-4 Wheat grain yields as affected by different pre-sowing depths of water application.

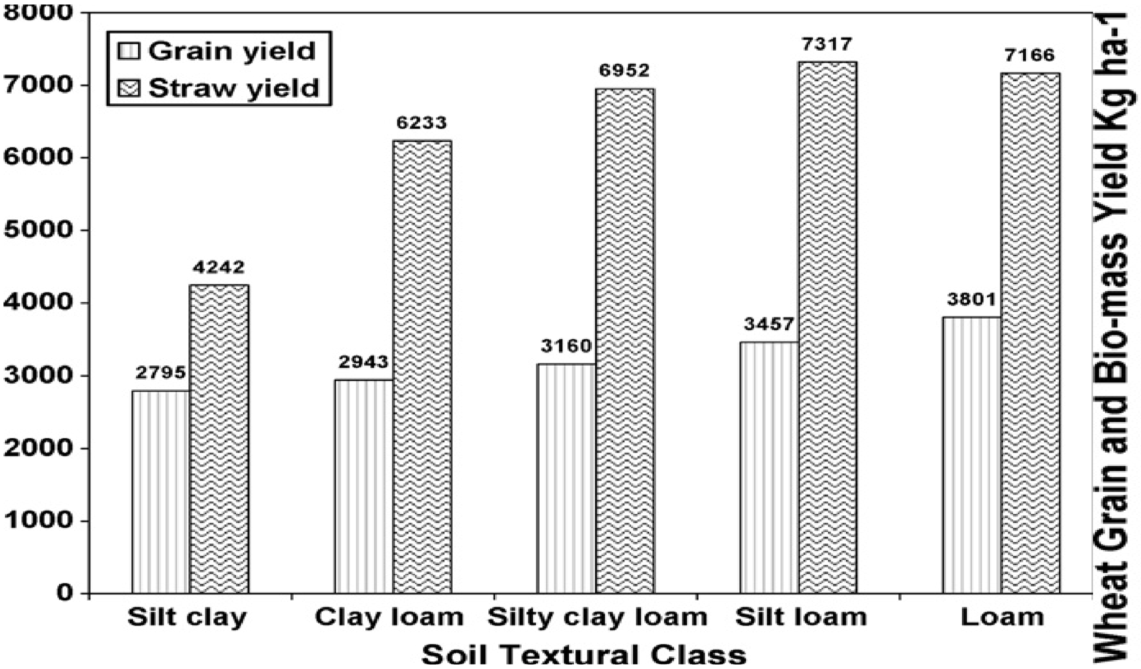
Treatment #	**Replication #** Wheat grain yield (kg ha_1)					**Mean**
	R1	R2	R3	R4	R5	
D1 (< 30 cm)	3646	2776	2943	3843	3302	3302
D2 (31 to 45 cm)	3683	3456	2903	3960	3237	3448
D3 (>45 cm)	2043	3386	3610	3543	2910	3098
Average	3124	3206	3152	3783	3150	

Table -5: Wheat straw yields as affected by different pre-sowing depths of water application

Treatment #	**Replication #** Wheat straw yield (kg ha_1)					**Mean**
	R1	R2	R3	R4	R5	
D1 (< 30 cm)	8070	4270	6230	6540	6280	6280
D2 (31 to 45 cm)	8940	6380	4730	6670	7690	6880
D3 (>45 cm)	3720	6920	6870	7430	6760	6340
Average	6910	5860	5940	6880	6910	

Effect of soil texture on wheat grain and straw yields: Soil texture appears to have had a significant effect on wheat grain and straw yields. In general, the highest wheat grain and straw yields were obtained from loam soils followed by silt loam and the lowest yields were recorded on silty clay. For further analyses, from the 14 experimental fields at three locations at each field, soils pre-sowing depths of water application, wheat grain and straw yields data were collected. Based on the soil texture analyses of the sampled fields, five soil classes were found in the study area as shown in Table 6. Silt loam (35.7% of the samples) was the dominant textural class, followed by silty clay and loams each with 21.4% of the samples. The effect of soils texture on wheat grain and straw yield is shown in Fig. 5.

Fig-5 Effect of soil textural class on wheat grain and straw yields



The five textural soil classes were then grouped into two (Group-A and Group-B) on the basis of having no statistical difference in their wheat grain yields. Soils placed in Group-A, were silty clay, clay loam and silty clay loam, while in Group-B consisted of silt loam and loam type of soil. For both soil groups, the maximum average wheat grain yields (3960 and 3220 kg ha^{-1}) were obtained from water application depths of D2 (30–45 cm) and the lowest wheat yield from water application depths beyond 45 cm (Fig. 6). It can be seen from the Fig. 6 that wheat grain yields increased with pre-sowing water application depths from D1 to D2 and then decreased with water application depth D3.

Fig. 6 Effect of different pre-sowing water application depths on wheat grain yield for clayey (Group-A) and loam type (Group-B)

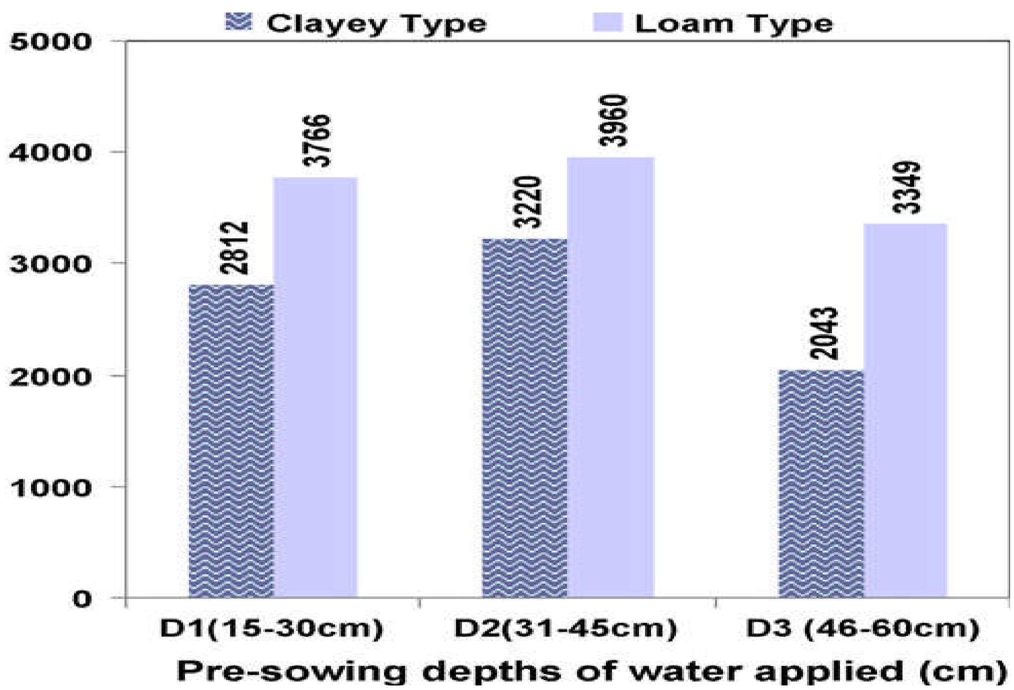


Table- 6 Soil physical properties of the experimental fields

Soil Group	Textural soil class	No. of samples	Soil particles sizes (%)			Water holding capacity (%)	Bulk density (g cm_3)
			Clay	Silt	Sand		
Group A	Silty Clay	9	45.47	45.27	9.27	34.94	29.75
	Clay loam	3	32.20	26.60	41.20	28.25	1.39
	Silty clay loam	6	41.20	41.60	17.20	30.59	1.40
Group B	Silt loam	15	14.96	67.28	17.76	32.58	1.39
	loam	9	26.87	29.27	43.87	29.75	1.40

Later wheat grain yields were plotted against the pre-sowing depths of water application for both groups of soils (Figs. 7 and 8). The figures show that the wheat grain yield was significantly affected by the pre-sowing water application depths. Greater depths of water application delay on-time sowing of wheat as well as the growth and root development. The greater depths of water application might well have resulted in leaching of some of the nutrients and also delayed the biological soil activities.

Fig 7: Effect of different pre-sowing water application depths on wheat grain yields for clayey type of soils (Group-A).

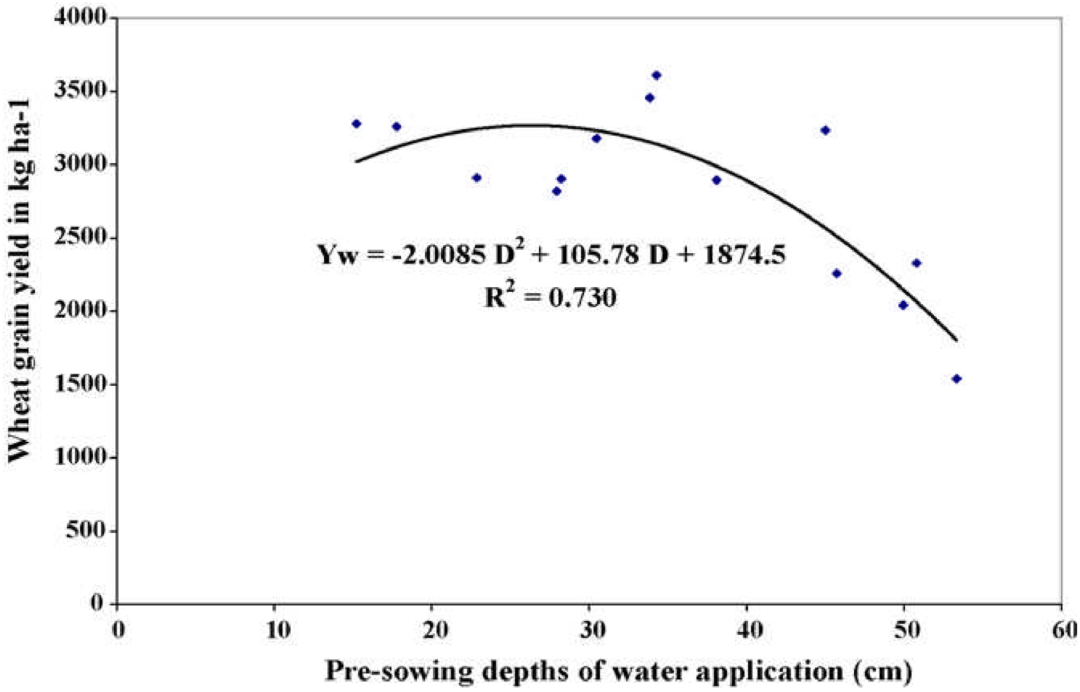
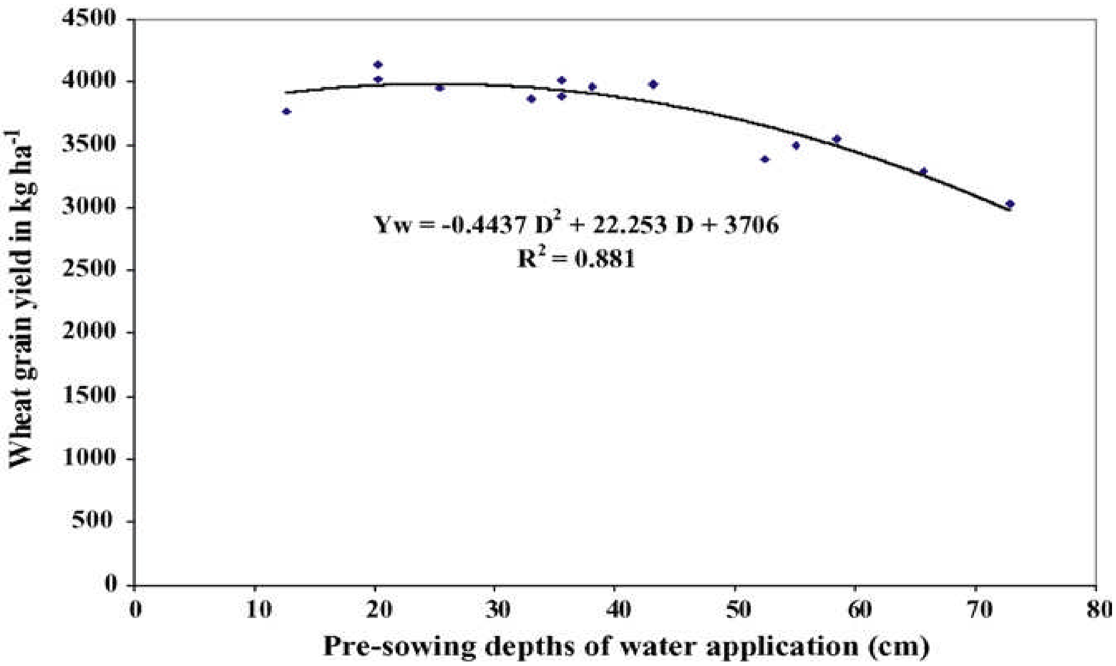


Fig 8: Effect of different pre-sowing water application depths on wheat grain yields for loam type of soils (Group-B).



5. Conclusion and recommendations

At the site, the issue of pre-sowing depths of water application was discussed with the farmers. They were aware of the fact that too much pre-sowing water depths does not necessarily increase the wheat yield but even results in delayed wheat cultivation. Over-irrigation of the fields occurs due to poor irrigation control infrastructure and quantum of the flash floods which is very difficult to control with the means available to the farmers in the project area. Different government and non-government organizations are working on the improvement of flow control and inlet structures for better management of spate irrigation system and to avoid the excessive use of irrigation water. There is a great potential for improvement of spate irrigation System and it needs coordinated efforts with the involvement of all stakeholders for overall development of sustainable spate irrigation system in the area.

- Spate irrigation system has great development potential and the production can be increased several folds through improved water diversion, distribution and fields inlet control structures through active participation of farming communities.
- The mean maximum wheat grain yield was found with pre-sowing water application depths in the range of 30–45 cm.
- On-farm application efficiency decreased with increase in pre-sowing depths of water application greater than 45 cm.
- Due to large unleveled fields and to compensate for evaporation losses the overall application efficiency was relatively low (49%).
- The pre-sowing depth of water application beyond 45 cm did not increase the wheat grain and straw yields. It seems to be that a significant amount of water can be saved and be used to irrigate downstream command area in the system.
- Soil texture significantly affected the grain and straw yield; maximum wheat grain and straw yields were obtained from loam soils and the lowest were obtained from silty clay soils due to relatively heavy rainfall in months of March before the harvest of wheat crop.
- Flow diversion and control structures should be improved for better management of spate irrigation system.
- For optimum wheat yield the pre-sowing water application depths may be in the range of 30–45 cm and excess or shortage in water application depths should be avoided.
- For better on-farm application efficiency and water conservation the fields should be leveled.

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