ABSTRACT

A well maintained subsurface tile drainage system plays an important role in the reclamation of waterlogged and saline area as well as improves crop productivity. A field study was conducted to evaluate the performance of subsurface tile drainage system during the years 1998 and 2011 in terms of depth to water table from the ground surface, drainage coefficient hydraulic conductivity and yield of major crops. The system was installed under Swabi Salinity Control and Reclamation Project (SCARP) in July, 1997 in the North-West of Pakistan. The study area is being drained by nine subsurface tile drains spaced 100 to 150 m and length ranged from 500 to 700 m at design depth of 1.5 m from the ground surface. Depth to water table and discharge of tile drains were measured on a weekly basis, while yields of major crops were recorded at harvest stage. Average depth to water table from ground surface ranged from 1.0 to 1.6 m and 0.8 to 1.2 m during the study periods 1998 and 2011 respectively. The water table was slightly (8%) higher in 2011 as compared with 1998 due to blockage of half of the laterals. Sugarcane and rice crops were not affected by the re-emerging water logging during 2011 due to blockage of tile drains while on the other hand wheat and maize were found sensitive to water logging as there yields were 42 and 9% lower under shallower water table condition. The overall mean drainage coefficient of 1998 was 1.65 mm day⁻¹, while in 2011 it decreased to 0.7 and 1.3 mm day⁻¹ in partially blocked and unblocked tile drains command area due to blockage of some of the tile drains. An average hydraulic conductivity before the project (1995) was 0.79 m day⁻¹ and it increased to 1.31 m day⁻¹ in 1998 and showed a further increase to 1.71 m day⁻¹ in 2011. It can be concluded that the major goals of the installation of singular subsurface pipe drainage system have been achieved during the early years after completion of the project as the project was successful in lowering the water table and increasing crop yield but the long term performance was adversely affected by improper maintenance of the main drain, subsurface tile drains and plantation of poplar (Poplus nigra) trees across the laterals.

Key words: Drainage performance, Water table depth, Drainage coefficient, Yield, Hydraulic conductivity

INTRODUCTION

Drainage of agricultural land is the natural or artificial removal of excess water from in or on the soil, reduced water levels and salinity results in a considerable increase in crop yield (Vagheta et al., 1995). Water is in excess’ when the amount present adversely affects the production of crops by reducing the soil air volume accessible to the roots. Excessive soil moisture also prevents the carbon dioxide formed by plant roots and other organisms from being exchanged with oxygen from the atmosphere, a process known as aeration. Without aeration the root development and uptake capacity for water and nutrients of most plants is reduced. When waterlogged or saline land is reclaimed by drainage, the usual types of monoculture (e.g. extensively exploited grass- or hay land, or in tropical monsoon areas, a continuous cultivation of rice) it makes way for a wider variety of crops. Most arable crops, e.g. cereals, root crops, fiber crops, and fruit trees, require well-drained soils. Roots require oxygen for respiration and other metabolic activities: they absorb water and dissolved nutrients from the soil, and produce carbon dioxide, which has to be exchanged with oxygen from the atmosphere. This aeration process, which takes place by diffusion and mass flow, requires open pore space in the soil. Plant roots and most soil micro-organisms utilize oxygen (O₂) from the soil air, and give off or respire carbon dioxide (CO₂). A continuous supply of oxygen is needed for this respiration process. An insufficient supply limits plant growth, particularly in medium to fine textured soils in irrigated soils.

When the total quantity of water arriving in a given area from the various sources exceeds the total quantity consumed by the plants and removed through natural drainage processes, the water table will rise in areas where the water table has not yet occupied the root zone. Water table should be managed in such a way that the crops can draw the maximum amount of water by means of capillary rise. Generally, the water table depth of 1.5-2.0 m was found to be optimum for all the crops (Kahlown et al., 2005). Under these conditions, the purpose of drainage system should be to keep the water table enough low to allow adequate aeration in the active root zone and to minimize capillary salinization during the fellow period. On the other hand, water table should be high enough to maximize the opportunity of sub-irrigation during the dry period. Sheikh et al. (1989) made a comparison between pre project and post project water table depth and found that drainage had lowered down the water table to 50 cm from ground

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surface in 89% of the pilot area. Similar results were also reported by Bhutta et al. (1992) and found that soon after the laying of the laterals and collector drains the water table depth reached the level of the drains and remained below or at the drain level for most of the year. Benefits of using ground water include reduced irrigation demand, lower production costs and a decrease in the amount of ground water that needs to be disposed of through the subsurface drainage system. An ideal irrigation is one that can apply the right amount of water over the entire region of interest without any loss (Zeerihan et al., 1997). Drainage and irrigation should be managed as an integrated Water Management system to reduce drainage volume and conserve irrigation water (Christen and Ayars 2001). According to modern research changes in current drainage design criteria in arid areas (spacing and depth of drains) to maintain water quality, reduce drainage volume and reduce the volume of required irrigation water (Ayars et al., 1997. Christen and Skehan., 2001).

The efficiency and performance of a drainage system do not age dependent but on the other natural factors like human perception and installation condition (Katkevicious et al., 2000). It is possible that an old drainage system may work properly even after 20 years while on the other hand a newly installed system may fail just after installation due to inappropriate design or unsuitable drainage material (Stuyt et al., 2000).

In humid areas on-farm recharge to ground water comes from precipitation which percolates into the soil to become groundwater. Where there is no influence from a river or a sea level, the winter storage of rainfall inside the permeable and often shallow soil lying above an impervious barrier results in temporary perched water tables. Where there is such an influence, on-farm recharge of groundwater contributes to the rising of the existing groundwater table, which may be permanently present throughout the year. Where there is poor surface drainage or impeded infiltration on flat or smoothly undulating lands, extensive flooding (on larger areas) or local flooding (in depressions or low spots) may occur. Coastal agriculture lands often face the twin problems of water logging and salinity for which subsurface drainage is an appropriate and proven solution (Singh et al. 2002).

Drainage coefficient is the depth of water to be removed in 24-hours and it is one of the most important factors in drainage design. A drainage rate of 3mm/day was used for calculation of the lateral’s spacing for Mardan SCARP. After installation and operation of the Tile drainage system it was observed that in many areas the water table went up to or even below the lateral’s depth. Thus for designing of Swabi SCARP, the Swabi SCARP Consultants (SSC) analyzed the water table depths and drain discharge data for the year 1988, 1989 and 1990 collected from monitoring of Mardan SCARP. They determined the drainage rate of 2 mm/day for Swabi SCARP. Similar estimation of 2.2 mm day\(^{-1}\) was also conducted by Ahmadi (1995) on measurement of water table depths, hydraulic conductivities and impermeable layer depth, assuming a steady state condition. Even then it was felt that a pilot project is needed to find out the appropriate drainage rate for Swabi SCARP. Thus Tile drains were laid in a pilot area in 1994 to confirm the design parameters. Johnson (1992) observed that the drainage rate could vary considerably from scheme to scheme and could be further influenced by rainfall which had a considerable influence on drain spacing’s and costs.

Hydraulic conductivity is the flow of water through a unit volume of soil and it is directly linked with soil fertility and porosity. The subsurface tile drainage system increases soil fertility and porosity by plant residues and plant roots penetration into the soil which ultimately increases hydraulic conductivity. Water logging can be prevented by a properly designed subsurface drainage system. The design and functioning of subsurface drainage systems depend to a great extent on soils saturated hydraulic conductivity. It is, therefore, necessary to determine the exact value of hydraulic conductivity as accurately as possible for the design or evaluation of a drainage project. Moustafa (2000) measured hydraulic conductivity (Ks) in seven different soils in Egypt to evaluate its spatial variability and to develop a model for estimating its representative value for a large scale subsurface drainage design.

An agricultural land is said to be waterlogged, when the soil in the crop root zone, get saturated with water. This is usually caused by a rise of the subsoil water table. Water logging can also be caused by excess soil moisture due to periodic flooding, overflow by runoff, over irrigation, seepage, artesian water and impeded subsurface drainage. These conditions affect the growth and yield of crops and in the course of time, turn the land saline or alkaline and ultimately render it unfit for cultivation. Soil and water salinity decreases the availability of soil water for crop and leads to reduced germination, growth and yields. In addition, certain constituents in water or soil may be toxic to plant growth. Others may affect soil physical properties, resulting in enhanced detrimental effects on plant establishment and growth. In the past different parameters of a drainage system were investigated by many researchers e.g. Bhutta et al., (1995 & 1996), Iqbal et al., (1997), IWASRI, (1997) and Azhar et al., (2004). However very little systematic information is available on long term performance of subsurface tile drainage system. Therefore, a study was conducted on the performance of a singular sub-surface drainage system during two time intervals (1998 and 2011) in term of water table depths from ground surface, drainage coefficient, hydraulic conductivity and crop yields.

MATERIALS AND METHOD

Description of the Research Site
The installation of sub-surface tile drainage system in Swabi SCARP was initiated in July 1995 and completed in June 1999. Swabi SCARP project covers a gross command area of 113,765 ha and a cultivable command area (CCA) of 74,494 ha, respectively in Districts of Mardan, Charsadda and Swabi and Malakand Agency of Khyber Pakhtunkhwa. About 80,081 ha of project areas are under command of Upper Swat Canal while 5,385 ha receives irrigation supplies from the Kalapani distributary of the Lower Swat Canal. The integrated Swabi SCARP envisaged remodeling of 457 km length of irrigation channels, repair of tunnels, remodeling of Headworks and embankments (to save the land from spilling over of the natural drainage channels in 33,603 ha), remodeling of 530 km of surface drains and installation of pipe drains in 28,340 ha. It has a designed water table depth of 1 m from the ground surface, with drainage rate for spacing calculations of $2 \text{ mmd}^{-1}(0.0062 \text{ m}^2 \text{d}^{-1})$ and the depth to lateral center was 1.8 m. Subsurface lateral tile drains depth to the lateral center varied from 1.6 to 2.1 m with an average depth of about 1.85 m.

The study was conducted at Shahbaz Ghari Pilot Project area of Swabi SCARP. The research site is located Eastward from Mardan about 15 Km away on Mardan-Swabi Road. Singular sub-surface tile drainage system was installed in the area and its construction completed along with the rehabilitation of Shahbaz Ghari drain in July 1997. A little modification was made in the drainage of the research site for direct outfall into the surface drain instead of joining with collectors.

Nine laterals at research site were installed at 1.5 m depth from the ground surface with length varied from 500 to 700 m and spacing ranged from 100 to 150 m. Water table depth data were collected from 18 observation wells during 1998. During 2011, these observation wells were re-installed at the same locations which were removed by the farmers intentionally or due to their obstruction in farm operation. The schematic diagram of the layout of subsurface tile drainage system is shown in Figure 1.
Water Table Depth Measurement

Water table depths from ground surface were measured from 18 selected observation wells in 1998 and 2011 at the research site on a weekly basis, with the help of an electrical water level indicator. Depth of water level from the rim of observation wells was measured directly from the plastic tape of the electrical water level indicator. The actual depth of water from the ground surface was determined by subtracting the length of observation wells above the ground surface from the already measured total water table depth.

The average water table depth for the research site was determined by adding all water table depths recorded at a given day and divided by the total number of observation wells at the site.

Rainfall

Daily rainfall data for the research period was obtained from Sugar Crop Research Institute (SCRI), Mardan at the end of each month during the study period. The data were used to compare the fluctuation in water table condition during normal and heavy rainfall events.

Yield Measurement
Yield data of all major crops were obtained from direct measurement as well as through farmer’s interviews. Thirty farmers were interviewed from the whole command area during 1998 while in 2011 yields were recorded from an area of 2 m² directly from farmers’ fields for all major crops.

**Lateral Discharge Measurement**

Lateral flow discharges were determined by volume method normally once per week and 3-5 days regularly after heavy rainfall events. In this method, the time required for the flow to fill a container of known volume was recorded. The flow rate was determined by dividing the volume of the container by the time required to fill it.

\[
Q = \frac{V}{t}
\]

Where
- \( V \): Volume of container (liters)
- \( T \): Time taken to fill the container (sec)
- \( Q \): Discharge (ls⁻¹)

**Drainage Coefficient \((q)\)**

Total volume of water discharged from each lateral was computed for 24 hours from already measured laterals' discharges. Drainage area for individual laterals was determined by multiplying length of each lateral with drain spacing. By dividing the volume of flow from lateral per day by the area drained, the actual depth of water removed from the area in mm day⁻¹ was calculated separately.

\[
q = \frac{86400 \times V}{A}
\]

Where
- \( V \): Total volume of flow from lateral per day (liters)
- \( Q \): Discharge of lateral (ls⁻¹)
- \( T \): Time taken as 24 hours (converted in seconds)
- \( q \): Drainage coefficient (mmday⁻¹)
- \( A \): Area drained by the lateral (m²)

**Determination of Hydraulic Conductivity \((K)\)**

An auger hole method was used to determine hydraulic conductivity of the soil. With the help of an auger a vertical hole was bored into the soil up to a depth of 3 m from ground surface. A float was attached to light-weight steel tape. Standard was then pressed into the soil near the hole up to a certain mark, so that the water level readings could be taken at fixed height above the ground surface. When the water in the hole became static with groundwater, its depth from the reference point above the ground surface was measured. With the help of a bailer, a part of water was removed from the hole. The float was lowered into the hole as quickly as possible. The groundwater then began to seep into hole and the rate at which the water rose in the hole was measured. Measurements were continued until recovery of the water in hole equaled about 20% of the depth initially bailed out. For a single bore hole the same procedure was repeated twice. Hydraulic Conductivity \((k)\) in m/day was calculated by using the following formula.

\[
K = \frac{4000 \times r \times \Delta Y}{(H \times 20) \times Y \times \Delta t}
\]

Where
- \( K \): Hydraulic conductivity (m/day)
- \( r \): Radius of the bore hole (cm)
- \( \Delta Y \): Difference of first and last drawdown depths (cm)
- \( Y \): Average of first and last drawdown depths (cm)
RESULTS AND DISCUSSION

In this section results related to performance of a singular subsurface tile drainage system evaluated during 1998 and 2011 of the Swabi SCARP is presented and discussed.

Fluctuation in Average Depth to Water Table

Comparison of average depth to water table (DWT) from the ground surface during the periods (July-September 1998) with current study (July-September, 2011) at the research site is shown in Figure 2. It is obvious from figure that depth to water table from the ground surface ranged from about 1.0 to 1.6 m and from 0.8 to 1.2 m during the study period in 1998 and 2011 respectively. It can be seen from the figure that after heavy rainfall events in the area, the water table responded positively and then moved down gradually and attained the original positions. Figure 2 shows that the water table was slightly (8%) shallower in 2011 as compared to 1998 due to blockage of some tile drains. The averages DWT of free flowing drainage units were relatively deeper than the blocked ones (Khan et al., 2007). Some of the farmers planted poplar trees on the drainage lines and due to root penetration of these trees into the tile drains resulted blockage of tile drains. Rafiq et al (2000) found that the drainage system operated by farmers helped to maintain the water table. Qamar (1990) reported that the subsurface drainage system controlled water logging and salinity and increased crop productivity. He suggested a strong monitoring and evaluation of SCARP projects to achieve the desired results, which has been ignored in the current study area since 1997 due to which 66 % of the drainage system was severely damaged by partially and completely blockage of tile drains installed in the area. Vaghera et al. (1995) reported that water table condition before and after installation of tile drains reflected positively.

Figure 2. Fluctuation in average depth to water table at research site during 1998 and 2011

Yield of Major Crops at Different Time Intervals

Figure 3 shows the yield of major crops (wheat, maize, rice and sugarcane) grown at the research site during 1998 and 2011. Sugarcane was the major cash crop its yield decreased (19%) from 43.61tons ha\(^{-1}\) in 1998 to 36.77tons ha\(^{-1}\) grown in unblocked tile drains command area in 2011 due to lowering of water table while, it was 16% higher in blocked tile drains command area because of relatively shallower water table from the ground surface. Comparing the yields of sugarcane during the year 2011 in the blocked and unblocked tile drain command area, sugarcane responded positively to shallow water table depth from the ground surface. Similarly rice yield increased only 14% from 1715 kg ha\(^{-1}\) in 1998 to 1962kg ha\(^{-1}\) grown on blocked tile drains command area, which was 21% lower than grown in blocked tile drains service areas during 2011.Wheat was the next dominant crop of the area and its production was increased (76%) from 2385 kg ha\(^{-1}\) in 1998 to 4203 kg ha\(^{-1}\) grown on unblocked tile drains command area during 2011 but this yield was 42% (2440 kg ha\(^{-1}\)) lower in blocked tile drains command area. Similarly maize yield increased (37%) from 1649 kg ha\(^{-1}\) in 1998 to 2264 kg ha\(^{-1}\) grown in unblocked tile drains command area during 2011 but this yield was 9% (2068 kg ha\(^{-1}\)) lower in blocked tile drains command area.
Results show that sugarcane and rice crops were not affected by the shallow water table depth from the ground surface, while wheat and maize were found sensitive to water logging and its yields were reduced by 42 and 9% respectively. These results are in line with the findings of Lu (1994) who found that water logging caused leaf yellowing, death of older leaves and in later stages caused early senescence and decreased grain yield.

![Figure 3. Yields of Major Crops in Two Time Intervals (1998 and 2011)](image)

**Drainage Coefficient**

The fluctuation in drainage coefficients during the 1998 and 2011 of the study area is shown in Figure 4. It can be seen from the figure that in the month of July, 1998 drainage co-efficient remained below the design drainage rate, but as the rainfall season started it got shallower in a week from designed drainage rate and then dropped again within in due course of time below the designed drainage rate. On the other hand in 2011 drainage coefficient was far below the designed drainage rate from the start of July to mid of August in partially blocked and unblocked tile drains service area. During the study period in 2011, drainage coefficient fluctuated between 0.5 to 1.0 mm day\(^{-1}\) in partially blocked tile drains command area while it was in the range of 1.0 to 2.7 mm day\(^{-1}\) in unblocked tile drains command area. The average drainage coefficient was 1.65 mm day\(^{-1}\) during 1998 while; it was 0.7 and 1.3 mm day\(^{-1}\) in partially blocked and unblocked tile drains service area during 2011. Similar results were also reported by Moustafa, (1998) who estimated a drainage coefficient of 1.1 mm day\(^{-1}\) and the design drainage capacity of 2.2 mm day\(^{-1}\), based on the peak discharge of the most critical crop (maize), rather than 4.0 mm day\(^{-1}\). He also observed a significant decrease in the drainage coefficient and in the drain pipe capacity from 18-45 % with the increase in irrigation efficiency from 5-15 %. Drainage coefficient measured in partially blocked and unblocked tile drains service area during 2011 were 134 and 29% lower than measured in 1998. Reason for this change was completely or partial blockage of some tile drains, due to root penetration of poplar trees in some of the tile drains, while in 1998 all the tile drains were functional as the system was completed in 1997 and was in full working condition.
Fig. 4  Comparison of drainage coefficient measured during 1998 and 2011

It is obvious that there were large changes in the value of drainage coefficient over time during 1998 as compared with 2011. Figure 4 shows that when the water table was deeper in the dry period, drainage coefficient of the area was below the designed drainage rate in both study periods (1998 and 2011). During the rainfall season drainage coefficient increased with the high water table during 1998 as well as in unblocked tile drains command area during 2011, while in partially blocked tile drains command area, rainfall events has no significant effect on the drainage coefficient. Ahmadi (1995) estimated the subsurface drainage coefficient of 2.2 mm day\(^{-1}\) which was within the range of local and published values of other researchers.

Changes in Average Hydraulic Conductivity

Average hydraulic conductivity increased from 0.79 to 1.31 m day\(^{-1}\) (65%) in 1998 and from 1.31 m/day to 1.71 m/day (31%) in 2011 (Figure 5). It is clear from the figure that in general the hydraulic conductivity increased with time except at location No -1 it decreased from 1.46 m day\(^{-1}\) in 1998 to 1.11 m day\(^{-1}\) (24%) in 2011 due to blockage of some tile drains of the area. The overall hydraulic conductivity of the area has increased from 0.79 to 1.71 m day\(^{-1}\) (116%) after 14 years of installation of tile drains. This increase could be due to the activity of aerobic microbes which increased the porosity of the soil. Similar findings have been reported by Youngs, 1976 and Wahdan et al. (1992) and found that, the aggregate stability and consequently, the water movement improved under drainage conditions. In addition, the drainage did not increase the total porosity but it raised the proportion of macro-pores and, consequently increased the hydraulic conductivity significantly of the low permeable soil under study.
CONCLUSION AND RECOMMENDATIONS

Blockage of some of the subsurface tile drains resulted shallower water table depth from the ground surface in 2011 as compared to 1998.

Sugarcane and rice were not affected by shallow water table less than one m from the ground surface, while the wheat and maize were found sensitive to water logging and its yield decreased 42 and 9% respectively.

Drainage co-efficient varied from 0.25 to 3.6 mm/day\(^{-1}\) in 1998 while in 2012 it ranged from 0.5 to 2.7 mm/day\(^{-1}\), in general the overall drainage coefficient decreased with time due to blockage of some of the subsurface tile drains.

Average hydraulic conductivity increased from 0.79 m/day to 1.31 m/day (65.32% increases) in 1998 and further from 1.31 m/day to 1.71 m/day (30.78 %) in 2011, which may be due to enhanced porosity resulting from microbial activities. Hydraulic conductivity of location 1 only has decreased from 1.46 m/day in 1998 to 1.11 m/day (24 %) in 2011 due to blockage of lateral of the area.

REFERENCES


