Irrigation Scheduling With Skimmed Groundwater To Manage Root Zone Salinity

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Abstract

Different skimming well technologies are being used to extract relatively fresh groundwater lenses from aquifers underlain by salty groundwater layers in the Indus basin. However, the discharge rates from these skimming wells are too low to apply efficiently on surface irrigated croplands. The salinity in the root zone also increases with the application of skimmed groundwater. Therefore, the limited water supply coupled with high pumping cost and salinity hazards, makes it more important than ever that irrigation water be used efficiently and judiciously. Different water saving techniques was evaluated in this study. In the first experiment, two furrow irrigation techniques, alternate furrows and regular furrows, for maize production, were evaluated. The application efficiency of alternate furrows was 45% greater than regular furrows. The water use efficiency obtained from alternate furrows was 49% greater as compared to regular furrows. Alternate furrows require less water input per irrigation and reduces the pumping cost without reducing crop yield significantly. With the application of the same quality skimmed water, the soil salinity in alternate furrows was relatively less than regular furrows most probably due to the less application of skimmed water.

In the second experiment, wheat was sown by bed & furrow, zero-tillage and conventional (basin) methods. The application efficiencies of bed & furrow and zero tillage fields were 37.15 and 38.54%, respectively and were about 45% greater than the conventional methods of wheat sowing. The total water applied was 34, 39 and 30 cm for bed & furrow, basin and zero tillage fields, respectively whereas the WUE was 1.22, 1.09 and 1.41 Kg m^{-3} for bed and furrow, basin and zero-tillage fields respectively. The farmer applied 79 cm of water, almost double than water applied under the scheduled fields, with a WUE of 0.63 kg m^{-3}.

The evaporation pan attached with a Marriate bottle was used to decide the time of irrigation. The irrigation was applied at 30 and 40% MAD for maize and wheat respectively. Soil moisture were also determined gravimetrically before each irrigation. The evaporation under predicted the soil moisture deficit in both experiments and therefore may be safe to use for irrigation scheduling where skimmed water is used for irrigation purposes.

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INTRODUCTION

In irrigated areas of arid and semi-arid zones, where canal water supplies are not sufficient to meet the crop water requirement, the necessity of pumped water application arises. Almost 30% of the irrigation water at the farm gate is derived from groundwater, which has a water quality far inferior to canal water (NESPAK, 1991). Different skimming well technologies are being used to extract relatively fresh groundwater lenses from aquifers underlain by salty groundwater layers in the Indus basin. However, the discharge rates from these skimming wells are too low to apply efficiently on surface irrigated croplands. Moreover, the salinity in the root zone increases with the application of skimmed groundwater. Therefore, the use of skimmed groundwater requires practical ways and means for irrigation applications so that the root zone salinity is managed for better crop yields.

Research and development of water saving agriculture is a challenging task today to make agriculture and industries sustainable in term of water consumption. The rapidly increasing cost of energy used for pumping the water is of equal or greater concern. The limited water supply coupled with high pumping cost and salinity hazards, makes it more important than ever that irrigation water be used efficiently and judiciously. Therefore, there is a need to achieve maximum production per unit water applied. Advanced irrigation methods and water management practices coupled with proper irrigation scheduling can help achieve high crop yields with minimum water applications.

Furrow irrigation however, if designed and managed properly makes it possible to use water more efficiently than the other methods of surface irrigation. Average water saving by furrow irrigation method is up to 30% as compared to border irrigation. Among the furrow irrigation systems, different options have been tried for further saving of water e.g. irrigating alternative furrows. Iqbal and Javid (1997) found that for a cotton crop, 41 to 46% less water was applied under alternate furrows as compared to the regular furrows. Graterol *et al.* (1993) also found that for a soybean crop, 46% less water was applied to alternate furrows as compared to the regular furrows without reduction in yields. The total water use efficiency was 0.6 and 0.5 kg m^{-3} for alternate and regular furrows, respectively. Stone and Nofziger (1993) reported that wide-spaced furrows were 15% more efficient than regular furrow and required 38% less water for the same yield of cotton. Wide-spaced furrows can be attained by alternate-furrows irrigation where furrow spacing is 1.25 m or greater. However, alternate and regular furrows have not been evaluated under skimmed water applications. Eischaver and Youth (1991) reported that alternate furrow irrigation could reduce water applications, irrigation cost, chemical leaching and results in higher crop yield. Naeem *et al.* (1999) showed that for cotton crop 40.6% water saving was achieved under alternate furrow irrigation and WUE was 8.99% greater in alternate furrows as compared to regular furrows.

Irrigation scheduling is the procedure used to determine the time and depth of water application for each irrigation. The time of water application is normally based on fixed depletion of stored soil water whereas the depth of application is equal to the value of soil water depletion plus some additional water to account for non-uniformity in water application and leaching fraction. Therefore, the time and depth of water application also depends on the root-zone depth and the salt concentration in the root zone. More application of water, more danger that nutrient will leach out of root zone. Therefore we have to be careful about leaching fraction. One of our main purposes for this study is to find out if leaching fraction is a *must* to be considered or does monsoon take cares of this requirement.

In spite of the importance of irrigation scheduling, its application has been a difficult task. Irrigation scheduling can be based on soil-moisture measurement, or on estimates of daily evaporation using climatological methods, evaporation pans and lysimeters. Soil moisture measurement by gravimetric method is laborious and time consuming. The use of tensiometers for the measurement of soil moisture requires special skill for their operation and maintenance. The use of models and empirical relations requires climatological data, which is also difficult to measure. Moreover these models require high skill and therefore cannot help common farmers to plan irrigation scheduling. However, evaporation pan is simple to use and may help common farmers to design irrigation scheduling.

The purpose of this paper is to investigate the usefulness of evaporation pan to predict soil moisture deficit in the field for planning irrigation scheduling and to compare the effectiveness of different water saving techniques in terms of water application/use efficiency and root-zone salinity management.

MATERIALS AND METHODS

The study was conducted at Akram's farm Nabishah, Bhalwal. The farm is located at about 10 km from Bhalwal city on Sardar Pur Noon road. The farm comprises 19 acres of land, out of which 10 acres are of citrus trees. The farm has three hours canal water supply on a fixed weekly rotation. Previously, the farm had a single strainer shallow well installed to a depth of 30 m near the farmhouse. Later on the farmer realized that his land and garden were being deteriorated with the tubewell water. He discarded the single strainer tubewell, the bore of which has now been converted to a piezometer, to observe the seasonal watertable fluctuations. The groundwater is about 4.0 m from the ground surface.

A skimming well with 16 strainers has been installed at the farm and has been described by Ashraf *et al.* (2001). The discharge of the skimming well is about 28 lps with electrical conductivity (EC) about 1.1 dS m^{-1}, sodium adsorption ratio (SAR) 4.3 and residual sodium carbonate (RSC) about 2.8.

A 90° V-notch weir has been installed in the diversion channel of the skimming well to measure the discharge. A small observatory has been

established at one corner of the field. A standard class A evaporation pan has been placed on a wooden frame, 20 cm above the ground surface. The pan has been painted with white colour from inside and out side. It has been filled to a level of 20 cm from the bottom. A Marriatte bottle has been attached to the pan that maintains water level at 20 cm. Loss of water from the pan is monitored from the Marriatte bottle (Plate-1). A standard rain gauge has been placed at a height of 1.37 m above the ground surface. The soil is a sandy loam type and is deficient in organic matter (about 0.4%). Organic matter affects the physical and chemical properties of soil to very large extent. It influences both the water holding capacity and permeability of soil.
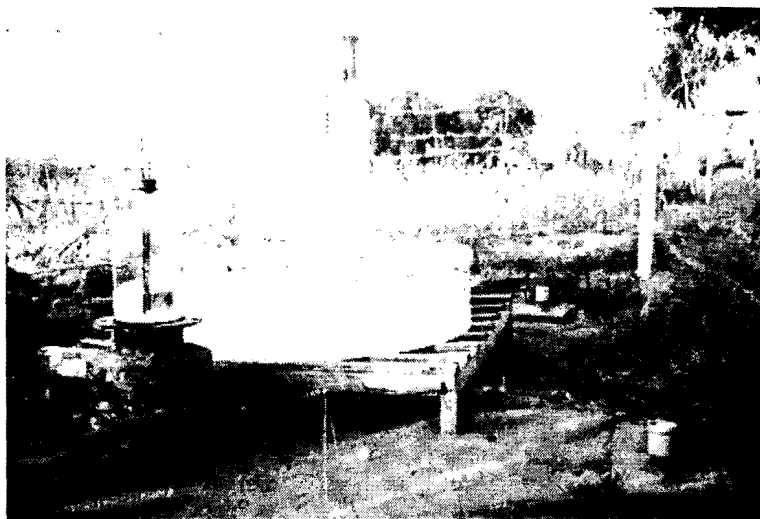

Plate 1.   Class A evaporation pan attached to a Marriatte bottle

The corn-wheat-junter crop rotation was selected for the study. Since corn is salt sensitive (threshold ECe and ECw = 1.7 and 1.1 dSm^{-1} respectively), it was decided to bring it immediately after the monsoon so that the salts in the soil are leached down due to rains. Salts may accumulate in the root zone during the corn season due to the application of skimmed water. Therefore wheat, a relatively salt tolerant crop (threshold ECe and ECw = 6.0 and 4.0 dSm^{-1} respectively), was selected for sowing after corn. To increase the soil fertility, a leguminous crop, junter (*Sesbania*) is selected for sowing after wheat (threshold ECe and ECw = 2.3 and 1.5 dSm^{-1} respectively). Junter is used as a fodder as well as a green manure crop for reclaiming land and adding organic matter to the soil (Ghafoor *et al.* 2001).

Maize variety, Pioneer 3062, was sown on 8th July 2000 at a seed rate of 10 kg/acre on the field adjacent to the skimming well. This field was laser levelled a season before. It is an elevated field and has never been canal irrigated. The corn was sown on furrow ridges. The field was divided into two plots of equal size (0.4 acre), each consisting of 35 ridges. One plot had regular furrows whereas the other had every alternate furrow blocked.

The row-to-row and plant-to-plant distances were 75 and 18 cm, respectively. Central 5 rows of each plot were harvested on 20th October for yield assessment.

After harvesting corn, the land was prepared for wheat sowing. The soil was ploughed and planked following the farmer's practices. About 86 mm of pre-sowing irrigation (*rouni*) was applied to field. At field capacity, the field was again ploughed and planked for seedbed preparation. Wheat variety MH-97 at seed rate of 60 kg/acre was sown on 12th November 2000. 0.4 acre was sown on furrow beds using furrow bed shaper and an other 0.4-acre was sown with a rabi drill. Both plots were further divided into two plots of equal size.

During kharif 2000, the farmer planted rice on two acres. Due to the non-availability of labor, the harvesting of rice was unnecessary delayed and it was harvested on 27th November 2000. Wheat variety Inqlab-91 at a seed rate of 60 kg/acre was sown on the rice field with zero-tillage seed drill on 28th November. If the field was sown by the conventional methods, it could have never been possible before the mid of December. Therefore, wheat sowing with zero-tillage directly saved about 86 mm of water/acre (*rouni*) (as was the case in bed and furrow and conventional plot) and also saved the time and soil preparation cost. Recommended fertilizer and insecticide doses were applied to both plots. Germination count and the crop stand were recorded regularly. Soil samples, up to 120 cm depth with 15 cm interval, were collected before sowing, during mid season and after the harvesting of each crop from all plots at head, middle and tail. Wheat was harvested on 26th April 2001.

There is a controversy in literature about maximum allowable depletion (MAD). Ahmad (1999) reported that for most grain crops like wheat, maize, sorghum and millet, the MAD should range between 50-75%. Hameed (1979) reported that at 75% moisture depletion level, maximum wheat yield was obtained. Hagan and Stewart (1972) showed that the soil moisture depletion level for wheat ranged from 50-85%. Mahar *et al* (1990) recommended 80% soil moisture depletion level whereas Rasul (1993) recommended 50% soil moisture depletion level for wheat. However, keeping in view the salinity level of the skimmed water and the soil type, the maize and wheat crops were irrigated at 30 and 40% MAD respectively.

The field capacity of a sandy loam soil is 0.11 m^3 water m^{-3} and its wilting point is 0.03 m^3 water m^{-3}. Therefore, available moisture content becomes 0.08 m^3 water m^{-3} (Allen *et al.*, 1998). Considering root zone depth of 1.50 m, 30 and 40% MAD becomes 36 and 48 mm respectively. Hence, irrigations were applied when evaporation from the open water surface reaches to the fixed MAD. Before each irrigation, soil samples were also collected up to 90 cm depths at 15 cm interval to determine moisture contents gravimetrically. The irrigation was applied to all plots on the same day. The intention was to apply water uniformly to the entire field. When water reached at the end of the field, its supply was cut off from the farm outlet (nakka). Since the fields were closed at the end therefore, the runoff from the fields was zero. Hence, the amount of irrigation applied was the

amount of water added to the field. It was assumed that all rainfall infiltrated into the soil, because no surface runoff was observed during the rainfall.

To monitor the soil suction in the soil profile, a set of 4 vacuum gauge tensiometers were installed at four different locations in the field, at depths of 30, 45, 60 and 90 cm from the soil surface. However, these could not give meaningful results, most probably due to air entrapment and lack of field experience. Moisture-retention curve of the soil was obtained from Soil Survey of Pakistan. van-Genuchten (1980) function was fitted to curve (r^2 = 0.92). From the moisture-retention curve, the moisture content at field capacity (at 33 cm suction) is about 0.2062 cm^3 cm^{-3} (which is very high for a sandy loam soil) and at wilting point about 0.0296 cm^3 cm^{-3}. Therefore available moisture content becomes 0.1766 cm^3 cm^{-3}. Considering a root-zone depth of 1.5 m, the maximum allowable deficit (MAD) at 30 and 40% comes 79 and 105 mm respectively (against 36 and 48 mm of our designed scheduling).

The maximum suction shown by the tensiometers installed at 15 cm depth from the soil surface was about 90 centibar (90 cm). When we transform it to the corresponding water content using moisture-retention curve, the moisture content comes about 0.1791 cm3 cm-3. However, on the same day, the moisture content determined by gravimetrically from 15 cm depth was about 0.04 cm^3 cm^{-3} that is close to the wilting point we assumed in our calculations. Therefore, it is clear that both moisture-retention curve and tensiometers data are not reliable. Moreover, the tensiometers work within limited range of soil suction i.e. up to 1 bar (100 cm) only whereas in field, the suction may go beyond 1 bar particularly near the maximum allowable deficit. Therefore, our assumed book values for field capacity and wilting point seem to be correct.

RESULTS AND DISCUSSIONS

Maize experiments

Soil moisture deficit and depth of water applied

Figure 1 shows the soil moisture deficit at the time of irrigation. It shows that evaporation pan under estimates the soil moisture depletion than estimated gravimetrically and is therefore safe to use for irrigation purposes. Regular furrows at the time of irrigation, show relatively greater moisture content at all the depths as compared to the alternate furrows. However, before each irrigation, moisture content was within the limit of available moisture content in both the treatments.

Figure 2 shows depth of water applied against the soil moisture deficit. The depth of water applied was always greater than the soil moisture deficit. It was mainly due to the non-uniformity in water application and to account for leaching fraction. The application efficiency of alternate and regular furrow was 55 and 38%, respectively. Therefore, the application efficiency of alternate furrows was 45% greater than regular furrows.

Since it is not possible for common farmers to measure the soil water content/soil matric potential or to calculate the crop water requirement in the field, an evaporation pan may help them to plan for irrigation scheduling. A simple method may be the provision of a graduated Marriatte bottle attached with pan in the field and training of the farmer to apply irrigation when the water loss from the Marriatte bottle equals 30 or 40% MAD depending upon the soil and crop types.

Table 1 describes the details of each irrigation events to both the plots. Number of irrigation was the same in both the treatments. However, on alternate furrow, 37% less quantity of water was applied. Table 1 also shows that 366.4 m^3 of water per acre was saved on sample farms under alternate furrows. Based on the prevailing water rate of Rs. 1.0 m-^{3} charged by the private tubewell owners, value of water saved arrives at about Rs. 900/acre for corn crop.

Table 1   Time of irrigation for both innovative irrigation systems

Date	Discharge (lps)	Alternate furrows		Regular furrows	
		Irrigation time (min)	Quantity of water (m^3)	Irrigation time (min)	Quantity of water (m^3)
08-07-00	31.86	35	66.90	55	105.13
15-07-00	31.86	16	30.58	21	40.14
21-07-00	31.86	25	47.79	30	57.34
01-08-00	31.86	40	76.46	52	99.40
09-08-00	15.17	35	31.85	45	40.95
15-08-00	22.80	40	54.72	60	82.08
20-08-00	22.80	23	31.46	42	57.45
27-08-00	31.86	25	47.79	53	101.31
31-08-00	31.86	32	61.17	56	107.04
06-09-00	31.86	25	47.79	45	86.02
16-09-00	31.86	30	57.34	50	95.58
03-10-00	31.86	30	57.34	55	105.13
Total		356	611.23	564	977.63

Cost of production, crop yield and water use efficiency (WUE)

Table 2 shows the germination count and the crop stand at different time intervals. The over all germination count in the field was good. However, crop stand was relatively poor on some of the area of the blocked furrows. It was probably due to the shifting of soil from blocked-furrow side to the regular furrow area during laser levelling. Moreover, there was a heap

of residual straw on one side of the blocked furrow field. The residual straw was removed from the soil surface before crop sowing. However, it was not possible to remove the straw completely. Therefore, the un-decomposed straw affected the germination of seeds. The survival rate for blocked furrow plot was 60% whereas for regular furrow, it was 70%. However, the plant height, number of leaves, number of tassels and number of combs were almost similar in both the plots. There was stem borer attack on the crop when the crop height was about 30 cm.

Table 2   Germination count and crop stand

	Alternate furrows				Regular furrows			
Date	Plant height (cm)	Plants per acre	Leaves per plant	Tassels per plant	Plant height (cm)	Plants per acre	Leaves per plant	Tassels per plant
04-08-00	20	28451	3	-	23.2	29202	3	-
24-08-00	144.2	-	13	-	160.5	-	13	-
04-09-00	163.1	17178	13	10	210.5	20398	13	10
12-09-00	217.1	17178	13	10	244.7	20398	13	10
22-09-00	234.0	17178	13	10	245.0	20398	13	10

The application of insecticide helped control the stem borer attack. Moreover, wild bore also attacked the crop and damaged it at some places. Since in blocked-furrows, at most places, crop germination and crop stand was as good as in regular furrows, it seemed that the poor crop stand in some area of the blocked furrows might not be due to water stress rather due to the above mentioned factors. Moreover, maize is sensitive also to deficiencies in certain tracer or minor elements especially zinc and boron.

To evaluate the impact of these techniques, the primary input-output data were used. Gross benefits were calculated at a rate of Rs. 400/40 kg, the market prices of corn for the year 2000-2001. Income from corn by-product i.e., straw was calculated based on average prevailing rate of Rs. 50/40 kg. The dry weight of straw was assumed to be equal to the weight of the grains. The cost of production per acre for corn is shown in Table 3. The main reason for low-cost of production for alternate furrows were the less cost of water applied. Though yield difference was not much in both methods however, cost of production was less in alternate furrows. Alternate furrows allows for efficient use of water resource without reducing the yield significantly. However, minor reduction in yield in alternate furrows in the present study may be attributed to the scraping of the topsoil and the presence of un-decomposed straw in the field as has already been discussed hereinbefore.

Table 3. Cost comparison, yield and water use efficiencies for both the treatments

Cost of production (Rs/acre)						
Techniques –furrows	Non-water input	Pumping water	Yield (kg/acre)	Net income (Rs/acre)	Water use efficiency (kg m^{-3})	Application efficiency (%)
Alternate	7710	1500	2550	19478	4.17	55
Regular	7710	2400	2735	20490	2.80	38

Water use efficiency is a simple estimate to measure how accurately irrigation water has been used for crop production. Any effort, which tends to increase crop yield or reduce the amount of water needed without disturbance to crop yield, increases the water use efficiency. In this investigation, water use efficiency has been worked out as kg of corn grains per cubic meter of water applied. Table 3 indicates that water use efficiency obtained from alternate furrows was 49% greater as compared to regular furrows. Alternate furrows require less water input per irrigation and reduces the pumping cost without reducing crop yield significantly. Kang et al., (2000) also tested alternate furrow irrigation for maize production. They found that alternate furrow irrigation maintained high grain yield with up to 50% saving in irrigation water. As a result water use efficiency was increased substantially.

Effect of skimmed water on root-zone salinity

The salinity level in the root zone increases if significant quantities of saline groundwater are used (Hoffman and van Genuchten, 1983). Therefore, under such conditions, care should be taken to manage root zone salinity below the salt tolerance level of the crop. Rhoades (1984) suggested that leaching should take place during a fallow period or early in the growing season, when crop's root system is shallow and the water demand is small and the water table is relatively deeper to avoid rising of the water table to the extent that the crop is damaged.

The main factors, which control the development of salinity in the root zone while irrigating with saline water under deep water table conditions, include: (i) quality of irrigation water, (ii) number of irrigations, (iii) soil texture, (iv) leaching fraction, and (v) rainfall. Maas and Hoffman (1977) and Mass (1990), concluded that under optimum management conditions, the crop yields remain at potential levels until EC_e reached at threshold level. $EC_{e\ threshold}$ is the average root zone salinity at which yield starts to decline. If the average EC_e of the root zone increases above this critical threshold value, the yield decreases linearly in proportion to the increase in salinity. The rate of decrease in yield with the increase in salinity is usually expressed as a slope, b, having units of % reduction in yield per unit increase in EC_e beyond $EC_{e\ threshold}$ (Rhoades, et al., 1992).

Figures 3 and 4 show the changes in electrical conductivity (EC) with depth for both alternate and regular furrows during the cropping season. The EC presented is an average of the head, middle and tail of each plot. The electricity conductivity of regular furrows increased at the mid and at the end of the season at almost all depths. The increase in salinity is mainly due to the addition of salts from the skimmed water. However, in alternate furrows, at the mid and end season, soil salinity did not increase significantly except near the soil surface. The possible reason might be the less amount of water applied and hence less addition of salts into soil. The increase in EC near the soil surface may be due to upward movement of salts under the evaporative flux. The EC values in alternate furrows at the end of season almost decreased throughout the soil profile.

Figures 5 and 6 show the changes in SAR with depth for both techniques. The increase in SAR is due to the addition of insoluble salts such as Na since the RSC of the skimmed water was higher than it threshold. However, this increase is more pronounced in regular furrows, most probably due to more application of skimmed water.

Wheat experiments

Soil moisture deficit, depth of water applied and water use efficiency

Table 4 shows that against a planned soil moisture deficit of 48 mm shown by the evaporation pan, the soil moisture deficit by the gravimetric method was almost 2 times less. Therefore evaporation pan under predicted the soil moisture deficit and therefore may be safe for use for irrigation scheduling particularly where skimmed water is used for irrigation purposes. This under prediction may take care of the leaching fraction. The application efficiency of bed and furrow and zero tillage fields were 37.15 and 38.54% respectively and were about 45% greater than the basin method of wheat sowing.

Figure 7 to 9 also show soil moisture deficit at the time of irrigation and depth of water applied for bed and furrow, basin and zero-tillage plots. These figures show that evaporation pan under estimates the soil moisture depletion than estimated gravimetrically. In basin fields, the water applied was the greatest mainly due to non-uniformity. Less soil moisture deficit coupled with high water application resulted in low water application efficiency. In zero-tillage plots, since soil was not ploughed before sowing, therefore water reached earlier to the end of the field during irrigation and resulted in relatively less water application than bed and furrow fields and consequently better WUE.

Chandio (1988) recommended a total water requirement of 45 cm for wheat crop including pre-sowing irrigation whereas Leghari et al. (1977) suggested 51 cm water for wheat to get maximum yield. In a lysimeter study, Asgher et al. (1962) found that wheat required 50.5 cm of water when the water table was maintained at 3.2 m. Hussain (1977) however, in a similar study, found that water requirement of wheat was 33.7 cm. Memon et al. (1999) used 39 cm of irrigation water for suitable irrigation scheduling.

Based on the stress day index (SDI) concept, they suggested that 5 irrigations were sufficient for maximum crop production and optimum WUE. Shafique et al. (2001) reported that for wheat 1999-2000, the depth of water applied for bed and furrow and basin irrigation methods was 13 and 19.4 cm respectively whereas the WUE was 1.45 and 1.69 kg m^{-3} respectively. Yasin et al. (1990) reported that for wheat crop, average seasonal evapotranspiration varied between 35.3-56.2 cm for major climatic zones in Pakistan. The WUE varied from 1.196 to 2.37 kg m^{-3}. Table 4 shows that for bed and furrow irrigation system 34 cm of water can give good WUE and for basin irrigation system the total water requirement was about 39 cm. Zero tillage technique required about 30 cm water for good crop yield and WUE. Table 4 also shows that for wheat, irrigation scheduling saved at least 50% irrigation water irrespective of irrigation method used with out affecting crop yield.

Table 4   Soil moisture deficit and depth of water applied to wheat crop during the rabi season including pre-sowing irrigation (*rouni*)

Irrigation methods.	Soil moisture deficit by evaporation pan (mm)	Soil moisture deficit by gravimetric method	Depth of water applied (mm)	Application efficiency (%)	Water use efficiency (kg m^{-3})
Bed and furrow	240	125.91	424.84	37.15	1.22
Basin (controlled)	240	100.98	467.28	26.48	1.09
Zero tillage	240	118.96	308.57	38.54	1.41
Basin (farmer controlled)	-	-	789.77	-	0.63

Cost of production and crop yield

Gross benefits were calculated at a rate of Rs. 300/40 kg, the market prices of wheat for the year 2000-2001. Income from wheat straw was calculated based on average prevailing rate of Rs. 50/40 kg. The dry weight of straw was assumed to be equal to the weight of the grains. The cost of production per acre for wheat is shown in Table 5. The grain yield and gross income of bed and furrow, basin and conventional (farmers) were almost the same and were greater than the zero-tillage plots. Low yield in zero tillage plots may be attributed to the late sowing of wheat (about two weeks). Wheat yield decreases at a rate of 1 percent every day delay in sowing after mid of November (Aslam et al., 1999).

However, water application and water use efficiencies of the zero-tillage plots were greater than the other techniques (Table 4). The water

application efficiency of zero-tillage technique was almost equal to the bed and furrow plots. Nevertheless, the net income in zero-tillage plots was almost equal to bed and furrow and basin plots and was 34% greater than the farmer's practiced basin fields. The difference in gross income in zero-tillage and the other techniques was offset due to less cultivation and sowing costs and less water input to zero tillage plots. Though the yield of farmer's practiced fields was almost equal to the bed and furrow and basin (scheduled) fields however, the net income of these fields was less mainly due to the irrational applications of heavy water and non-water inputs. The indiscriminate applications of water not only results in loss of money but also leaches the nutrients below the root zone that finally affects the crop yield and the net income. The net income of bed and furrow, basin and zero-tillage plots was almost the same. However, WUE of zero-tillage plots and bed and furrow fields were 35 and 10% greater than basin fields (scheduled field) with almost the same water applications and net income.

Table 5. Cost of production and crop yield for different techniques

Cost of production (Rs/acre)						
Techniques	Non-water inputs	Water input	Total	Yield (kg/acre)	Gross income (Rs/acre)	Net income (Rs/acre)
Bed and furrow	5081	1342	6423	2061	18034	11611
Basin	5081	1510	6591	2060	17762	11171
Zero tillage	3377	1222	4599	1860	16275	11676
Basin (farmer controlled)	5685	3127	8812	2000	17500	8688

Figure 10 shows the number of irrigations and depth of water applied in farmer's field where no irrigation scheduling procedures was used. The Fig. 10 also explains the psychology of the farmers towards irrigation. The farmer applied about 79 cm water with 7 irrigations, almost double than water applied under the scheduled fields. However, more application of water could not increase the crop yield rather resulted in decreased water use efficiency and net income. Farmers normally over irrigate the field due to (i) lack of proper knowledge about irrigation scheduling (ii) with the intention that more water will produce more yield. However, Table 4 shows that more water applications result in low WUE and net income. Moreover, over irrigation leaches the nutrients out of the root zone and decreases the crop yield. Particularly, under skimmed water applications, more water applications, more cost, more danger of salinity built up in the root zone and less net income. Figure 10 also shows the attitude of the farmers towards heavy irrigation. If the farmer gets more water i.e. tubewell + canal, he applies more water e.g. irrigation 1, 2 and 5. If he gets less water, then he applies less as was the case with the irrigation

3, 4, 6 and 7. It is therefore clear from the above discussion that irrigation scheduling alone can save at least 50% irrigation water irrespective of irrigation method used with out affecting crop yield.

Effect of skimmed water on root-zone salinity

Figure 11-13 show the effect of skimmed water application on the soil salinity with depth for bed and furrow fields. The ECe of the soil increased at 30-60 cm depth however at other depths the ECe remained almost unchanged. This was perhaps due to the application of poor quality water. The pH of the soil decreased significantly at all depths whereas the SAR of the soil behaved very similar to the ECe of the soil profile. The Figs 14-16 shows the effects of water application on the soil salinity with depth for basin fields. Contrary to the bed & furrow fields, the ECe of the soil decreased at all depths. However, the decrease was more at 30 to 90 cm depths. This might be due to more leaching of salts in the basin fields since in basin fields, all the area is irrigated that enhances the leaching of salts. The decrease in ECe was more pronounced from 30 to 90 cm depths. Soil pH and SAR also decreased almost at all depths.

Water saving in orchards

MREP area is famous for citrus orchards. Farmers normally flood irrigate their orchards. Flood irrigation of orchards results in the wastage of water and fertilizers. The moisture and fertilizer in the fallow area encourages the germination of weeds. Farmers normally cultivate the land between the plants to control the weeds. The movement of machinery in the orchard damages the plants as well as the roots.

Keeping in view the shortage of water supply, trenches around the citrus trees are introduced (Fig. 17, Plate-2). One trench is sufficient to irrigate two rows of plants. The fallow area between the plants was covered with mulches of sugarcane residue. Crop residues, plant leaves and dung can also be used as mulch. Some agricultural wastes like wheat straw, rice straw, maize straw, sugar cane residue etc. are burnt in the fields, which not only kill the micro-organisms present in the soil but also pollute the air. These wastes however, if used as mulch can protect the soil from water and wind erosion and also provides favorable environment for micro-organisms to play their role in the decomposition of organic matter to increase the fertility of the soil. Mulches conserve moisture in the soil and discourage the weed germination. Moreover, these mulches after some time decomposes and adds organic matter in the soil. With trenches, about 6 times less water is required to irrigate the same number of plants as compared with the flood irrigation. Since the depletion of surface and groundwater resources is increasingly becoming a serious problem, it becomes imperative that such innovative irrigation methods should be practiced to irrigate more area with the available water supplies.

The evaporation from the soil surface results in an increase in soil salinity at the soil surface. The water evaporating from the soil surface mainly comes from the groundwater, which transports salts alongwith it.

This is particularly true if soil remains fallow for several months. The shallow water table contributes significantly to evaporation and soil surface salinization (Doering *et al.*, 1964). Mulches reduce the evaporation and hence the salinization of the soils.
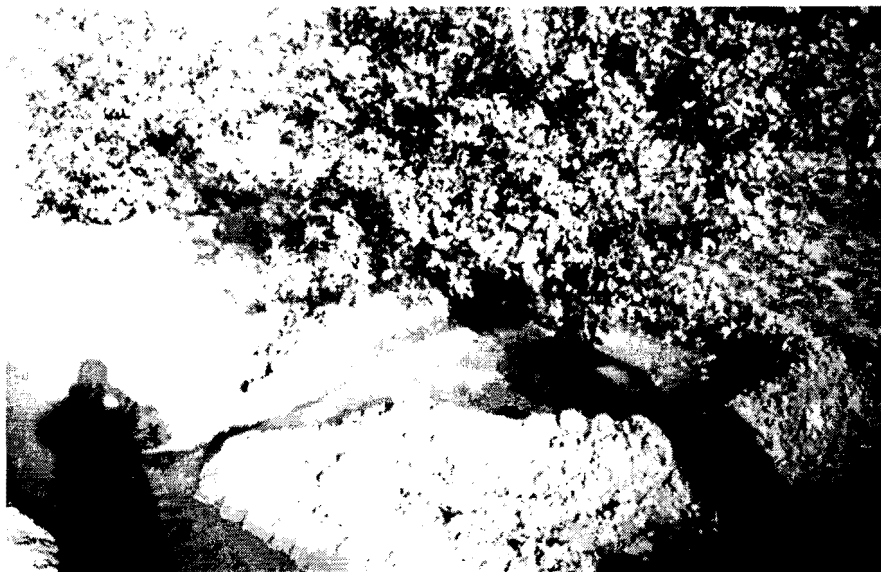

Plate 2.   Trenches around the citrus tress for efficient water applications

CONCLUSIONS

1. The application efficiency of alternate furrows was 45% greater than regular furrows. The water use efficiency obtained from alternate furrows was 49% greater as compared to regular furrows. Alternate furrows require less water input per irrigation and reduces the pumping cost without reducing crop yield significantly. With the application of the same quality skimmed water, the soil salinity in alternate furrows was relatively less than regular furrows most probably due to the less application of water.

2. For wheat irrigation scheduling saved at least 50% irrigation water irrespective of irrigation method used with out affecting crop yield. The application efficiencies of bed and furrow, and zero tillage fields were 37.15 and 38.54%, respectively and were about 45% greater than the basin methods of wheat sowing. The net income of bed and furrow, basin and zero-tillage plots was almost the same. However, WUE of zero-tillage & bed and furrow fields were 35 and 10% greater than basin fields with almost the same water application and net income.

3. The evaporation pan under predicted the soil moisture deficit and may be safe to use for irrigation scheduling under skimmed water applications. The evaporation pan may help the common farmers to

plan for irrigation scheduling. A simple method may be the provision of a graduated Mariatte bottle attached with pan in the field and training of the farmers to apply irrigation when the water loss from the Mariatte bottle equals the maximum allowable depletion, depending upon the soil and crop types. However, further research is needed to test the effectiveness of evaporation pan in the field for planning irrigation scheduling with varying level of MAD, water quality, soil and crops.

4. For orchards, a significant amount of irrigation water can be saved with little modification in irrigation application methods.

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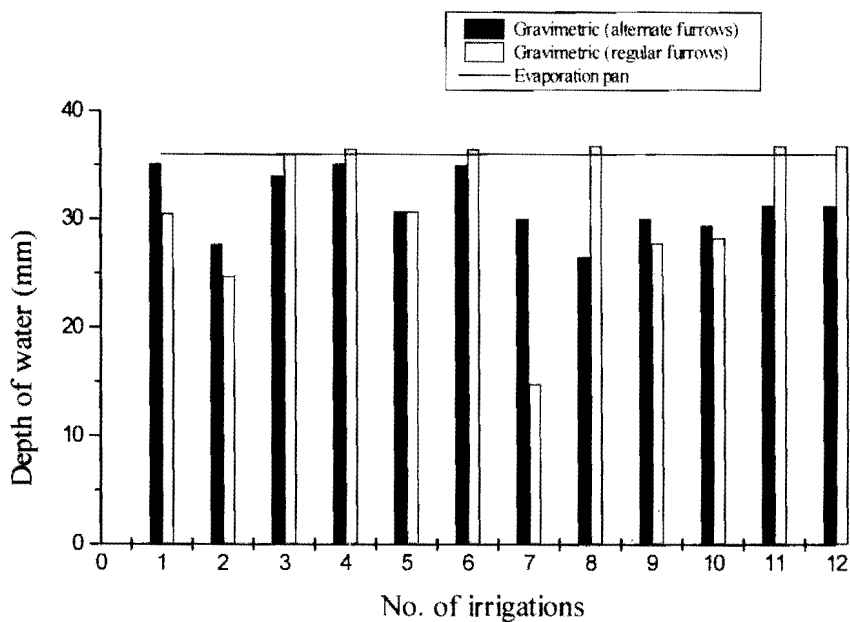
Figure 1. Soil moisture deficit before each irrigation
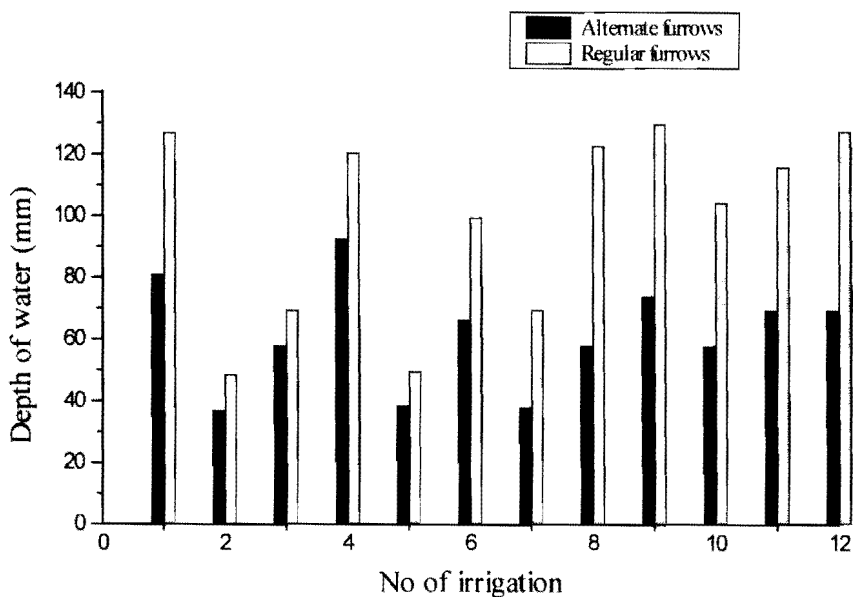
Figure 2. Depth of water applied during each irrigation
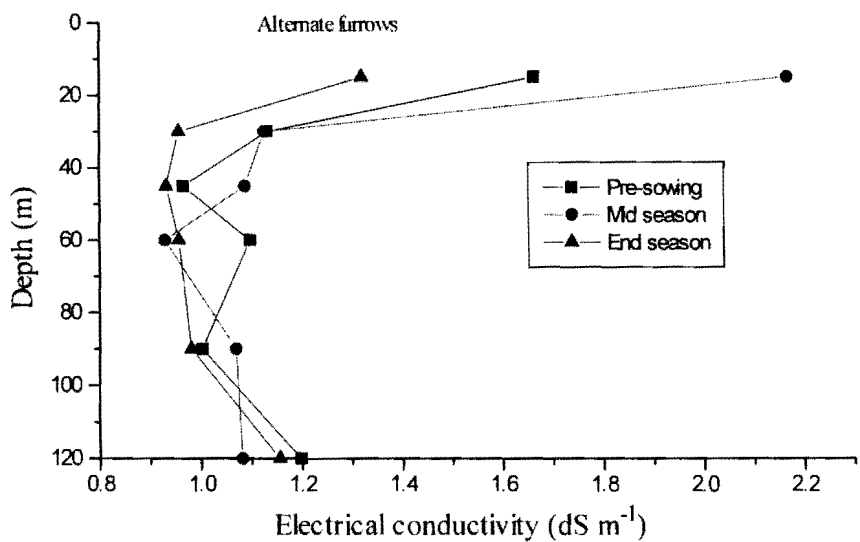
Figure 3. Variation in electrical conductivity as a function of depth
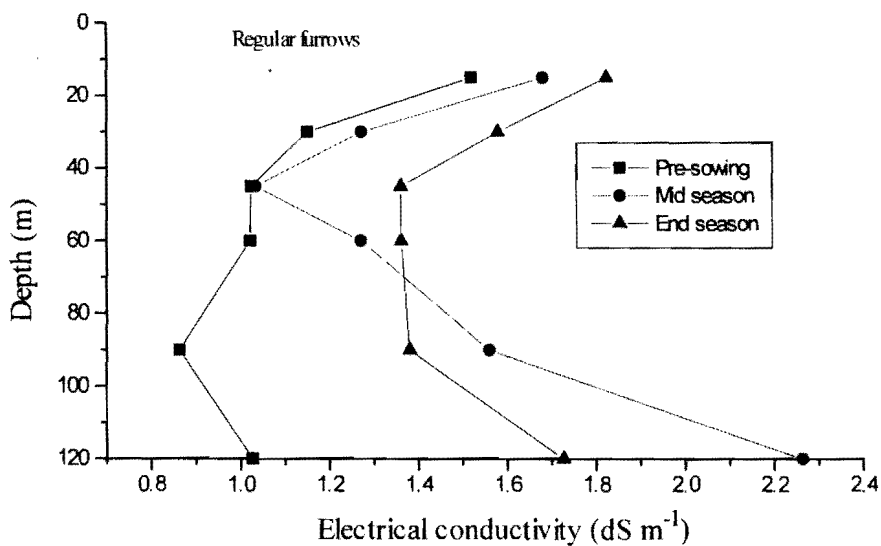
Figure 4. Variation in electrical conductivity as a function of depth
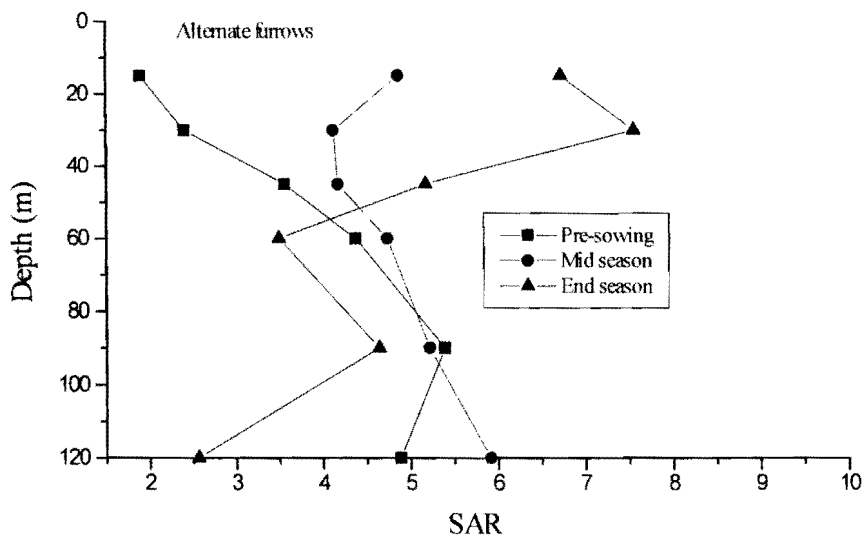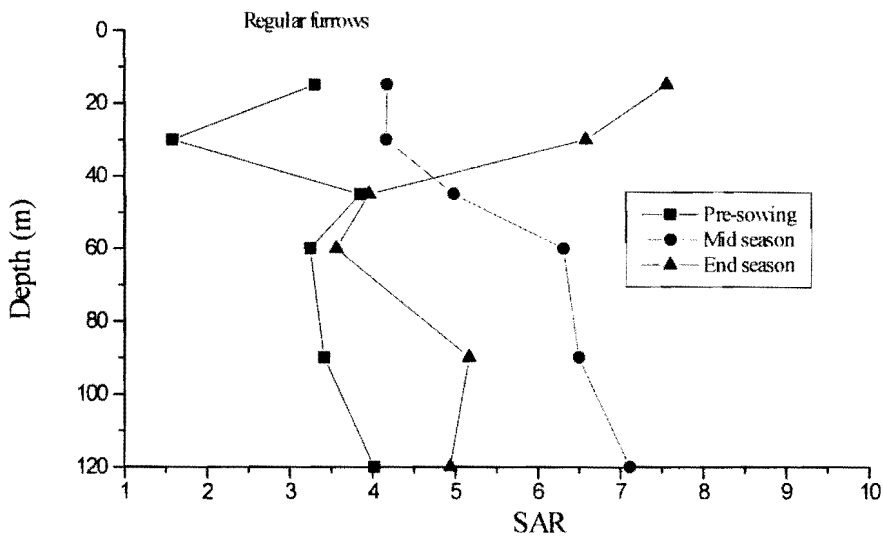
Figure 5. Variation in SAR as a function of depth

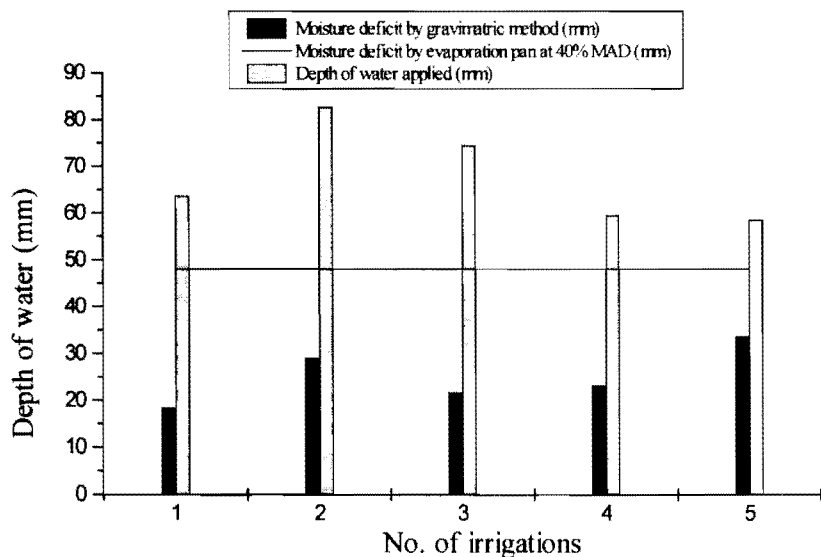

Figure 6. Variation in SAR as a function of depth

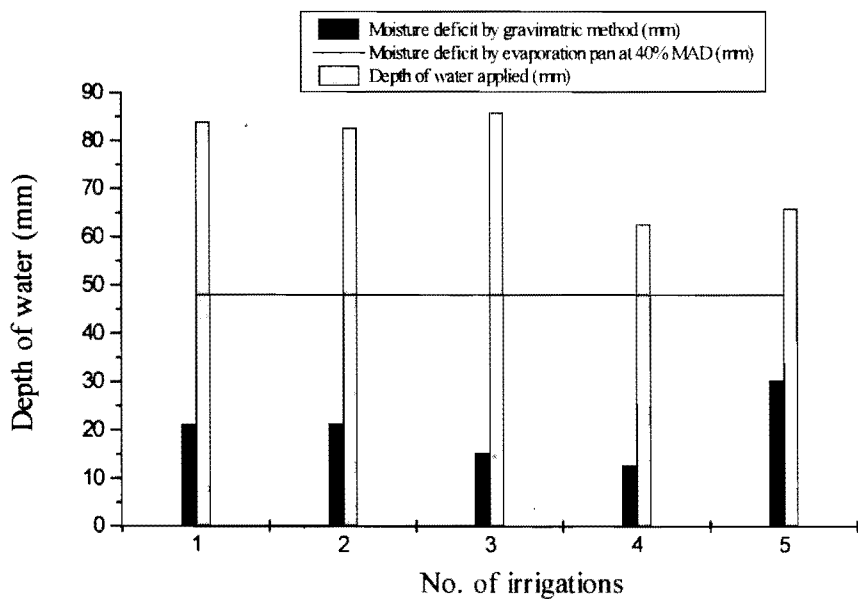Fig 7. Soil moisture deficit and depth of water applied for bed & furrow irrigation
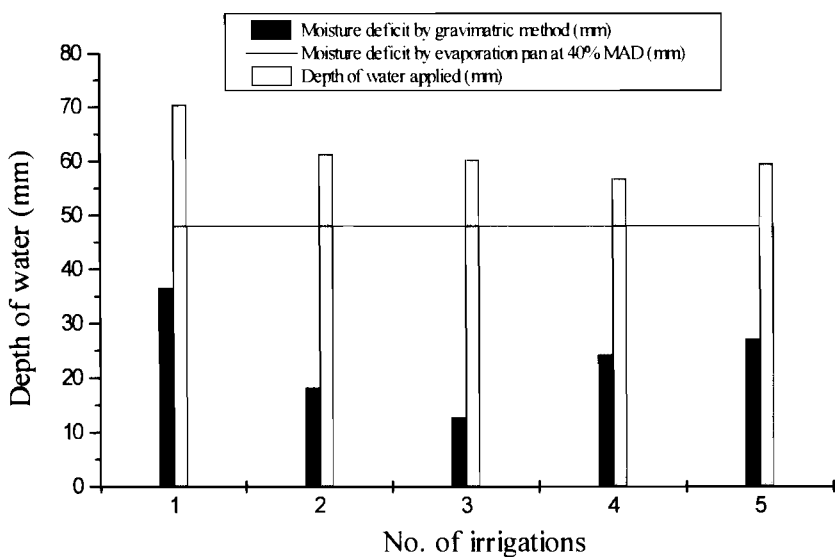

Fig 8. Soil moisture deficit and depth of water applied for basin irrigation

Fig 9. Soil moisture deficit and depth of water applied for zero tillage plots
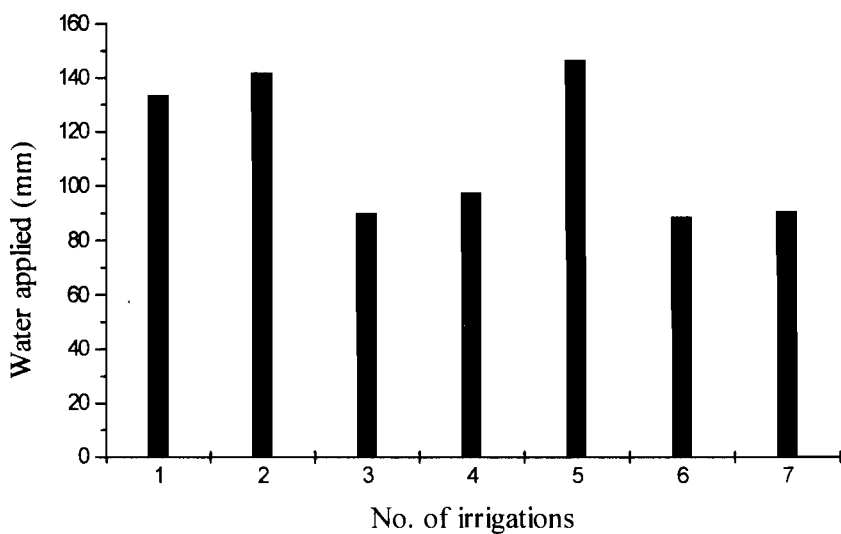
Fig 10. Depth of water applied to wheat field under farmer's practice
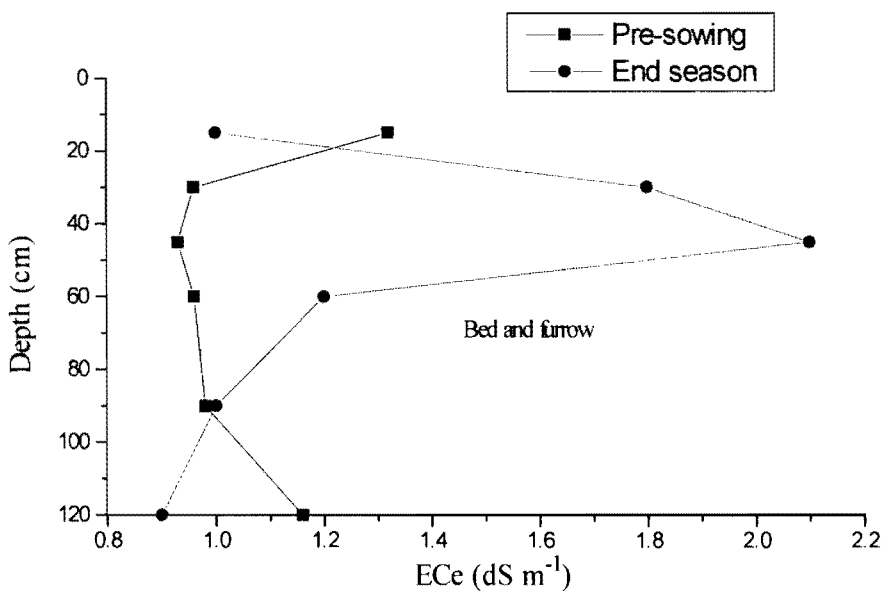
Fig 11. Effect of skimmed water on ECe of the soil profile
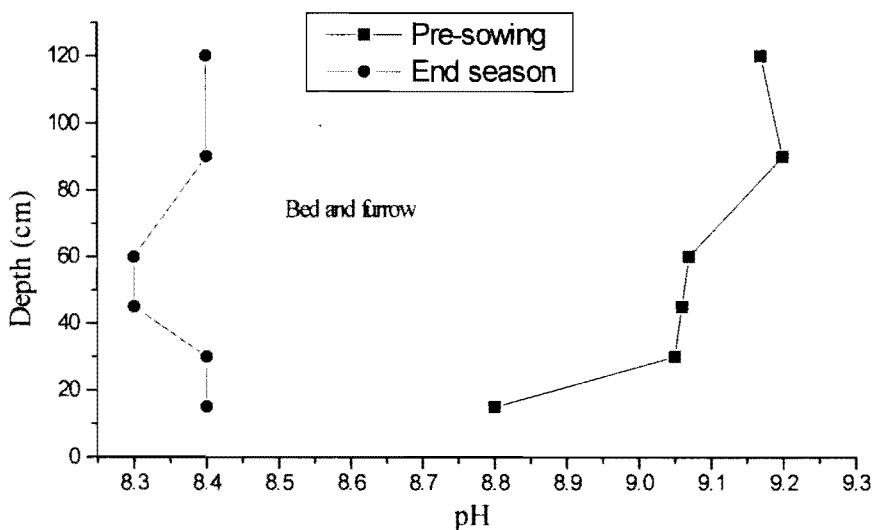
Fig 12. Effect of skimmed water on pH of the soil profile
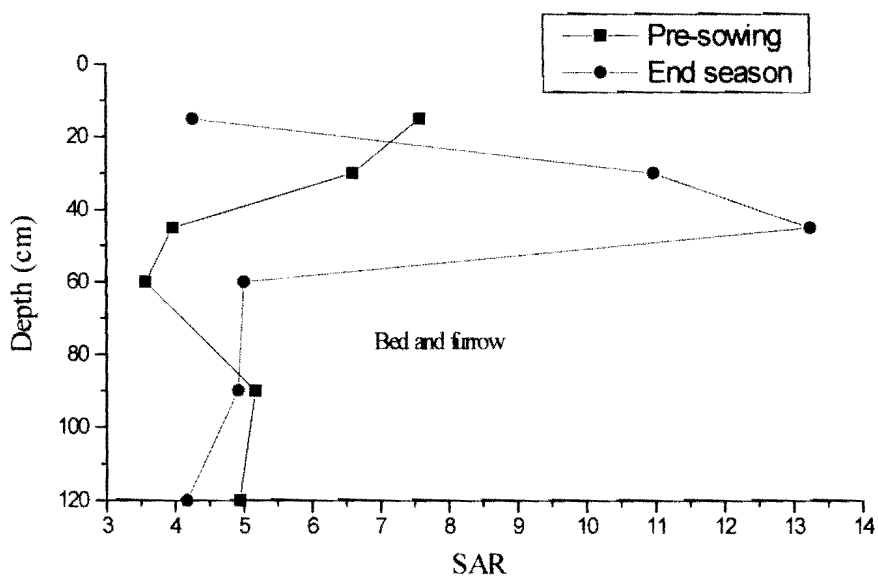
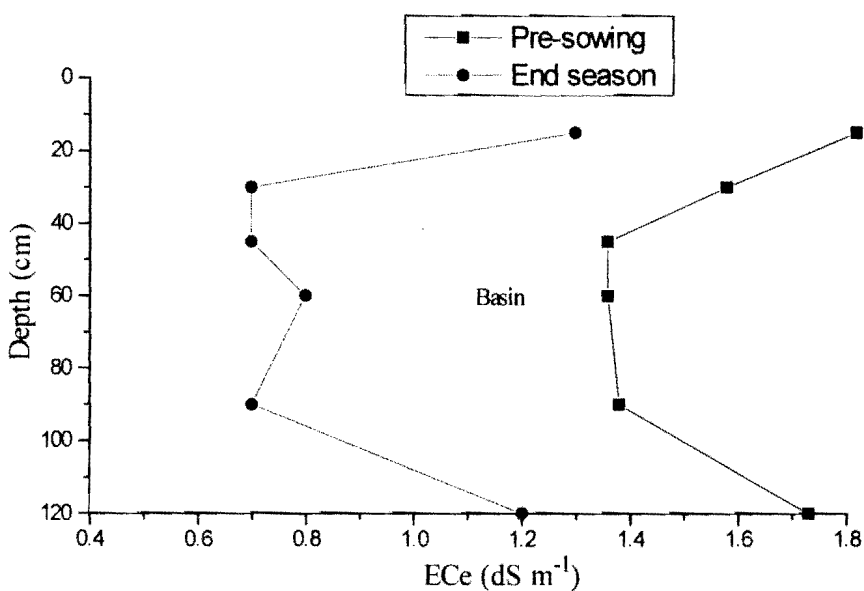Fig 13. Effect of skimmed water on SAR of the soil profile

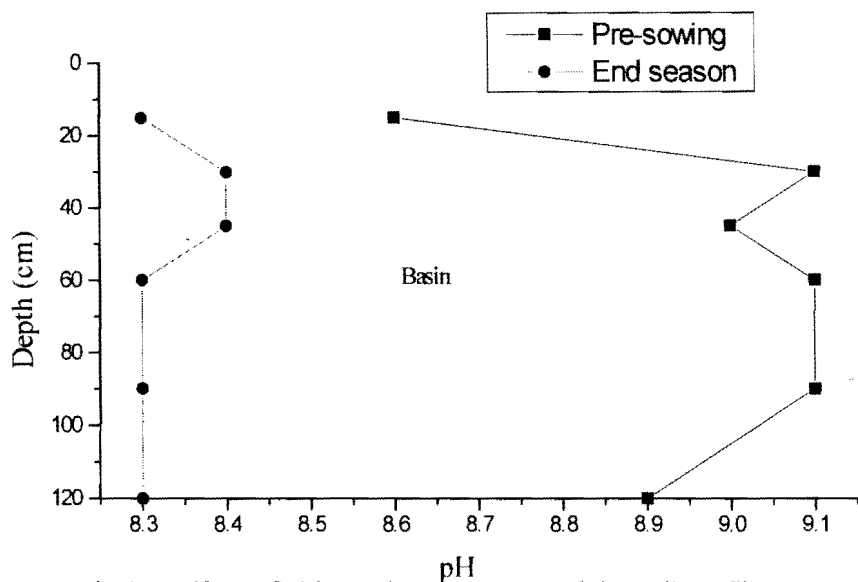Fig 14. Effect of skimmed water on the ECe of the soil profile
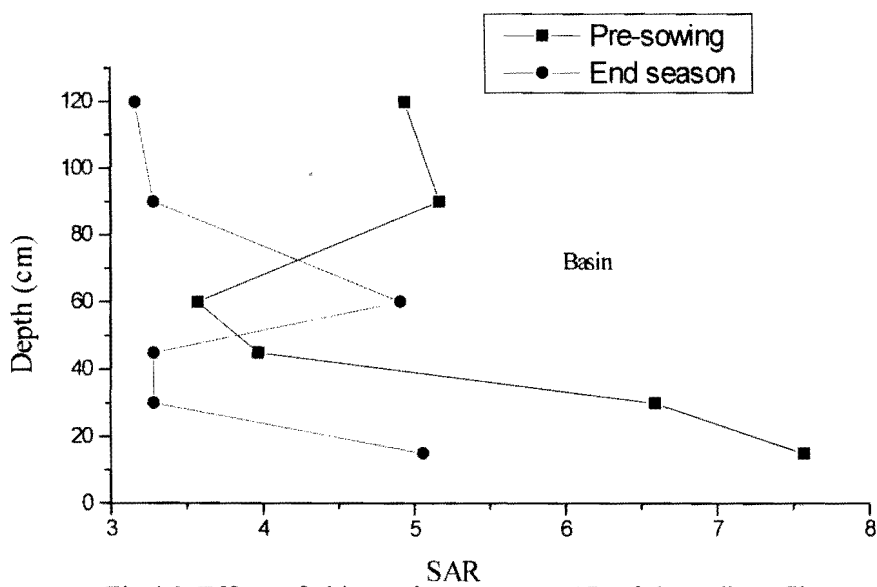
Fig 15. Effect of skimmed water on pH of the soil profile

Fig 16. Effect of skimmed water on SAR of the soil profile