New drainage technologies for salt-affected waterlogged areas of southwest Punjab, India

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New drainage techniques, viz. multiple well-point system, conjunctive use of canal water (CW) and poor quality groundwater, biodrainage and conventional drainage system, were conceived, developed, demonstrated and adopted by a large number of farmers in the salt-affected waterlogged areas of southwest Punjab. The multiple well-point system constitutes a number of well points installed in a line connected with each other at about 1 m below land surface, pumped or siphoned centrally. Different treatments using CW and tubewell water (TW) were applied in various sequences to irrigate sodic soils. The performance and improvement in soil characteristics and grain yield under irrigation treatment using CW only and cyclic use of two CW (2CW) followed by one TW (1TW) were compared. The biodrainage system consists of raised bunds covered with polythene sheet buried at about 15 cm below soil surface on which eucalyptus plants were planted after applying soil amendments farm yard manure, etc. Presence of polythene sheet prevented capillary salinization. The drainage studies were also carried out for planning, design and installation of subsurface drainage system (SSDS) for the 787 ha area of Muktsar district. The SSDS was laid using a drain laying machine in 160 ha area of Jamuana village in Muktsar district.

Keywords: Bio-drainage, drainage, groundwater, waterlogging, well-point system.

PUNJAB has three major rivers, Ravi, Beas and Sutlej, and a dense canal irrigation and drainage network system. About 95% of the net sown area is irrigated, out of which 30% depends on surface water supplied by canals and the remaining 70% on groundwater through tubewells[1]. The drainage of Punjab in general is from northeast to southwest direction, resulting in rising water table in the southwestern districts. Waterlogging, salinity and alkalinity problems have arisen in Faridkot, Ferozepur, Muktsar, Bathinda and Sangrur districts. The water table in the affected districts rose at the rate of 15–20 cm per annum due to introduction of canal irrigation network and inadequate drainage system[2]. According to an estimate, about 85,000 ha of agricultural land in 332 villages of Faridkot and Muktsar districts are severely affected by waterlogging and salinity[3]. The groundwater in many parts of southwest Punjab contains high concentration of dissolved salts with electrical conductivity (EC) varying from 2 to 7 dS/m and residual sodium carbonate (RSC) being greater than 10 me/l up to 10 m depth[2]. In general, groundwater salinity of this area increases with depth and the water is not fit for irrigation and drinking purposes. The installation of subsurface drainage system (SSDS) by trenching was not possible as the soil turned into a slurry due to presence of high sodium levels when the trenching was constructed below the water table. Mechanized operation was not feasible due to low bearing capacity of soil, high sodium content and presence of water table at the ground surface. Kumar and Singh[4] studied different drainage systems to control water table below 2 m in areas with pronounced capillary characteristics and reuse the drainage effluents locally on a long-term basis.

New drainage/water management techniques were developed and demonstrated in 1984 through a pilot project located at Golewala watershed of Faridkot by the Department of Soil and Water Engineering, Punjab Agricultural University, Ludhiana. The pilot project was financed by the Indian Council of Agricultural Research (ICAR) under 'All India coordinated research project on agricultural drainage under actual farming condition on watershed basis'. The techniques used are multiple well-point pumping/siphon system, cyclic use of canal water (CW) and poor quality groundwater, biodrainage and conventional drainage system which are working satisfactorily. The farmers have adopted multiple well-point systems on a large scale. They are now harvesting bumper crops of paddy and wheat. The SSDS has been installed in village Jamuana of Muktsar district, Punjab in 160 ha area using a drain laying machine.

Drainage technology development

In order to tackle the complex drainage problem of the region, the following drainage technologies were developed and tried out.

- Multiple well-point system;
- Cyclic use of CW and groundwater;
- Biodrainage system;
- Subsurface drainage system.

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Multiple well-point system

A layer of relatively fresh water gets collected and floats over poor quality groundwater at places where irrigation is provided through CW. It is difficult to tap this thin layer of good quality water through a single well even though the screen is placed in good quality water zone, as it causes up-coning of saline water following the Ghyben–Herzberg principle[5]. If a drawdown occurs in good quality water during pumping, then the saline water rises (up-coning) mixing the saline and fresh water. Singh[6] suggested the use of multiple well-point system in areas where groundwater mounds exist and a fresh water layer forms over a saline water body in the aquifer. The multiple well-point system was conceived, designed, installed and tested in the experimental area of Golewala watershed for tapping the floating thin layer of good quality water without causing much turbulence in the lower saline water zone[7–11]. The system consists of a number of well points arranged in a line and interconnected to each other through a horizontal pipeline (lateral) buried at about 70–100 cm below the ground level. The well-point system so developed is pumped centrally. The discharge from the system may be considered to be equally divided over the well points though there may be some variation due to friction loss in pipe flow. The low discharge is withdrawn from each well point. The laterals are brought to the centrally located sump such that the delivery points remain about 15 cm above the sump floor level and the sump floor level should be kept about 2 m below the expected water level in the sump for water movement under siphon action. The moment water is lowered in the sump through pumping, subsurface water starts moving from well points into the sump due to siphon action. This technique has been named as multiple well-point siphon system. A battery of 24 wells were installed with lateral spacing of 100 m and well spacing of 50 m with eight wells on each lateral. These wells were connected by a common polyvinyl chloride (PVC) pipeline of 90 and 110 mm diameter with the help of 'T' sections and bends at 70 cm below the ground surface (Figure 1). Each well-point had an effective perforated area of about 16% surrounded by pea size, clean, well-rounded riverbed gravel[12]. After experimentation, cost consideration and operational suitability, a four well-point system was considered for a command area of 4–5 ha. The system has been modified and designed for small farmers with four well points spaced 6 m apart keeping the rest of the characteristics the same (Figure 2). It prevents mixing of floating fresh water with poor quality groundwater as the drawdown is distributed over four well points resulting in reduction of up-coning during pumping. It is recommended that the discharge from each well-point should not exceed 3 l per sec (0.1 cusecs) and that the screen should have effective perforated area of 16–20%, surrounded by pea size clean and well-rounded riverbed gravel[12].

These techniques were demonstrated in Golewala watershed of Faridkot and have been helpful in controlling the groundwater levels in the region. The multiple well-point system was installed in Golewala Watershed, covering an area of 60 ha. The estimated installation cost of 152 well-

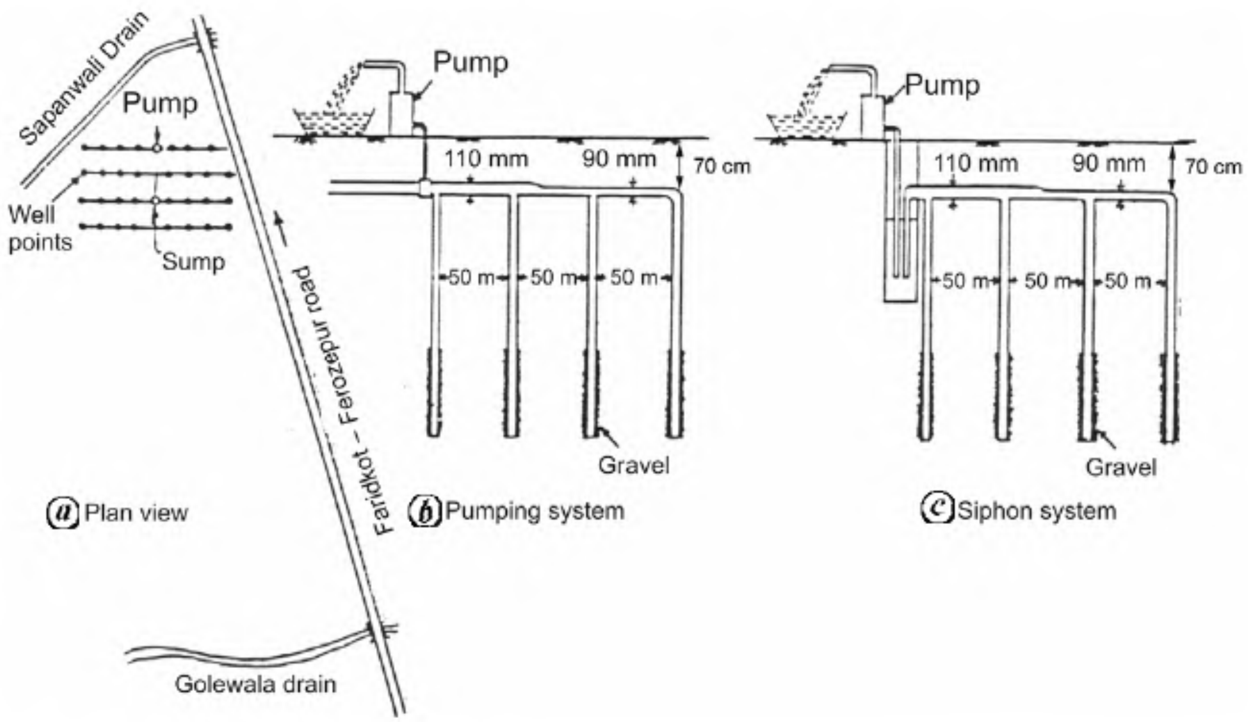

Figure 1. Experimental layout plan for multiple well-point pumping/siphon system.

points system was found to be Rs 30,000 (US$ 750) per ha. The multiple well-point system was found to be technically feasible and economically viable. This system was recommended to small and marginal farmers, irrigating with the pumped good quality water. The cost of installation of a system of four well points worked out to be Rs 20,000 (US$ 500) per set. It has been reported that about 1400 four well-point systems have been installed in the farmers' fields, which have been running satisfactorily for the last 10 years with no up-coning of saline water[13].

The multiple well-point systems designed for drainage can also be adopted for the following conditions.

- Withdrawal of good quality water in coastal aquifer preventing up-coning of seawater.
- Withdrawal of water for domestic, agricultural and industrial uses from thin aquifers.
- Artificial groundwater recharge with available rain and CW.

Cyclic use of poor quality groundwater and CW

Surface and subsurface drainage has been useful in the reclamation of waterlogged areas. However, such drainage systems produce poor quality effluents and their disposal is a serious problem. With the increasing problem of disposal of saline water and increasing demand for good quality water, the conjunctive use of poor quality groundwater and CW has gained popularity[14]. Results of various studies have indicated a potential for the use of saline drainage water for crop production[15–18] and various strategies have been proposed to use this water for irrigation[19,20]. Minhas and Gupta[21,22] demonstrated successfully the use of brackish groundwater with CW in different modes for irrigation in the canal command area. Sodicity in the soil is a major constraint in increasing agricultural production in many arid and semi-arid regions. These soils have high levels of pH, exchangeable sodium percentage (ESP), soluble carbonates of Na and are poor in hydraulic conductivity[23]. Gypsum is commonly used to reclaim these soils, which reduces alkalinity and improves soil permeability. Use of poor quality groundwater and available CW is not only beneficial for raising crops, but also helps in lowering the groundwater table. This process ultimately leads to drainage of waterlogged areas and reduction in the cost of the drainage system.

To study the effects of cyclic use of irrigation treatments in canals and poor quality groundwater on physico-chemical properties of soil and crop growth, the experiment in Golewala watershed was started during Kharif season of 1988 with multiple well-point drainage system. A chemical analysis of irrigation water (TW and CW) was carried out before using irrigation water for the treatments (Table 1). The study comprised different treatments of CW and poor quality TW through multiple well-point system in various sequences.

- CW only: Only CW was used for irrigation throughout the experiment.
- 2CW : 1TW: First two irrigations were applied through CW followed by one irrigation with TW. This sequence was repeated till the maturity of the crop.
- 1CW : 1TW: Alternative irrigation by CW and TW throughout the experiment.
- 1CW : 2TW: First irrigation was applied through CW followed by two irrigations with TW.

The performance evaluation of each treatment was conducted through grain yield and soil sampling. Soil

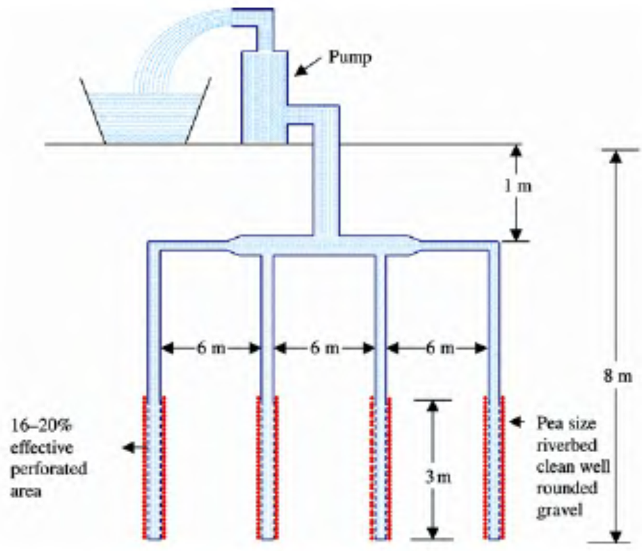

Figure 2. Modified four well-point system for small farmers.

Table 1. Chemical analysis of irrigation water (tubewell water and canal water)

Chemical characteristics	Tubewell water	Canal water
pH	9.47	7.89
Electrical conductivity (dS/m)	3.01	0.27
Ca^{++} + Mg^{++} (Me/l)	1.85	3.15
Na^{+} (Me/l)	37.00	0.45
Cl^{-} (Me/l)	10.50	0.70
CO_3^{-2}+ HCO_3^{-3} (Me/l)	13.00	3.00
Residual sodium carbonate (Me/l)	10.15	0.00
Sodium adsorption ratio $(Me/l)^{1/2}$	38.47	0.47

Table 2. Effect of irrigation treatments (CW and TW) on average chemical properties of soil in four years

Irrigation treatments	Soil depth (cm)	pH (1 : 2), soil : water	Electrical conductivity (dS/m)	Soluble ions (1 : 2, soil water extract (Me/l)				Sodium adsorption ratio (Me/I)$^{1/2}$
				$CO_3^{-2} + HCO_3^{-3}$	Cl^-	$Ca^{++} + Mg^{++}$	Na^+	
Initial properties	0–15	10.37	3.72	9.67	–	0.62	32.88	58.80
(June 1988)	15–30	10.29	2.18	8.31	–	0.81	22.03	34.55
	30–60	10.17	1.89	7.21	–	0.84	18.52	28.50
	60–90	9.99	1.44	5.21	–	1.02	14.16	19.85
	90–120	9.92	1.12	4.95	–	1.29	11.41	14.20
After wheat (April 1992)								
CW only	0–15	7.98	0.23	1.31	1.60	7.59	4.20	2.15
	15–30	8.01	0.34	1.74	1.51	5.38	5.31	3.24
	30–60	8.14	0.50	2.70	1.41	5.10	7.00	4.38
	60–90	8.20	0.61	3.18	1.30	4.90	7.02	4.48
	90–120	8.22	0.68	3.61	0.72	4.60	8.60	5.67
2CW : 1TW	0–15	8.02	0.42	1.51	1.50	6.98	4.32	2.31
	15–30	8.03	0.54	1.95	1.34	4.60	4.81	3.17
	30–60	8.15	0.73	2.91	1.32	4.55	5.20	3.45
	60–90	8.20	0.90	3.38	1.00	4.37	7.61	5.15
	90–120	8.23	0.92	3.82	0.71	4.20	8.90	6.14
1CW : 1TW	0–15	8.14	0.69	1.61	1.41	6.45	4.40	2.45
	15–30	8.19	0.71	2.85	1.31	4.34	4.62	3.13
	30–60	8.25	0.84	3.61	1.22	4.14	6.60	4.58
	60–90	8.40	0.86	4.57	0.92	3.80	8.01	5.81
	90–120	8.52	0.92	4.83	0.63	3.20	8.21	6.49
1CW : 2TW	0–15	8.23	0.76	2.10	1.31	5.45	4.52	2.72
	15–30	8.35	0.90	2.33	1.10	4.30	4.60	3.13
	30–60	8.70	0.91	3.01	0.81	3.99	5.15	3.61
	60–90	8.92	0.96	3.43	0.70	3.60	6.02	4.47
	90–120	8.98	0.98	3.95	0.40	3.10	7.91	6.35

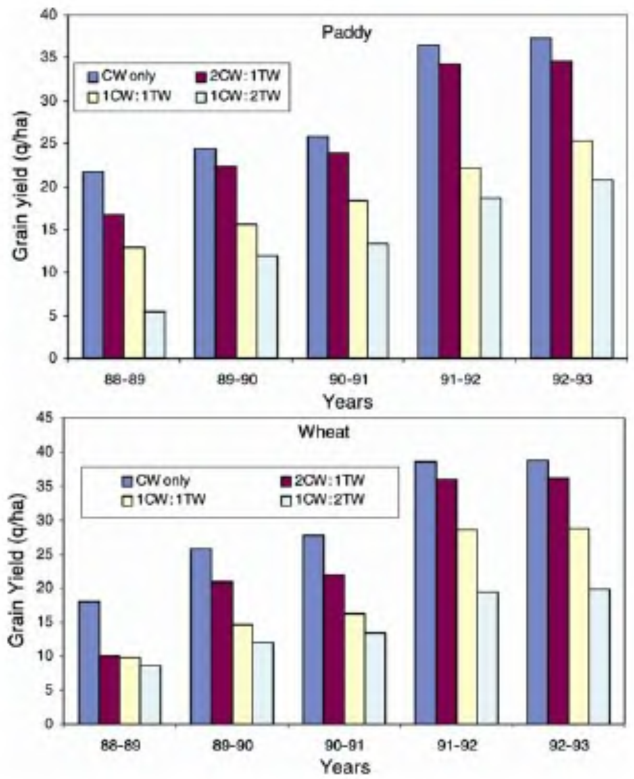

Figure 3. Effect of different irrigation treatments on mean grain yield.

samples from 0–15, 15–30, 30–60, 60–90 and 90–120 cm depth were collected before and after harvest of paddy and wheat crops which were analysed for various physico-chemical properties to monitor the changes over a period of four years (Table 2). The decrease in soluble Na^+ content was due to decrease in soil pH, and higher concentration of $Ca^{++} + Mg^{++}$ content. Sodium adsorption ratio (SAR) behaved almost similar to soluble sodium content. Overall mean grain yield of wheat and paddy obtained from different irrigation treatments was recorded year-wise (Table 3). In general, only CW produced the highest grain yield of paddy and wheat followed by 2CW : 1TW, 1CW : 1TW and 1CW : 2TW irrigation treatments (Figure 3). However, a substantial increase in wheat yield was observed from 18 q/ha (1988–89) in the first year to 38.8 q/ha (1992–93) in 5th year, about 115% improvement for CW irrigation treatment. Better improvement in grain yield was obtained for 2CW and 1TW (258%) and 1CW and 1TW (190%) irrigation treatments than CW (115%) alone. Gupta *et al.*[24] supported the alternative use of poor quality groundwater with fresh water on soil properties and crop yield in salt-affected waterlogged areas.

It is concluded from the study that the cyclic use of CW and poor quality groundwater (2CW : 1TW) on sodic soils with the application of gypsum @ 13.5 t/ha resulted in an improvement in the pH, EC, $CO_3^{-2} + HCO_3^-$, soluble

$Ca^{++} + Mg^{++}$ content, soluble Na^{+} content and SAR values (Table 2) of the surface soil, which ultimately improved the grain yield (Table 3).

Biodrainage system

The transpiration rate of eucalyptus trees is higher than that of any other plant species and it acts as a biological pump, withdrawing water from the subsurface reservoir and delivering it to the atmosphere. However, to establish these plants in waterlogged sodic soils or saline sodic soils is very difficult. Therefore, a technology to establish eucalyptus in waterlogged sodic soils was developed. It constitutes a wide ridge covered with polythene sheet buried at about 15 cm below the soil. The holes for transplanting seedlings are made on the top of ridge at 4 m spacing. Gypsum @ 500 g and farmyard manure (FYM) @ 2 kg/hole are mixed with the soil and added to the hole. The rain falling on the ridge was allowed to percolate through the soil surrounding the seedlings. The undesirable salts leached down below the root and the ridge soil conserved good quality water for the plants. Water table closer to or at the surface did not affect the plants, which were planted on the elevated ridge. It also cuts off the capillary fringe, hence terminating the process of desalinization/resodification.

Table 3. Mean grain yield (paddy and wheat) for different irrigation treatments

Year	Treatment	Paddy (q/ha)	Wheat (q/ha)
1st (1988–89)	CW only	21.73	18.00
	2CW : 1TW	16.80	10.07
	1CW : 1TW	12.87	9.87
	1CW : 2TW	5.40	8.67
	CD (5%)	3.93	8.08
2nd (1989–90)	CW only	24.43	25.67
	2CW : 1TW	22.28	20.97
	1CW : 1TW	15.64	14.67
	1CW : 1TW	11.88	12.00
	CD (5%)	5.21	5.37
3rd (1990–91)	CW only	25.86	27.64
	2CW : 1TW	23.89	21.88
	1CW : 1TW	18.37	16.30
	1CW : 2TW	13.42	13.52
	CD (5%)	3.41	5.85
4th (1991–92)	CW only	36.50	38.50
	2CW : 1TW	34.20	35.90
	1CW : 1TW	22.10	28.50
	1CW : 2TW	18.70	19.50
	CD (5%)	3.99	2.70
5th (1992–93)	CW only	37.33	38.80
	2CW : 1TW	34.66	36.10
	1CW : 1TW	25.33	28.70
	1CW : 2TW	20.66	19.80
	CD (5%)	2.69	2.80

Experiments on the planting eucalyptus hybrid seedlings in the waterlogged sodic soil were taken up in September 1986. The effect was observed with and without amendments. Three amendments, viz. gypsum, pyrite and ferric sulphate (industrial waste) were applied at the rate of 9, 18 and 27 kg/pit. The square pits of 1 m side and 30 cm depth were dug and the amendments were mixed with the soil. The soil surface was covered with a polythene sheet of 50 microns thickness having a hole of 15 cm diameter at the centre for planting. The polythene sheet was buried below the 15 cm soil surface, sloping towards the hole for infiltration of rain/irrigation water (Figure 4). This experiment gave encouraging results by leaching down undesirable salts from the root zone and cut off the upward movement of salts through capillaries.

Three types of studies were conducted at three different sites to investigate the effects of land configuration, land cover and chemical amendments on the establishment and growth of eucalyptus hybrid seedlings. Three land configurations and cover conditions, viz. flat, ridge and ridge covered with polythene sheet were used for planting eucalyptus seedlings. A polythene sheet of 1.5 m width and 50 micron thickness having 15 cm diameter holes along the centre at an interval of 1 m was placed on the ridge. Gypsum @ 500 g and FYM @ 2 kg per hole mixed with soil were filled into the holes. We applied 12 g N, 25 g P_2O_5 and 6 g K_2O to the soil surface of each seedling after planting followed by 1 litre of aldrin solution (0.05%). The plant mortality, height (*H*), diameter (*D*), and biomass production were monitored at a height of 1.3 m above the ground level (Table 4). The eucalyptus plants on a ridge covered with polythene sheet

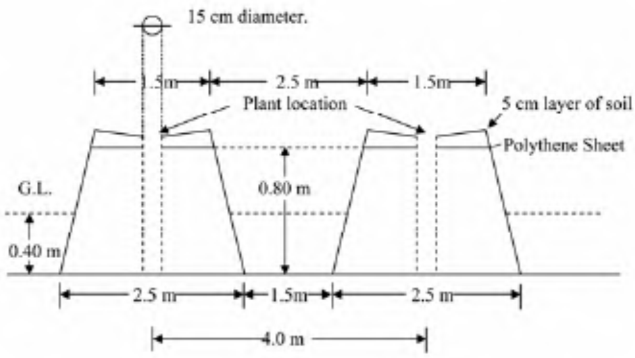

Figure 4. Layout of ridges for bio-drainage.

Table 4. Effect of planting method on plant parameter

	Planting method		
Plant parameters	Flat	Ridge	Ridge covered with polythene
Mortality (%)	5.6	23.9	4.2
Height (cm) *H*	250	363	494
Diameter (cm) *D*	3.3	5.6	6.9
Biomass (cm^3/m^2) D^2H	1115	2808	6425

Table 5. Effect of chemical amendments on mortality and biomass (after 1 year of planting)

	Mortality (%)		Biomass (cm^3/cm^2)	
Amendments	Ridge	Ridge with cover	Ridge	Ridge with cover
Control	86	57	1.1	1.3
Gypsum (500 g)	76	29	1.7	5.9
Gypsum (1000 g)	72	30	3.2	19.6
Pyrites (750 g)	33	5	21.4	66.8
Pyrites (1500 g)	35	5	47.6	115.6

showed lower mortality, higher plant height and diameter compared to flat land and ridge without polythene sheet. Higher mortality (23.9%) was observed in plants on ridge without cover due to lack of moisture in the no-irrigation treatment (Table 4). The groundwater through capillary rise under flat land and stored water under ridge covered with polythene sheet was available to the seedlings. The biomass production was estimated after about 2 years of planting and the ridge covered with polythene sheet produced 3.3 and 5.8 times more biomass than uncovered ridge and flat land planting respectively (Table 4).

The chemical amendments, viz. pyrite @ 750 and 1500 g and gypsum @ 500 and 1000 g per hole were applied to the plants on the ridge with and without cover respectively. In the highly saline alkali soil, 100% seedling mortality was observed under flat land irrespective of the chemical amendments. The mortality decreased and biomass production increased with the application of chemical amendments under both the ridge planting methods (Table 5). Therefore, eucalyptus plantation on ridges covered with polythene sheet has been recommended in severely waterlogged salt affected soils. It was further observed that the application of amendments decreased mortality and increased the plant height and girth compared to the control treatments but their effectiveness varied with the type of amendment and dose of application. Pyrite and ferric sulphate amendments produced about 2.6 and 2.9 times more biomass respectively compared to gypsum[25]. The cost of eucalyptus establishment is very nominal; about Rs 250 (US$ 6) per plant.

Subsurface drainage system

Subsurface drainage system (SSDS) is a well-developed drainage technology, which lowers the water table to a specified depth. Spacing and pattern of the drainage system depends upon the hydraulic conductivity of the soil, specific drainage discharge and water table condition. The SSDS constitutes a system of perforated lateral pipes surrounded by filter materials buried below the root zone depth, collector and pumped outlet if gravity drainage does not exist. All the undesirable salts are leached down and taken out of the field through a network of subsurface drains.

Table 6. Subsurface drain depth for different drain spacings at 1.2 m water table depth

Subsurface drain spacing (m)	Drain depth (m)
40	1.3
60	1.5
80	1.75
100	2.25

When the water table conditions permitted, SSDS was also laid manually at Golewala Watershed at 40, 60 and 80 m spacing in gridiron pattern (Figure 5 *a*) and 100 m spacing in herringbone pattern (Figure 5 *b*) by using Glover–Dumn equation. It was observed that the hydraulic conductivity of the soil increased with the reclamation process and therefore a large spacing could be planned though reclamation would take little longer time. According to the lysimeter studies conducted at PAU, Ludhiana for optimum depth of subsurface drainage under sodic conditions, the water table could be maintained at 1.3 m below the ground surface keeping the effective root zone salt free resulting in better crop yield. It has been observed that the capillary rise for Golewala soil takes place up to 61.2 cm under irrigated conditions. The water table could be maintained at 1.2 m (61.2 cm + 60 cm = 1.212 m) by considering root zone depth to be 60 cm. The optimum drain depths for different lateral spacing of 40, 60, 80 and 100 m were determined as 1.3, 1.5, 1.75 and 2.25 m respectively at 1.2 m water table depth (Table 6). It is recommended that the SSDS installed at 1.75 m below the ground surface at 80 m spacing and the optimum water table at 1.2 m is economically viable and keeps the effective root zone salt free. The chemical properties of the soil have improved after installation of SSDS for paddy–wheat crop rotation. The depthwise EC of the soil decreased from 3.72 dS/m in the surface layer to 1.12 dS/m at 1.2 m depth. The EC of the soil in the surface layer decreased from the initial 3.72 dS/m to 0.36, 0.36 and 0.30 dS/m for 40, 60, 80 m spacing after wheat crop (April 1997) respectively (Table 7). The depthwise SAR of the soil samples in the layers decreased from the initial 58.8 at 15 cm $(Me/l)^{0.5}$ at 1.2 m depth (Table 8). This table depicts that the SAR decreased initially from 58.8 to 2.52, 1.57 and 1.01 $(Me/l)^{0.5}$ at 15 cm depth

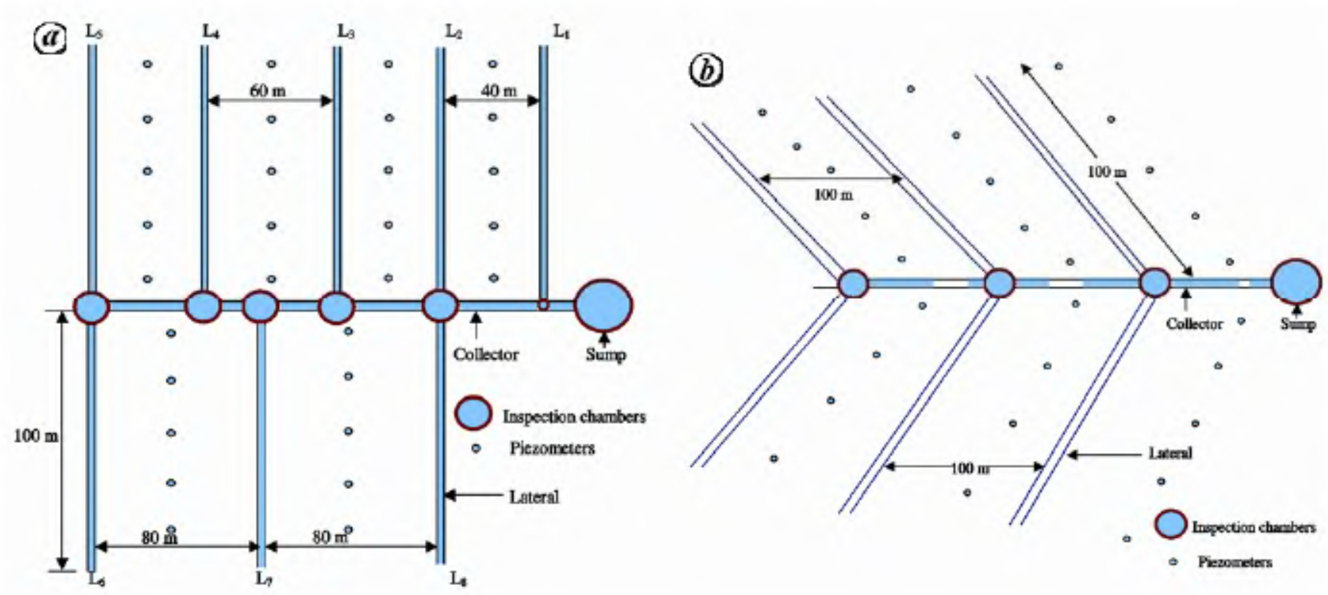

Figure 5. Layout plan for subsurface drainage system in (***a***) Gridiron pattern and (***b***) Herringbone patterns.

Table 7. Variation of electrical conductivity (dS/m) under different drain spacings

Lateral spacing (m)	Soil depth (cm)	Initial value June 1995	October 1995	April 1996	October 1996	April 1997
40	0–15	3.72	0.82	0.80	0.81	0.36
	15–30	2.18	0.99	0.90	0.81	0.41
	30–60	1.89	0.81	0.81	0.81	0.67
	60–90	1.44	0.81	0.81	0.81	0.94
	90–120	1.12	0.81	0.82	0.82	1.06
60	0–15	3.72	0.77	0.78	0.76	0.36
	15–30	2.18	0.79	0.78	0.76	0.38
	30–60	1.89	0.79	0.79	0.76	0.30
	60–90	1.44	0.79	0.80	0.76	0.44
	90–120	1.12	0.80	0.80	0.79	0.38
80	0–15	3.72	0.75	0.76	0.75	0.30
	15–30	2.18	0.78	0.76	0.77	0.25
	30–60	1.89	0.78	0.72	0.77	0.35
	60–90	1.44	0.78	0.76	0.78	0.60
	90–120	1.12	0.79	0.78	0.78	0.62

for 40, 60 and 80 m drain spacing respectively after wheat crop (April 1997). This is due to decrease in sodium concentration and increase in $Ca^{+2} + Mg^{+2}$ content in the soil. The chemical properties of the leachate have also improved. The EC of the leachate decreased initially from 4.34, 3.87 and 3.17 (1994–95) to 0.27, 0.26 and 0.25 dS/m for 40, 60 and 80 m lateral spacing respectively at the end of 1997–98 (Table 9). The value of SAR has also decreased from 11.0, 12.0 and 11.42 (1994–95) to 1.06, 0.99 and 0.95 $(Me/l)^{0.5}$ for 40, 60 and 80 m lateral spacing respectively by the end of 1997–98 (Table 9). The most significant increase in grain yield of wheat and paddy has been reported at 1.3 m water table depth due to leaching of salt and low capillary rise (Table 10). This is further supported by Rao *et al.*[26] through the studies on the drainage requirements of alluvial soils of Haryana that the soil could be reclaimed rapidly by leaching out excess salts from the root zone and the potential yield could be obtained in a period of about 4–5 years after drainage. Water table could be maintained well below the harmful depth (1.0 m) with SSDS at drain spacing of about 75 m in the semi-arid part and 75–100 m in the arid part of the state.

The mechanized laying of SSDS was planned in Muktsar and Ferozepur through a central government sponsored project (Ministry of Rural Development, Government of India) executed by the Government of Punjab under the supervision of Department of Soil and Water Engineering, Punjab Agricultural University, Ludhiana. The Department of Irrigation, Punjab has installed 450 km of link drains to clear off the surface impounding

Table 8. Variation of sodium adsorption ratio $(Me/l)^{1/2}$ under different drain spacings in different years

Lateral spacing (m)	Soil depth (cm)	Initial value June 1995	October 1995	April 1996	October 1996	April 1997
40	0–15	58.8	19.65	20.77	18.55	2.52
	15–30	34.55	21.97	23.13	20.55	3.32
	30–60	28.50	22.36	24017	21.17	3.47
	60–90	19.85	22.36	25.18	22.18	2.43
	90–120	14.20	22.26	27.32	24.32	1.80
60	0–15	58.8	15.97	18.70	13.70	1.57
	15–30	34.55	16.47	20.25	14.25	1.07
	30–60	28.50	16.75	20.55	15.55	0.92
	60–90	19.85	16.80	21.43	15.78	1.00
	90–120	14.20	16.80	21.42	16.42	1.23
80	0–15	58.8	14.94	16.94	15.46	1.01
	15–30	34.55	16.75	18.75	15.75	0.65
	30–60	28.50	17.32	20.32	16.32	1.17
	60–90	19.85	17.57	22.57	16.59	1.76
	90–120	14.20	17.81	23.81	17.99	2.30

Table 9. Change in chemical properties of leachate under different drain spacings for the period of four years

Lateral spacing (m)	Chemical properties	After 1st year (1994–95)	After 2nd year (1995–96)	After 3rd year (1996–97)	After 4th year (1997–98)
40	Electrical conductivity (dS/m)	4.34	1.25	0.56	0.27
60		3.87	0.95	0.64	0.26
80		3.17	0.87	0.59	0.25
40	Sodium adsorption ratio $(Me/l)^{1/2}$	11.00	6.75	4.51	1.06
60		12.00	7.25	3.39	0.99
80		11.42	6.60	3.06	0.95

Table 10. Effect of different water table depths on grain yield (wheat and paddy)

Water table depth (m)	Grain yield (tonne/ha) Wheat (1998)	Paddy (1998)
D 1.0	3.36	3.88
D 1.3	3.93	4.72
D 1.5	3.89	4.67
D 1.8	3.89	4.68

resulting from subsurface waterlogging. Drainage investigation for hydraulic conductivity, soil profile analysis, groundwater quality, etc. were carried out at four villages of the Muktsar district. The drain spacing for these areas were computed using modified Glover–Dumm equation, as less than 30 m, but it was not economically viable. SSDS for Jamuana village for different subareas was redesigned and installed at 30 m drain spacing and 1.75 m drain depth with 3 mm per day specific discharge. A layout plan was designed for 160 ha waterlogged area and accordingly SSDS was laid out in Jamuana village using a drain laying machine. Different lengths and sizes of laterals and collectors installed at certain slopes are presented in Table 11. The water through the drainage network was brought to a sump in each block and pumped into the nearby natural drain.

Summary and conclusion

Various drainage technologies, viz. multiple well-point system, conjunctive use of CW and poor quality groundwater, biodrainage system and SSDS have been described which have great potential for reclamation of waterlogged sodic saline and nonsaline soils. These have been developed and demonstrated in the Golewala Watershed of southwestern Punjab which faced severe waterlogging and sodicity problems. The multiple well-point system could be used for the control of groundwater table and consequently in the drainage of waterlogged lands. The four well-point system spaced at 6 m apart was economically viable and the same was recommended to the small holdings farmers. The cyclic use of CW and TW improved the soil quality and lowered the groundwater table. Alternative use of 2CW and 1TW was recommended for paddy and wheat crop rotation for better crop yield. Woody tree species like eucalyptus was recommended in waterlogged sodic soils where water table is at the surface. Ridges were constructed and polythene sheet of 1.5 m width and 50 micron thickness was spread

Table 11. Details of collectors and laterals in different blocks of Jamuana village

		Collector			Lateral (100 mm)	
Drainage block	Area (ha)	Length (m)	Size (mm)	Slope (%)	Length (m)	Slope (%)
J-1	55.00	700	300	0.07	12,000	0.1
		721	200			
J-2	37.00	400	300	0.07	11,400	0.1
		500	200			
J-3	36.00	165	300	0.1	8,888	0.1
		772	200			
J-4	24.29	90	300	0.1	6,931	0.1
		437	200			

on the ridge. The SSDS installed at 1.75 m drain depth, maintaining water table at 1.2 m below the ground surface is economically viable, in which salts are manageable and crop yield improved. The mechanized SSDS has been designed and installed in 160 ha area of the Jamuana village in Muktsar. The farmers of this region have adopted these techniques in a big way resulting in complete disappearance of waterlogging and salt problems. The aforesaid various drainage technologies are the long-term solutions for drainage problems in the region.

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