PERFORMANCE EVALUATION OF SUBSURFACE DRAINAGE SYSTEM IN AGRICULTURAL RESEARCH STATION MALNOOR UNDER UPPER KRISHNA COMMAND

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PERFORMANCE EVALUATION OF SUBSURFACE DRAINAGE SYSTEM IN AGRICULTURAL RESEARCH STATION MALNOOR UNDER UPPER KRISHNA COMMAND

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CERTIFICATE

This is to certify that the thesis entitled **“PERFORMANCE EVALUATION OF SUBSURFACE DRAINAGE SYSTEM IN AGRICULTURAL RESEARCH STATION MALNOOR UNDER UPPER KRISHNA COMMAND”** submitted by **RAHUL PATIL** for the degree of **MASTER OF TECHNOLOGY (AGRICULTURAL ENGINEERING) in SOIL AND WATER ENGINEERING** to the University of Agricultural Sciences, Raichur, is a record of research work carried out by him during the period of his study in this University, under my guidance and supervision, and the thesis has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar titles.

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Affectionately Dedicated

To

My Beloved Parents

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LIST OF ABBREVATIONS

ARS	-	Agricultural Research Station
AM	-	Arithmetic mean
bgl	-	Below ground level
BCR	-	Benefit-cost ratio
CADA	-	Command Area Development Authority
cm	-	Centimetre
cm yr^{-1}	-	Centimere per year
C_t	-	Net cash inflow during the period ‘t’, Rs.
C_o	-	Total initial investment costs, Rs.
Dia	-	Diameter
D	-	Depth to impervious layer
dS m^{-1}	-	Deci Siemen per metre
ESP	-	Exchangeable sodium percentage
ECe	-	Electrical conductivity
Eq.	-	Equation
et al.	-	and others
E	-	East
FAO	-	Food and Agriculture Organization
Fig.	-	Figure
FYM	-	Farm yard manure
GM	-	Geometric mean
GDP	-	Gross Domestic Product
GPS	-	Global Positioning System
G	-	Gram
h	-	Hour
h_t	-	Height of water column in the hole at time ‘t’, cm
h_o	-	Height of water column at time ‘t_o’, cm
ha	-	Hectare
h’	-	Available hydraulic head, m
h	-	Elevation of the water table midway between drains, m
h_e	-	entrance head, m
i.e.	-	that is
IRR	-	Internal rate of return
km	-	Kilometre

kg ha^{-1}	-	Kilogram per hectare
K	-	Hydraulic conductivity
K_a	-	Hydraulic conductivity above drain level
K_b	-	Hydraulic conductivity below drain level
L	-	Lateral spacing, m
ml	-	Millilitre
mm d^{-1}	-	Millimetre per day
meq l^{-1}	-	Milliequivalent per litre
m	-	Metre
m^2	-	Square metre
M ha	-	Million hectare
m d^{-1}	-	Metre per day
mm	-	Millimetre
N	-	North
No.	-	Number
NPV	-	Net present value
NLBC	-	Narayanpur Left Bank Canal
ppm	-	Parts per million
pHs	-	Soil reaction
PVC	-	Poly vinyl chloride
q ha^{-1}	-	Quintal per hectare
q	-	Drain discharge
q_w	-	weighted average drain discharge, mm d^{-1}
q_i	-	drain discharge, mm d^{-1}
r	-	Discount rate, per cent
Rs ha^{-1}	-	Rupees per hectare
RSC	-	Residual sodium percentage
SE	-	Standard error
SAR	-	Sodium adsorption ratio
SSD	-	Subsurface drainage
SE	-	Standard Error
t	-	Tonne
t_p	-	Number of time periods
UKP	-	Upper Krishna Project
viz.	-	namely
%	-	Per cent
^{o}C	-	Degree Celsius

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I. INTRODUCTION

Agriculture plays a vital role in the Indian economy with its large resources of land, water and sunshine. Despite the focus on industrialisation, agriculture remains a dominant sector of the Indian economy both in terms of contribution to gross domestic product (GDP) as well as a source of employment to millions across the country. The Indian agriculture sector accounted for 13.7 per cent of India's gross domestic product and employed just a little less than 60 per cent of the country's workforce in 2013. Over 70 per cent of the rural households depend on agriculture as their principle means of livelihood. Agriculture, along with fisheries and forestry, accounts for one-third of the nation's GDP and is its single largest contributor.

The statement "Agriculture Sustains Life, but Irrigation Sustains Agriculture" is true for India. One of the major factors that have greatly contributed to Green Revolution was the development of irrigation in the country. The spectacular development of irrigation since independence in India is unparalleled in the world; which has greatly boosted the agricultural production. Irrigation development in India, with a mere 22.7 M ha during 1950 has gone up to 114.8 M ha at present. However, the same attention has not been given to land drainage to create conductive atmosphere to the crop growth. As a result, the impact of irrigation over decades due to the absence of appropriate drainage measures and unscientific land and water management practices over the years have led to groundwater table rise to nearby or at root zone. This in turn has caused development of twin menacing problems of waterlogging and salinity in irrigation commands with variable intensity.

1.1 Problems of Waterlogging and Salinity

The problems of waterlogging and salinity are common world over. According to the FAO Land and Plant Nutrition Management Service, a significant proportion of cultivated land is salt-affected globally. Of the current 230 M ha of irrigated land, 45 M ha is waterlogged and salt-affected (19.5%) and of the 1,500 M ha under dryland agriculture, 32 M ha is salt-affected. These problems result in a monetary loss of about US $ 27.3 billion per annum and also about 1.85 M ha is being threatened by these problems every year. It is estimated that up to 20 per cent of irrigated land in the world is affected by different levels of salinity and sodium content (Fard *et al.*, 2007). In India about 12 M ha of land area is affected by waterlogging and soil salinity from Kashmir to Kanyakumari and from east to west. The area under waterlogging and soil salinization is increasing at the rate of 3,000 ha per annum in the country.

Waterlogging and salinity processes can be either natural or imposed by human activities. The excess water resulting from over irrigation of lands, seepage from canals and surrounding upper reaches as well as high intensity rainfall events cause either stagnation of water on the land surface or groundwater rise. The water table rise also brings up salts with it from subsurface thereby rendering salinity in the root zone. The advent of irrigation in command areas in the absence of adequate drainage facilities and lack of integrated land development and scientific practices of irrigation leads to water table build up and in turn causes secondary salinization. Due to waterlogging and subsequent development of salinity or sodicity depending upon the nature of salts, the fertile productive land is gradually becoming unproductive and is abandoned when the problems become severe. Also, the development of salinity in lands over time usually arises from irrigation in areas of arid and semi-arid conditions with low rainfall, capillary rise of water and high evaporation (Kapourechal *et al*., 2013).

The waterlogging lowers the rate of photosynthesis, transpiration and stomatal conductance and therefore the decline in crop yield (Lu, 1994). The water table depth <1 m has significant effect on yield of almost all the crops with the exception of rice. Moreover, the combined effect of waterlogging and salinity is found more harmful to crop yield than the individual effect of waterlogging (Kahlown *et al*., 2002). These problems have become a major limiting factor for agricultural crop production (Kapourechal *et al*., 2013). They not only threaten the sustainability of irrigated agriculture and capital investment in irrigation sector, but also have created the problems of environment (Balakrishnan *et al*., 2001).

If the natural drainage is insufficient to remove excess water and salts away from an affected area, it is necessary to install artificial drainage system for disposal of excess water and leaching of salts. Drainage system consists of surface or subsurface drains or combination of both and addition of amendments like gypsum in case of sodic soils for reclamation of waterlogged and salt-affected lands. Open surface drainage is useful in draining off excessive surface ponding of water whereas, subsurface drainage is required for lowering of water table and also removal of excess salts from the root zone and out of the fields through outlet into natural water courses. Surface drain is also useful in reducing the excess water load on the subsurface drainage system. Subsurface drains may consist of horizontal perforated and corrugated PVC pipe drains or vertical well drains or depending on the local soil / geological conditions or deep open drains.

Adoption of subsurface drainage technology is probably one of the best ways to increase resource use efficiency in order to increase crop production and sustain natural resources like soil and water in severely waterlogged saline soils (Babu *et al*., 2008). Drainage maintains the productive capacity of soil by removing excess water, improving the soil moisture, air circulation, reducing salt content and erosion (Chahar and Vadodaria, 2008). The seepage water that originates from the canal and reaches low-lying areas could be cut-off through interceptor drains to reduce waterlogging and soil salinization in the low-lying areas (Schmid and Luthin, 1964; Donnan, 1969 and Conachar *et al*. 1983). In conditions of soil salinity, the necessary steps are conducting leaching practices and installing a desirable drainage system (Kapourechal *et al*., 2013).

The FAO estimated that current drainage improvement programmes cover less than 0.5 M ha per year and therefore, insufficient to balance the current growth of affected drainage areas. They estimated that 10-20 per cent of the irrigated land is already equipped with drainage, 20-40 per cent of the irrigated area is not in need of any artificial drainage, while 40-60 per cent is in need of drainage but remains without drainage facilities.

1.2 Nature and Scope of the Present Investigation

The state of Karnataka is no exception to the phenomena of waterlogging and salinity as the command areas of its many irrigation projects are suffering from these problems. According to guesstimates about 4 lakh ha has been affected by waterlogging and salinity in the state. The Upper Krishna Project (UKP) is the most prestigious and an ongoing major irrigation project in the state, that aims to irrigate the chronically drought hit areas of Kalaburgi, Yadgir, Raichur, Koppal and Vijayapura districts in northern Karnataka. Under the UKP, the irrigation water was first let out in September, 1982 and about 6 lakh ha irrigation potential has been created till date. The project on its full development envisages bringing 1 M ha under irrigation. As the predominant soils of the UKP command areas are black soils (*vertisols*) with fine texture and poor water transmission properties, the problems of waterlogging and salinity are increasing at alarming rate. Groundwater monitoring in the command area showed that the water table was found to rise at an alarming rate of about 13 cm yr^{-1}.

A report of monitoring surveys revealed that the number of villages affected by waterlogging has been increasing over the years since the commencement of irrigation. No systematic surveys were carried out so far regarding the areas affected by the salinity and waterlogging problems. However, at present according to guesstimates about 50,000 ha have been affected by waterlogging and salinity problems in the UKP command area (Balakrishnan, 1998). Only surface drains were provided in the command by the UKP Command Area Development Authority (CADA) and sporadic attempts were made in respect of subsurface drains (SSDs) for land reclamation work.

Realizing the importance of tackling these problems, the University of Agricultural Sciences, Dharwad, Karnataka carried out an Indo-Dutch Network Operational Research Project on “Drainage and Water Management for Salinity Control in Canal Commands” of the UKP at the Agricultural Research Station, Bheemarayanagudi during 1995-2002. Systematic research studies were undertaken for diagnosis and quantification of waterlogging and salinity problems and developing methodologies for tackling the same. As a result of the studies, a package of drainage and water management practices was recommended for reclamation of waterlogged and salt-affected lands for adoption in the UKP command area. Despite these recommendations, large scale land reclamation works using the subsurface drains are not being taken up in the command area except in few areas. Because of the socio-economic dimensions associated with the farmers, contiguous and vastness of the problems of waterlogging and salinity in rendering the agricultural lands either under or unproductive, the state Government needs to take up the reclamation works urgently on top priority in large areas.

Further, after execution of subsurface drainage works, proper monitoring of the water table, soil salinity, crop yield and cropping intensity, drain discharge *etc*. of the drains installed in the site in timely and consistent manner is of critical importance to check whether the actual functioning of the drainage system is in accordance with the adopted design criteria and material specifications. Due to installation of SSD system, the degraded lands would be reclaimed and restored to their original production capability. As a result, the crop productivity and production would increase leading to enhanced economical farm return, higher employment opportunities and more income to the farmers. This in turn would improve the economic status and standard of living of the farmers, rural development and therefore would lead to regional development. The site would also be a good demonstration area to the farmers of the region.

The Agricultural Research Station, Malnoor is one of the 12 Agricultural Research Stations coming under the jurisdiction of the newly established University of Agricultural Sciences Raichur, Karnataka during 2009. The types of soils found in the research station are shallow to medium deep black soils. The farm consists of a total area of about 165 ha and an extent of about 55 ha was affected by the problems of waterlogging and salinity leading to under productivity of crops. Therefore, the subsurface drains using PVC perforated and corrugated pipes were installed during 2014 summer for reclamation of 10.65 ha. These drains needed to be monitored for their performance and impact in the reclamation process of improvement in field conditions and crop yields. Hence, the present investigation was taken up with the following objectives:

1. To evaluate the performance of subsurface drains installed in the Agricultural Research Station Farm, Malnoor.
2. To monitor the impact of SSD system on soil properties, water table depth, crop area and crop yield improvement compared to pre-drainage conditions.
3. To study the economics of the subsurface drainage system.

II. REVIEW OF LITERATURE

The studies related to problems and properties of waterlogged saline soils, subsurface drainage for reclamation as well as the performance evaluation, drainage efficiency, effect of drainage on soil hydrologic, physico-chemical parameters, water table, cropping intensity and yield of crops are reviewed and presented in this Chapter.

2.1 Influence of Subsurface Drainage System on Water Table and Soil Salinity

Borin *et al.* (1997) carried out a survey in three regions of northeast Italy - Emilia Romagna, Veneto and Friu Venetia Giulia, to update the statistics of the use of pipe drainage and to assess its performance. It was observed that most of the pipe drainage systems were installed in heavy clay and their performance in terms of control of water table depth was satisfactory in all the cases. It was also observed that the crop yield was also higher as compared to the traditionally drained fields.

Ali *et al.* (2001) reported that soon after the completion of the high Aswan dam in 1970, one of the largest drainage programmes was started in Egypt. The effects of drainage on groundwater table and soil salinity were assessed and the impacts on yield and farm income were determined. The results showed that the drainage programme was an effective measure in controlling groundwater table and soil salinity and a highly profitable investment for both the national economy and farmers.

Tahir and Nasir (2008) conducted a field study at Shahbaz Ghari Pilot Project Area of Swabi SCARP Project, Pakistan to evaluate the effect of enhanced water allowance on the performance of tile drainage system from August to December, 2002. The data on average water table depth from 17 observation wells at site 1-A and from 25 observation wells at site 1-C were recorded weekly. The average water table depth from the ground surface at site 1-A ranged from 0.54 to 1.34 m and at 1-C it varied from 0.75 to 1.45 m during the study period. According to the farmers, salinity and waterlogging problems significantly declined after the increase in water allowance. It was concluded from the results that after increase in water allowance, the singular tile drainage system of Shahbaz Ghari Pilot Project area was found working well.

Jung *et al.* (2010) undertook an experiment at four poly drained paddy fields located at Oesan-ri, Buk-myeon and Changwon-si out in Korea on sloping paddy fields in alluvial soil to monitor on-farm water table fluctuations and to evaluate the effect of drainage in the soil and its relation to soybean yield. Four drainage methods namely open ditch, vinyl barrier, tile drainage and tube bundle were installed within 1 m position from the lower edge of the upper embankment of sloping alluvial paddy fields. The tile drainage method drained the field faster as compared to the other drainage methods. The results also revealed that the subsurface drainage system could increase crop yield and the overall economic productivity of the soil.

Kale (2012) performed a field experiment in Kesikkopru Basin with an altitude of 750 m above sea level, located in Central Anatolia of Turkey and the irrigated area from Kesikkopru Dam on the Red River is about 6,600 ha and the field experiment was conducted on 1,350 ha to determine the comparison of salt accumulation in soil profile and crop yields under drained and undrained conditions. To put forward drainage system impacts, soil salinity and relative crop yields for well drained conditions were compared to poorly drained conditions. Soil, crop and site parameters were obtained from coordinated 40 soil sampling locations where dry bean, winter wheat and fallow crop rotations were applied. The results of the study showed that water table decreased rapidly after installing proper drainage system. Salt reduction in soil profile occurred by 24.10, 37.90 and 14.40 per cent for wheat, bean and fallow locations respectively with adequate drainage conditions.

Abdullah *et al.* (2013) studied the hydrological effects of different drainage systems as a pilot study in 4.5 ha of paddy fields of Sari Agricultural Sciences and Natural Resources University located at Mazandaran province, Northern Iran, during two successive growing seasons of rice and canola from July 2011 to May 2012. Experimental treatments were: three conventional subsurface drainage systems including drainage system with drain depth of 0.90 m and drain spacing of 30 m ($D_{0.9L30}$), drain depth of 0.65 m and drain spacing of 30 m ($D_{0.65L30}$), and drain depth of 0.65 m and drain spacing of 15 m ($D_{0.65L15}$); a bi-level subsurface drainage system with drain spacing of 15 m and drain depths of 0.65 and 0.90 m as alternate depths (bi level), and surface drainage system (control). Water balance components were determined in both rice and canola crop seasons. Measurements of water table and discharge were done on daily basis. Shallow drains were more effective in controlling water table compared with deep drains so that, average of measured water table depths in the representative observation wells of $D_{0.9L30}$, Bilevel, $D_{0.65L30}$, and $D_{0.65L15}$ were 2.1, 15, 24.1, and32.4 cm, respectively. Also, values of SEW30 (sum of excess water) were 3461, 1498, 1038 and 450 cm for $D_{0.9L30}$, Bi-level, $D_{0.65L30}$ and $D_{0.65L15}$, respectively.

Ahmadi *et al.* (2013) took up a study by installing a singular subsurface drainage system consisting of three drain pipes with drain spacing of 20 m and drain depth of 1.5 m, in approximately one hectare field of Sari Agricultural Sciences and Natural Resources University, Northern Iran. They investigated on the effect of elimination of draw down flow to the drain pipe on the water table level and drain flow by placing a layer of plastic cover on sand envelop of middle drain pipe. They revealed that the average drainage discharge of no plastic drain (drain A) was more than that of the plastic cover drain (drain B) and the average depth of water table within the trench of drain A was 9.10 cm, which was more than the corresponding water table depth of drain B.

Raju *et al.* (2014) observed that after the advent of subsurface drainage system in Haryana state, average soil salinity decreased by 44 per cent, the groundwater table improved by 35 per cent and the benefit-cost ratio increased from 1.10 to 1.40.

2.2 Influence of Subsurface Drainage System on Soil Physico-Chemical and Hydrologic Parameters

Rogers and fouss (1989) employed finite-element solution technique to obtain values to compare equivalent hydraulic conductivity values estimated from subsurface flow to vertical (auger holes) and horizontal (subsurface drains and open trenches) drains in selected layers soil profiles under steady state saturated flow conditions. The equivalent K values for profiles with the more conductivity layer at the top of the profile tended to be smaller, while the same for profiles with a less conductivity layer in the upper part of the profile tended to be larger when derived from vertical drains than from horizontal drains, depending upon the conductivity of the individual layers and the assumptions made in modelling the horizontal drain. Thus, vertical drain should be used continuously when the soil profile had layers with significantly different conductivities.

Suryawanshi *et al.* (1991) investigated on subsurface drainage system covering an area of 2.50 ha with respect to water table fluctuations, hydraulic properties of soil, electrical conductivity and pH of soil water. A drain spacing of 50 m with a depth of 1.60 m was found to be effective in lowering the water table to the depth of 75 cm for most of the time. Basic infiltration rate and hydraulic conductivity improved from 3 mm h^{-1} and 0.320 m d^{-1} to 5 mm h^{-1} and 0.432 m d^{-1} respectively. It was also observed that there was significant change in EC and pH of soil.

Singh *et al.* (1994) carried out studies on drainage characteristics and performance of subsurface drainage system for Dabhou and Moraj valley sites in Gujarat. Their results indicated that root zone salinity of 14.8 dS m^{-1} in April, 1987 was reduced to 7.25 dS m^{-1} at the end of September, 1987. Also, drain water salinity also reduced and the highest yield of 4,000 kg ha^{-1} was achieved.

Rao *et al.* (1994) conducted an experiment at the fodder farm of the Central Institute for Research on Buffaloes in Rohatak district, Haryana state on 40 ha area laid with subsurface drains at 75 and 100 m spacings at a depth of 1.75 m on silty loam soil. The salinity in 30 cm surface layer reduced from 84.15 to 7 dS m^{-1} in two years time. The improvement with 100 m spacing plots was lesser than that of 75 m spacing.

Kelleners *et al.* (1996) carried out an experiment to study the effluent salinity of pipe drains in 225 ha drainage unit in the Fourth Drainage Project area, Punjab Province, Pakistan and for a pipe drained area of 0.80 ha (observation field) in Bahr Selia command area, Fayoum Depression, Egypt. The study area mainly consisted of loam to silty loamy soils and the Fayoum soils were mainly clay. It was observed that the salinity remained constant over a period of six years with its EC varying between 2.5 and 4 dS m^{-1}. Effluent salinity in Fayoum field, Egypt was found strongly correlated with irrigation application in the field. The salinity level varied from 3 dS m^{-1} shortly after irrigation to 14 dS m^{-1} just before the next application.

Rajkumar *et al.* (1998) monitored the subsurface drains on farmers' fields at four different locations in Tungabadra Project command area, Karnataka during 1988 to 1994. The lateral drains of the subsurface drainage were installed at a uniform spacing of 27 m at a depth of 0.90 m, while the collector drain was placed at 1.05 m depth. The results indicated that the subsurface drainage system reduced soil salinity which in turn increased the crop yield at all locations.

Balakrishnan *et al*. (2005) evaluated hydraulic conductivity (K) in black soils of Islampur - Devapur (J) villages, Gulbarga district in the Upper Krishna Project command (UKP) area, Karnataka. *In situ* measurements on grid basis in the Indo-Dutch Network Operational Research Project (ORP) area (180 ha) and aerial estimates using q-h relationships of pipe drains in Phase-I area (14.90 ha) of the above project were obtained and compared. The results revealed that the areal K values were observed to be much greater than that of the point measurements, which also explained the reasons for higher drain discharges in and around the study area. Further, the areal estimates were found to give realistic results in the design of subsurface drain spacing.

Shirahatti *et al.* (2005) performed studies on hydraulic conductivity in SSD laid out area at Islampur-Devapur (J) villages, Gulbarga district in the UKP command area, Karnataka. *In-situ* K measurements on grid basis by post hole auger method in the Indo-Dutch ORP area (180 ha) varied from 0.004 to 0.559 m d^{-1} and followed the log normal distribution with the geometric mean (GM) of 0.07 m d^{-1}. For determining the dependable K value, the values were plotted on the normal and log normal probability papers and median values were also considered. It was found that straight line of the best-fit obtained with log normal distribution showed 0.077 m d^{-1}. The median value of K (0.083 m d^{-1}) was very close to this value. Therefore, it was concluded that though, log mean could be the more reliable value but median value might be quickly obtained and it was almost nearer to the log mean value. Hence, the median value of K might be considered for the designing the subsurface drainage system.

Hebsur *et al.* (2006) undertook an experiment to study the effect of poor quality groundwater on the yield of maize and soil chemical properties at Nandagaon village of Mudhol taluk in Bagalkot district, Karnataka during *kharif* 2003-'04 and 2004-'05 with subsurface drainage as main plots and amendments as sub plots. The highest total dry matter yield at all the stages of crop growth and grain yield (66.09 q ha^{-1}), test weight (31.52 g) and number of grains per cob (629.89) were recorded in subsurface drainage plot compared to no drainage plots. The soil chemical parameters such as pH, water soluble Na^{+}, Ca^{++} and Mg^{++} and sodium adsorption ratio were reduced in subsurface drainage plots than no drainage plots.

Kamble *et al.* (2006) assessed the subsurface drainage system installed on-farm with corrugated perforated PVC pipes in 8.81 ha of salt-affected soils at Agricultural Research Station, Digraj, District Sangli, Maharashtra during December, 2002 to study its effect. The results revealed that the pH, ECe, SAR and ESP of soil in SSD with synthetic envelope, coarse sand filter and synthetic envelope plus coarse sand filter were decreased in monsoon and winter seasons but slightly increased during the summer season. This indicated that the improvement in salt-affected soils was due to subsurface drainage and gypsum application within a period of one year.

Abdulla *et al.* (2008) observed the variation of the saturated hydraulic conductivity (Ks) with time as a function of temperature at the University of Tehran, Iran. The results showed that the lowest values of K_s were obtained in the winter when the water, soil and air temperature were minimal and these values increased when the temperature increased.

2.3 Performance Evaluation of Subsurface Drainage Systems

Manjunath *et al.* (1998) studied vertical drainage system with laterals and without laterals in the farm of Agricultural research Station, Gangavati, Karnataka. They concluded that the performance of vertical drain with laterals was better than vertical drain without laterals. But for long gains, they reported that vertical drain without lateral was as effective as vertical drainage with laterals.

Singh *et al.* (1999) conducted a performance study of subsurface drainage in heavy textured layered soils of Mahi Right Bank Canal Command of Gujarat by modifying the drainage equation of de Zeeuw and Hellinga for layered soils. This predicted the water table fluctuations and drain discharge corresponding to irrigation or rainfall inputs taking into account the stratification of the soil profile. The equation was tested on the field data obtained from a pilot project of the study area. The study showed that the water table head was influenced by the location of interface between the soil layers and the predicted results confirmed with the field data.

Shrivastava *et al.* (2001) assessed the impact of subsurface drainage on the removal of salts from their study area of 188 ha block in Segwa drainage pilot area, Gujarat. Pre-drainage estimations were done to quantify the total salts deposited during 1996-'97. Later post-drainage estimation of salts left out during the year 1999-2000 was done based on field measurements. Equations on salt and water balance were formulated separately for pre- and post-drainage situations depending upon the available data. From the study, it was observed that during pre-drainage period about 7 t ha^{-1} of salts remained as balance, whereas during post-drainage period about 4.7 t ha^{-1} of salts remained as balance. Moreover, this was the condition when only 11 per cent of the pilot area was brought under drainage.

Dennis (2002) pointed out that many countries invest public funds in large-scale drainage projects to alleviate problems of waterlogging and salinization, and to enhance agricultural development. The estimated returns on those investments were substantial when crop yields were expected to increase significantly with drainage service. However, when the need for enhancing agricultural productivity included investments both in irrigation and drainage facilities and in politics that motivated improvement in water management. The policy implications that followed this perspective were described in empirical form for Egypt.

Rimidis and Dierickx (2003) evaluated the performance of subsurface drainage system by an experiment consisting of seven plots at Pikeliai, a village in the Kedainiai district, Lithuania. Various combinations of drainage materials were used to evaluate drainage performance, discharges and water heads on top of and midway between drains were measured during four consecutive seasons. Low rainfall during the second and third seasons resulted in small discharges and low groundwater tables compared to the first and fourth seasons. Second degree polynomial similar to Hooghoudt's equation was used to express the relationship between hydraulic head loss and discharge for each of the plots during each season. Comparison of the data for the four measuring seasons clearly showed completely different equations for the low rainfall second and third-year observations. Although applicable within the measured range, extrapolation with the equations beyond the measuring range was less accurate. The results clearly illustrated that the original design criteria were not satisfied and that the drains might be too widely spaced in all the plots.

Srikanth *et al*. (2004) observed the effect of the subsurface drainage in reclaiming the waterlogged and saline black soils in the UKP command area of Karnataka using salt and water balance approach. The study revealed that from the influence area of a selected lateral, 321 and 634 mm of quantities of water were drained off from the soil profile in the form of runoff, evapotranspiration and drain discharge during *kharif* and *rabi* seasons respectively. Further, the amounts of salt removed from the area were 0.98 and 1.09 t, respectively in these two seasons.

Manjunatha *et al.* (2004) took up a study on subsurface drainage system in reclamation of waterlogged saline land in Virupapur village, Sindhanur taluk, Karnataka. The studies revealed that with the introduction of SSD, the water table lowered, electric conductivity (EC) of the soil decreased, crop yield and cropping intensity increased in the drained area.

Pradeep *et al.* (2005) carried out experiment on subsurface drainage and no drainage in Mudhol Taluk of Bagalkot District. They reported that physical properties like per cent aggregate stability indices, infiltration rate, and porosity were higher and chemical properties such as pH, EC and ESP values in soil after harvest of maize were lower in subsurface drainage plot when compared to control.

Pradeep *et al.* (2005a) conducted a field experiment using poor quality ground waters at Nandagaon village of Mudhol taluk in Bagalkot district during *kharif* 2003 to study the effect of subsurface drainage and amendments on osmotic potential and uptake nutrients by maize. Osmotic potential in maize leaves was lower in subsurface drainage plots than no drainage plots. The uptake of nutrients such as N, P, K, Ca and Mg was significantly higher in subsurface drainage plots than no drainage plots.

Chinnappa *et al.* (2006) performed a study on equity issues concerning soil degradation and reclamation in Tungabhadra (TBP) command area of Karnataka. The results revealed that small and marginal formers were the worst affected by soil degradation as they did not have alternative source of livelihood. Further, the reclamation programmes launched by the government were found to have a positive impact on the income distribution during the post land reclamation.

Hornbuckle *et al.* (2007) undertook an experiment in New South Wales, Australia to compare traditional single level drainage system and multi-level drainage system in the irrigated field setting. The single level drainage system consisted of 1.8 m deep drains at 20 m spacing. The multi-level drainage system consisted of shallow closely spaced drains (3.3 m spacing at 0.75 m depth) underlain by deeper widely spaced drains (20 m spacing at 1.8 m depth). Comparisons of water and solute movement between the multi-level drainage system and single level drainage system were made. Differences between them were found in the water table regime, drain water salinity and soil salinity.

Ritzema *et al.* (2008) reviewed the subsurface drainage systems installed by the Indo-Dutch Network Operational Project at Karnataka, Rajasthan, Andhra Pradesh, Gujarat and Haryana and the results indicated that crop yield in the drained fields increased by 69, 64, 54 and 136 per cent in rice, cotton, sugarcane and wheat respectively. Further, the economic analysis revealed that subsurface drainage system was highly cost-effective.

Naseri and Arvahi (2009) assessed the performance of subsurface drainage system in date palm gardens of Abadan. Four cases of drain envelopes including local gravel, standard gravel, and synthetic envelopes (polypropylene 700 and polypropylene 450) were employed and a comparison with the traditional drainage (tile) made. To achieve the purpose, 16 laterals (subsurface drains) installed in a 12 ha area of date palm gardens in Irrigation and Drainage Project of Abadan Subsurface Drainage systems were used. Methods that presented better performance of controlling water table and salts in soil profile in comparison with the traditional drainage (tile) were finally determined.

Jadho *et al.* (2009) carried out an experiment on subsurface drainage of salt-affected area over 8.1 ha during 2001-'02 in Mahatma Phule *Krishi Vidhyapeeth*, Rahuri, Maharastra. They collected soil samples and analysed them for different soil salinity parameters *viz*., pHs, ECe, Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Cl^{-}, CO_3^{-2}, HCO_3^{-} and SO_4^{-2} with respect to drain spacing and depth. By these they concluded that the 15 m drain spacing with 120 cm drain depth was found better in improving the soil properties.

Azhar and Latif (2011) carried out studies during 2001-'04 in which four subsurface drainage projects *viz.*, Mardan SCARP Project (MSP), Fourth Drainage Project, Faisalabad (FDP), Chashma Command Area Development Project (CCADP) and Mirpurkhas Tile Drainage Project (MTDP) were assessed for their impact on crop yield in irrigated areas of Pakistan. Quantitative comparison made on the change in pre- and post-project conditions revealed that crop yield significantly improved due to project implementation at all sites. The yield increased from 13 to 94 per cent for most crops. The exception was rice, where it decreased by 23 per cent at MTDP due to shortage of irrigation supplies. Maximum yield increase was observed in CCADP for cotton (80%), sugarcane (94%), and wheat (67%) and at MSP for rice (46%). For chilli the maximum increase (147%) was observed at MTDP study site. Overall quantitative comparison indicated a positive impact of drainage system installation in terms of crop yield improvement.

Rohitashw *et al.* (2013) made a study of the performance and evaluation of subsurface drainage system on the basis of drain spacing equations for disposal of effluent and hydraulic characteristics of envelope materials, like entrance resistance created by envelope and hydraulic conductivity in North Western Rajasthan, India. Three important synthetic envelopes, HG 22, SAPP 240 and CAN 2 were tested in laboratory using sand tank model and permeability apparatus to compare their performances in terms of entrance resistance and hydraulic conductivity of soil envelope system. The hydraulic conductivity for SAPP 240 filter was found the highest and entrance resistance the lowest. Performance of four unsteady state drain spacing equations *viz*., Glover-Dumm, Van Schilfgaarde, Integrated Hooghoudt and Modified Glover equations were also tested to evaluate disposal efficiency of excess water. The percentage deviations between predicted drain spacing and actual spacing were -33.31 to -31.55 per cent, 9.40 to 17.07 per cent, 11.84 to 20.83 per cent and 6.10 to 14.62 per cent for the above equations, respectively. Modified Glover equation showed minimum deviation from actual drain spacing due to its versatile applicability. Therefore, the Modified

Glover equation with SAPP 240 filter was recommended for subsurface drainage system in sandy soil texture areas.

2.4 Influence of Subsurface Drains on Crop Yield and Economics

Madani and Breston (1995) studied the performance of subsurface drainage system for drain spacings of 3, 6 and 12 m on slowly permeable soils in Nova Scotia. Daily discharge per ha from 3 m spacing treatment was 2.5 to 5 times and from 6 m spacing was 2 times that of the 12 m spacing treatment outflow. Water table height midway between the drains averaged 100 mm lower on 3 m spacing plots. Further, they observed that there was no significant improvement in crop yields with narrow drain spacing when compared to the conventional 12 m spacings.

Balakrishnan *et al.* (1996) carried out a study on reclamation of waterlogged and salt-affected soils at Islampur in UKP command area in Karnataka through a combination of open and SSDs. The spacing of subsurface drains ranged from 20-60 m depending on the severity of problems with a depth of 1-1.2 m. As a result, the cropping intensity increased from 42 to 138 per cent and the yield of various crops improved by 46 to 525 per cent and became consistent.

Singh and Gautam (1996) investigated on crop yield performance under various drain envelopes and unsteady state drain spacings in Chambal command area, Rajasthan. Maximum grain yield of wheat (4.79 t ha^{-1}) was obtained under 15 m drain spacing for the drains installed at 1 m depth. There was significant difference in yield between drain spacings of 15 and 60 m. To assess the envelope performance, the weight of sediment deposited per metre length of drain was determined for geo-textile envelope, gravel and no envelope cases. It was noticed that drains without envelope material performed better compared to others.

Finney (1997) reported that lowering water table by installing subsurface drainage in irrigation schemes could increase cropped area, crop yield and obtain more profitable cropping patterns. The analysis of limited available data from Pakistan, Egypt and USA indicated that crop yield increased from 25 to 43 per cent for cotton and maize, 11 to 25 per cent for wheat and 43 to 100 per cent for citrus.

Lal and Fausey (1998) examined the effect of subsurface drainage system on crop response and soil properties of alkaline bed clayey soil in Northwest Ohio, USA. The results indicated that maize grain yield was significantly affected by drainage treatment, with the lowest yield of 8.7 t ha^{-1} for gravel back fill and highest of 9.5 t ha^{-1} for tile control. Soil samples from 0 to 50 cm depth indicated significant effect of drainage treatment on K and cations exchange capacity and also cropping system had significant effect on soil pH and Ca.

Patra *et al.* (2000) conducted field trials during *rabi* seasons of 1997-’98 and 1998-’99 in the flood prone areas of Dankuni basin of Hooghly river. It is one of the large drainage basins of West Bengal and is located between 22°39'32" to 23°01 '20" N latitude and 87°30'20" to 88°30'15" E longitude to investigate the techno-economic feasibility of subsurface tile drainage on four important crops. The study revealed that with the adoption of drainage measures, the economic yield of crop was increased by 79.20 per cent for mustard, 111.90 per cent for pea, 74.70 per cent for okra and 115.70 per cent for wheat, respectively as compared with control. The average gross and net returns and benefit-cost ratio were also higher in case of adoption of drainage measures indicating its feasibility in this situation. There was a considerable loss of plant nutrients in the form of organic matter, available P and K through drainage water and therefore needed their application regularly.

Datta *et al.* (2000) studied on the techno economic feasibility of subsurface drainage system at Haryana State. The results revealed that, after the installation of drainage system, land use was intensified and a sizeable area of formerly fallow land was brought under cultivation. They also reported that the cropping pattern changed in favour of more remunerative crops and crop yield increased.

Chan and Cheong (2001) undertook studies on subsurface drainage on sandy clay loam soil in MARDI (Malaysian Agricultural Research and Development Institute), Seberang Perai Research Station, Malaysia from 1995 to 2000. The subsurface drains were installed at a constant depth of 45 cm. The results showed that average yields obtained under subsurface drainage systems were noticeably higher when compared with harvest from fields without such drainage facility irrespective of the season.

Rajkumar *et al.* (2001) evaluated the performance of subsurface drainage system installed on farmers’ fields at four different locations *viz*., Vaddarhatti, Gundur, Siddapur, and Gangavati, Karnataka. The results showed that the subsurface drainage had positive effect on soil physic-chemical properties, hydrologic parameters and crop yield.

Mathew *et al.* (2001) installed the subsurface drainage system at Kuttanad, the low laying tract in Kerala state of south-west India with two different spacings at 15 and 30 m for evaluating its influence on improving soil quality and crop production. The results indicated that drain spacing up to 30 m was found to significantly improve the productivity of area.

Srinivasulu *et al.* (2005) experimented on working of subsurface pipe and open drainage systems at Konanki pilot area in Nagarjuna Sagar Project Right Canal command in Andhra Pradesh. Two types of envelope materials, nylon mesh and geo-textile were used and two spacings of 30 m (design spacing) and 60 m (double the design spacing) were adopted for the pipe drainage system. The analysis of discharge data from the individual pipe drains revealed that among both the spacings, the drains enveloped with geo-textile performed better (0.45–1.85 mm d^{-1}), when compared with those enveloped with nylon mesh (0.25–0.86 mm d^{-1}). Total magnitudes of 50.40 and 115.60 t of salts were disposed through pipe and open drainage systems, respectively during the period of 3 years.

Srinivasulu *et al.* (2006) attempted performance evaluation of drainage systems at Uppugunduru pilot area in Krishna Western Delta (KWD) in South India. Ten pipe drains were laid at three different spacings of 30, 45 (design) and 60 m using two types of synthetic envelope materials, namely nylon mesh and geo-textile. Six open drains were laid at 50 m spacing. Monitoring of the performance of drainage systems from 1999-’00 to 2001-’02 indicated that the average discharge from the pipe drains laid at 30 m spacing was the highest in all the years when compared to the pipe drains laid at 45 and 60 m spacing. They also found that the water table lowered by 0.25 to 0.40 m below the ground surface because of drainage systems and a total of 765.13 t of salts was disposed through the drainage systems during the period of three years.

Shekhawat (2007) evaluated the cost effectiveness of subsurface drainage installed at Indra Gandhi Nahar Priyojna (IGNP) command area, Rajasthan and the results revealed that net return value was found to be Rs. 34,275 per ha, over cost of installation Rs. 23,767 per ha, whereas B:C ratio was found to be 2.44. Thus, it was concluded that installation of SSD clearly well established the financial feasibility of the project at IGNP command area.

Babu *et al.* (2008) performed an experiment in the farmers fields of drainage pilot area located in Pathareddy Palem village under Mutluru Channel command of Krishna Western Delta, Guntur District, Andhra Pradesh to evaluate the performance of open subsurface drainage system (OSSD) for improving the yield of rice under saline and waterlogged conditions for three consecutive seasons starting from *kharif*, 2005. The grain yield increased from 2.20 to 4.90 t ha^{-1} over a period of four years indicating an overall increase of 123 per cent due to installation of OSSD.

Jung *et al.* (2010) took up study on the effect of drainage in the soil and its relation to soybean yield by four drainage methods namely open ditch, vinyl barrier, tail drainage and tube bundle at Oesan-ribuk-myeon, Korea, and they concluded that the tile drainage method drained fields faster compared to the other drainage methods. The results also revealed that the subsurface drainage system could increase crop yield and overall economic productivity of soil.

Padalkar *et al*. (2012) implemented drainage system in some parts of Western Maharashtra, where soil salinity was creating various problems such as loss in productivity, increased cost of cultivation and thus food security problems. It was necessary to find out practical solutions to overcome these problems. Subsurface drainage treatment was one of the recommended treatments for soil salinity reclamation. In the present study, subsurface drainage was carried out in the salt-affected area for 5 months. The irrigation water analysis and soil analysis were carried out before and after the subsurface treatment in the field. It was found that the treatment was effective for saline soil reclamation with certain conditions

Abdullah and Shahnazari (2014) explored by an experiment the effect of surface and subsurface drainage system on the productivity of paddy yield at Sari Agricultural Science and Natural Resource University, Iran. The results showed that rice yields of subsurface drainage were 1.22-1.66 and 1.32-1.70 times higher than that of the surface drained area during 2011 and 2012.

2.5 Concluding Remarks

The problems of waterlogging and salinity are global problems and they occur under varied climatic conditions resulting in land degradation and causing reduction of crop yields and even abandonment of agricultural lands in severe cases. Wherever appropriate scientific irrigation practices and drainage measures were not taken in command areas of irrigation projects, soil pH, EC and ESP were observed to increase and in the process soils became saline and later got converted from saline to sodic soils. Equity issues concerning soil degradation revealed that small and marginal formers were the worst affected by the problems of waterlogging and salinity as they did not have alternative source of livelihood. However, the reclamation programmes launched by the government were found to have a positive impact on the income distribution during the post land reclamation.

The research studies revealed that subsurface drains either deep open drains or tile / pipe drains with different types of filters or envelopes and amendments in case of sodic soils or vertical drains were adopted to lower the water table and leach away the excess salts from the crop root zone. These drains were useful in reclamation of waterlogged saline lands, by improvement in soil hydrologic, physico-chemical parameters of aggregate stability indices, porosity, hydraulic conductivity and infiltration and reduction in pH, EC, ESP, water soluble Na^+, Ca^{++} and Mg^{++} and sodium adsorption ratio. Osmotic potential was lower and the uptake of nutrients such as N, P, K, Ca and Mg was significantly higher in subsurface drainage plots compared to undrained areas. The areal K values obtained in subsurface drainage project sites were observed to be much greater than that of the point measurements, which explained the reasons for higher drain discharges in and around the study areas compared to that computed using point measurements of K. Thus, the areal estimates were found to give realistic results in the design of subsurface drain spacing.

Due to improvement in soil hydrologic, physico-chemical properties and lowering of water table, the crop growth conditions become highly favourable and conducive. The subsurface drains thereby were found to have resulted in increased cropping / irrigation intensity and enhanced crop yield, leading to higher gross and net farm returns and B:C ratio. The investment in subsurface drainage venture in reclamation of waterlogged and salt-affected lands proved to be cost-effective and profitable with acceptable payback periods. Overall, the technology of subsurface technology was found to be socially acceptable, technically feasible and economically viable. However, the negative aspect of subsurface drainage was considerable loss of irrigation water particularly in rice fields, plant nutrients in the form of organic matter, available P and K through drain discharge / leachate water and therefore they were needed to be applied regularly and poor quality leachate causing environmental problems to downstream area fauna and people. Further, the contiguous nature, magnitude and vastness of the problems of waterlogging and salinity in irrigation command areas considering the socio-economic dimensions mainly associated with majority of small and marginal farmers, demand the State and Central Governments come forward and jointly take up the land reclamation work on large scale and community basis.

III. MATERIAL AND METHODS

In the present study, investigation was carried out to evaluate the performance of subsurface drainage system laid out in the Agricultural Research Station (ARS) Farm, Malnoor in UKP command area. The materials and methods adopted in studying the performance of subsurface drainage system, monitoring and measurement of soil hydrologic, physico-chemical properties, quality and quantity of the leachate, crop yield improvement and economics of the drainage system are described in this Chapter.

3.1 General Description of Study Area

3.1.1 Location

The area selected for the present study comes under the command of Narayanapur Left Bank Canal (NLBC) of UKP and is located in the Agricultural Research Station (ARS) Farm, Malnoor of the University of Agricultural Sciences Raichur at a distance of about 7 km from Hunasagi in Shorapur taluk, Yadgir district, Karnataka. In and around the farm also, considerable area was affected by the problems of waterlogging and salinity. The total area of the farm is 160 ha, of which about 55 ha was afflicted by these problems. The study area of investigation was G-Block, which comprised of 10.65 ha and was one of the affected areas within the farm. During 2014, subsurface drains were laid out in the study area for reclamation of the affected lands. The study area is bounded by Talikot road on the southern side and a main nala on the northern side. One distributary runs nearby which serves the area for irrigation. The satellite image of the study area in ARS farm, Malnoor is shown in Fig. 3.1. The project area lies at 17^0 03’ N latitude and 76^0 15’ E longitude at an elevation of 460 m above the mean sea level.

3.1.2 Climate

The area is a part of semi-arid region characterized by mild winter, short monsoon and hot summer. The difference between the mean annual summer and the mean annual winter temperature is about 8.5 ºC. The mean annual temperature is 23.2 ºC. Summer season is very hot with temperatures rising to 42 ºC or more, whereas winter season (November to February) is relatively cool and dry. The hottest months are April and May, and December is the coldest month. The annual average rainfall of the nearest rain gauge station at Hunasagi is 547.1 mm, of which 340.6 mm occurs during June-September, which is 62.26 per cent of the average annual rainfall. The average number of rainy days in a year is 35. On an average daily

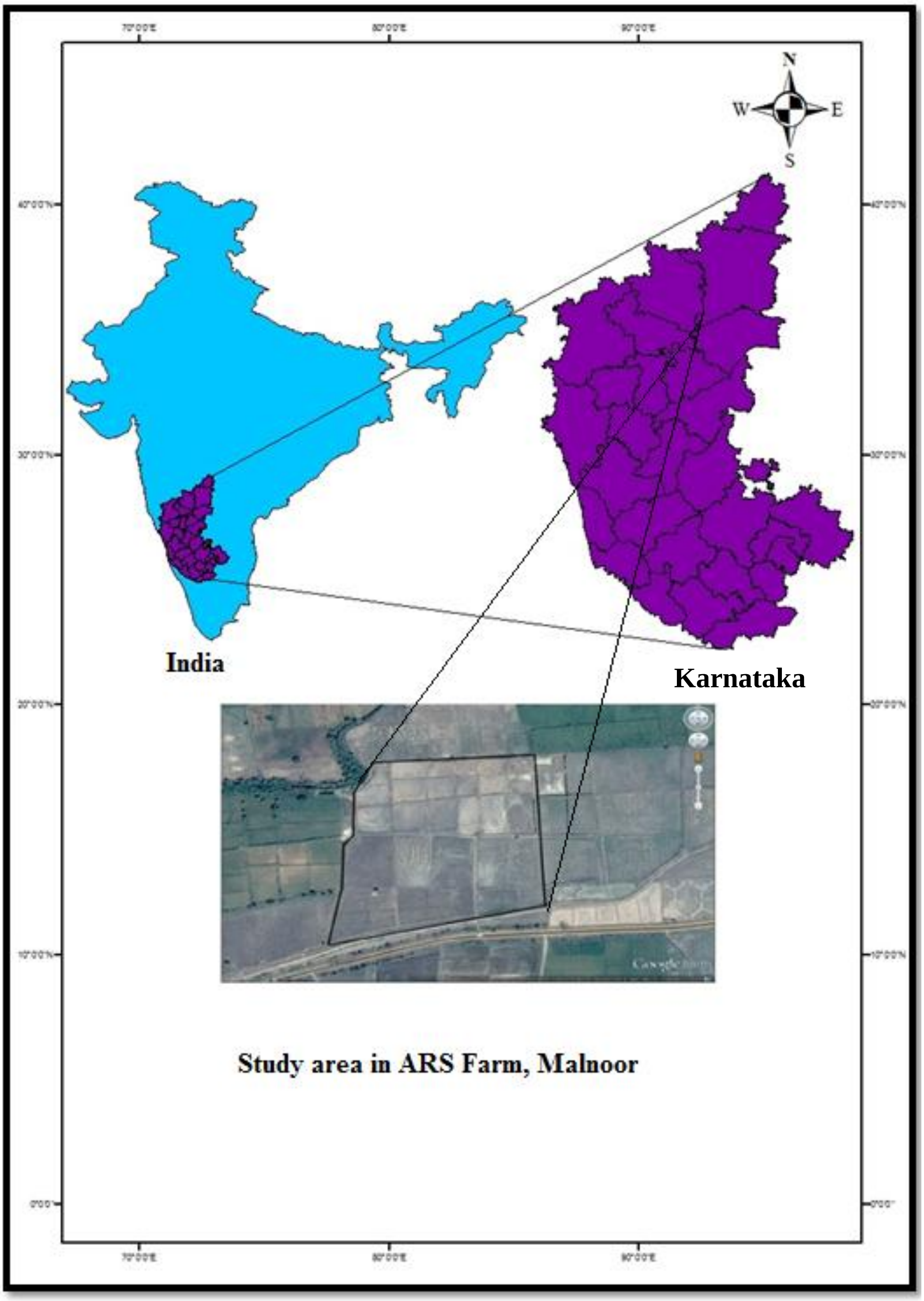

Fig. 3.1 Satellite image of the study area in ARS Farm, Malnoor under UAS Raichur in Upper Krishna Project command area, Karnataka

evaporation is about 6 mm. The monthly evaporation generally ranges from 180 to 300 mm and the maximum is attained during the peak summer. The rainfall data in the study area during 1991 to 2014 and during the period of investigation from September, 2014 to January, 2015 are presented in Appendix - I.

3.1.3 Soils and geology

The soils present in the study area are predominantly Vertisols shallow to medium black soils and the texture of top soil is sandy clay loam, while the lower soils are clay loam. The clay content of the soil generally ranged from 32 to 41 per cent (Table 3.1). The geology of the area consists of horizontally bedded limestone underlain by closepet and other granites.

Table 3.1 Particulars of soil texture at different depths in the study area

Soil depth, cm	Sand (%)	Silt (%)	Clay (%)	Textural class
0-30	46	22	32	Sandy clay loam
30-60	27	37	36	Clay loam
60-90	26	33	41	Clay loam

3.1.4 Experimental area and drainage layout

The study areas consisted of good lands in the beginning and accordingly yields from crops like cotton, wheat, sorghum and pulses *etc*. were obtained. Most of the times at least one crop in a year was assured under rainfed condition. After the advent of irrigation in mid 1980s for a couple of years farmers used to get good crops and later as time passed the twin menacing problems of waterlogging and salinity erupted in considerable portion of the farm due to unscientific practices of land and water and also seepage from canals or surrounding higher lands. In 1991, the University of Agricultural Sciences Dharwad had taken over the ARS farm, Malnoor. Only a portion of the farm was cultivated, while most of the farm land was kept fallow or unproductive, infested with typha grass and became inaccessible too. Because of these reasons, the area was not cultivated for a decade or so.

During 2009, ARS Farm, Malnoor was brought under the University of Agricultural Sciences, Raichur. Further, in 2012 the land was levelled and brought under cultivation. Due to excess of soil salinity and waterlogging, the yield obtained was quite low. Therefore, in order to tackle this problem, subsurface drains (SSDs) were installed in few blocks of the farm. The study area of 10.65 ha falls under G-Block and the drainage system was installed during 2014. The SSD consisted of composite system of subsurface drainage system layout with pipe laterals and pipe collector mains to lower the water table and to leach out the excess salts from the area. The drainage layout of study area at ARS farm, Malnoor is given in Fig. 3.2. The SSD system was laid out using PVC perforated and corrugated drain pipe laterals of 10 cm dia in herringbone type at 50 m spacing at a depth of 1 m and connected to the collector drain on either side. The collector mains consisting of blind PVC corrugated pipes of 12 cm dia were installed at a depth of 1.20 m. The overall SSD system in the study area (only cropped area was considered here) consisted of two collector drains, to each of which six laterals each were connected on either side of the drain with two inspection chambers (manholes). The particulars of length and area of influence of the drains were given in the Table 3.2. The present investigation was carried out to study the performance evaluation of subsurface drainage system and its impact on soil parameters, crop area and crop yield.

3.2 Materials Used and Methods Adopted for SSD Monitoring Evaluation Measurement and Analysis

3.2.1 Measurement of subsurface drain discharge

The drain discharges were monitored during September 2014 to January 2015 and during the remaining period there was no discharge as there were no crops. The drain discharge was collected at main drain outlets and also at the laterals from the inspection chambers weekly during the study period. The discharge from the SSDs was measured using a bucket, stop watch and a graduated cylinder on volume basis. Taking the area of influence of each drain, the drain discharge was converted and expressed in the form of mm d^{-1}. The drain discharge was presented weekly and monthly for the outlets and the laterals. The drain discharge was monitored, collected and measured in 2 main outlets and only 3 laterals which were connected to the manholes and located within the cropped area. Therefore, the each main drain discharge was the added discharges of all the respective laterals connected to it. weighted average was done considering entire area of influence. The sample calculation for computation of weighted average subsurface drain discharge is presented in Appendix - II.

3.2.2 Water table measurement for performance of SSD system

In order to assess the impact of the SSDs on water table, the water levels were monitored fortnightly in observation wells, which were installed in the study area at a distances of L/2 and 2L/3 along the laterals and in between laterals at a depth of about 1 m

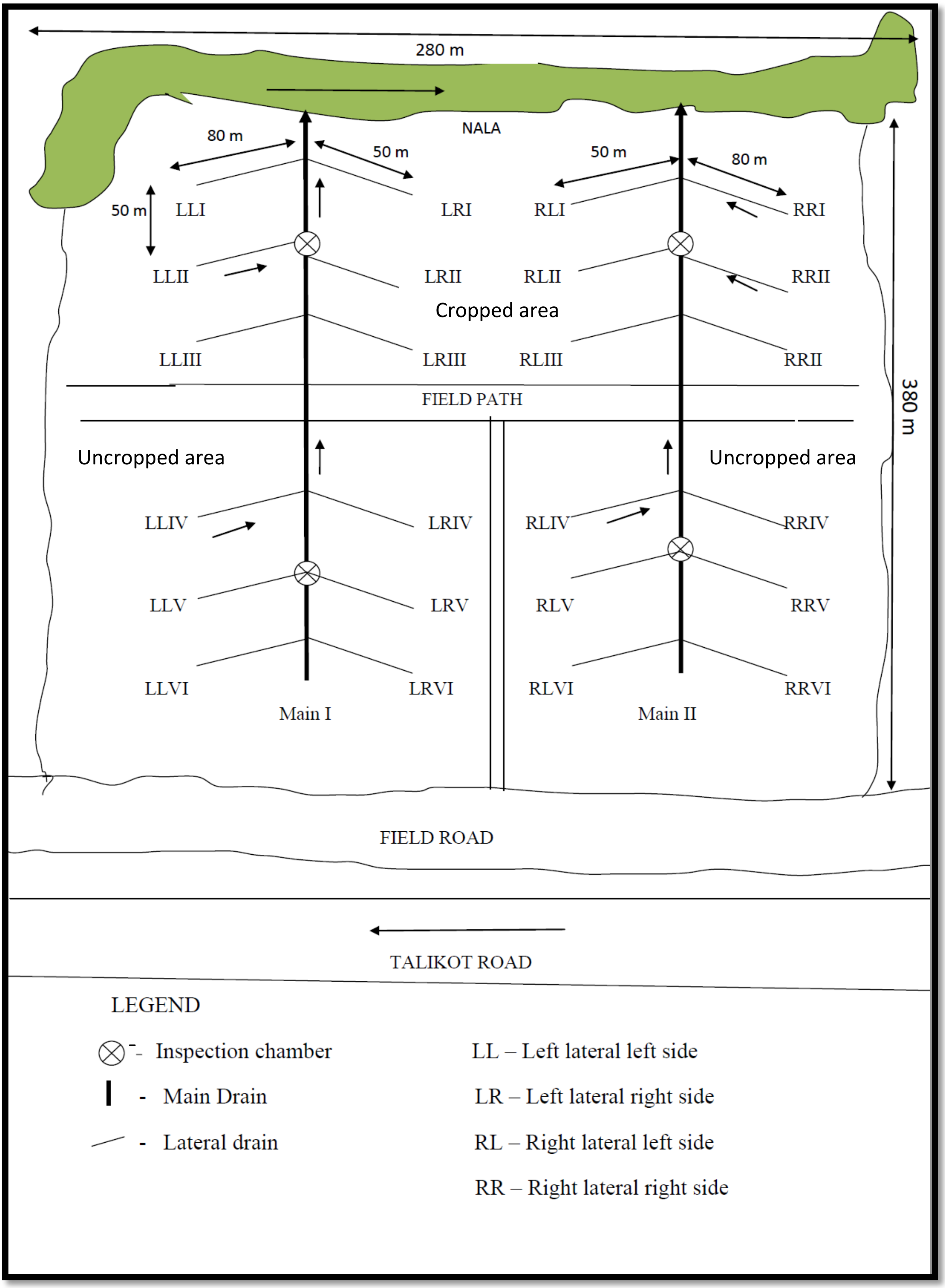

Fig. 3.2 Field layout of SSD system at study area in ARS, Malnoor

Table 3.2 Particulars of length and area of influence of subsurface drains in the study area

Subsurface drain	Total length, m	Overall area of influence, ha	Total length within the cropped area, m	Area of influence within the cropped area, ha
Main drain I	380	5.60	144	2.01
Main drain II	385	5.05	144	2.02

from the ground level. The PVC pipes of 50.8 mm (2”) dia with perforations at the lower portion of the pipes below the ground level from about 60 cm till their bottom and blind pipe till the ground surface were fitted with the cap at top were used as the observation wells for monitoring the groundwater table. A 10 cm dia soil augur was used for drilling the hole for installing the observation wells. The observation wells were made of PVC pipes of 5.08 cm dia with perforations of approximately 2 mm dia all over the pipe periphery at regular intervals except at top 60 cm were then lowered in to the augured hole and annual space of the pipe was filled with sand and gravel. The ground water levels were monitored fortnightly and measured using tape at the centre of the parallel drains at half and two third distances along the laterals.

3.2.3 Water table measurement for efficiency of SSD system

After installation of subsurface drainage system for evaluating proper functioning of the drainage system, drainage efficiency of the laterals (i.e. effectiveness of system in lowering of the water table) needs to be checked. To study the drainage efficiency of the system, series of observation wells were placed in between the pairs of representative laterals. In the spacing of 50 m between the laterals, the observation wells were installed at distances of 0, 12.5, 25, 37.5 and 50 m at L/2 (mid way between the lateral drains) position (Fig. 3.3). The water table fluctuations in these observation wells were monitored and measured along with the discharge measurements in the inspection chambers during the study period to find out the effectiveness in lowering of the water table between the laterals. The water level fluctuations obtained between the laterals were presented in tables and graphs.

3.2.4 Quality of groundwater and canal water

The groundwater samples were collected from the observation wells during September and December, 2014 and analysed for EC and pH. Similarly, the quality of canal irrigation water was also analysed during the same periods and compared with that of the groundwater.

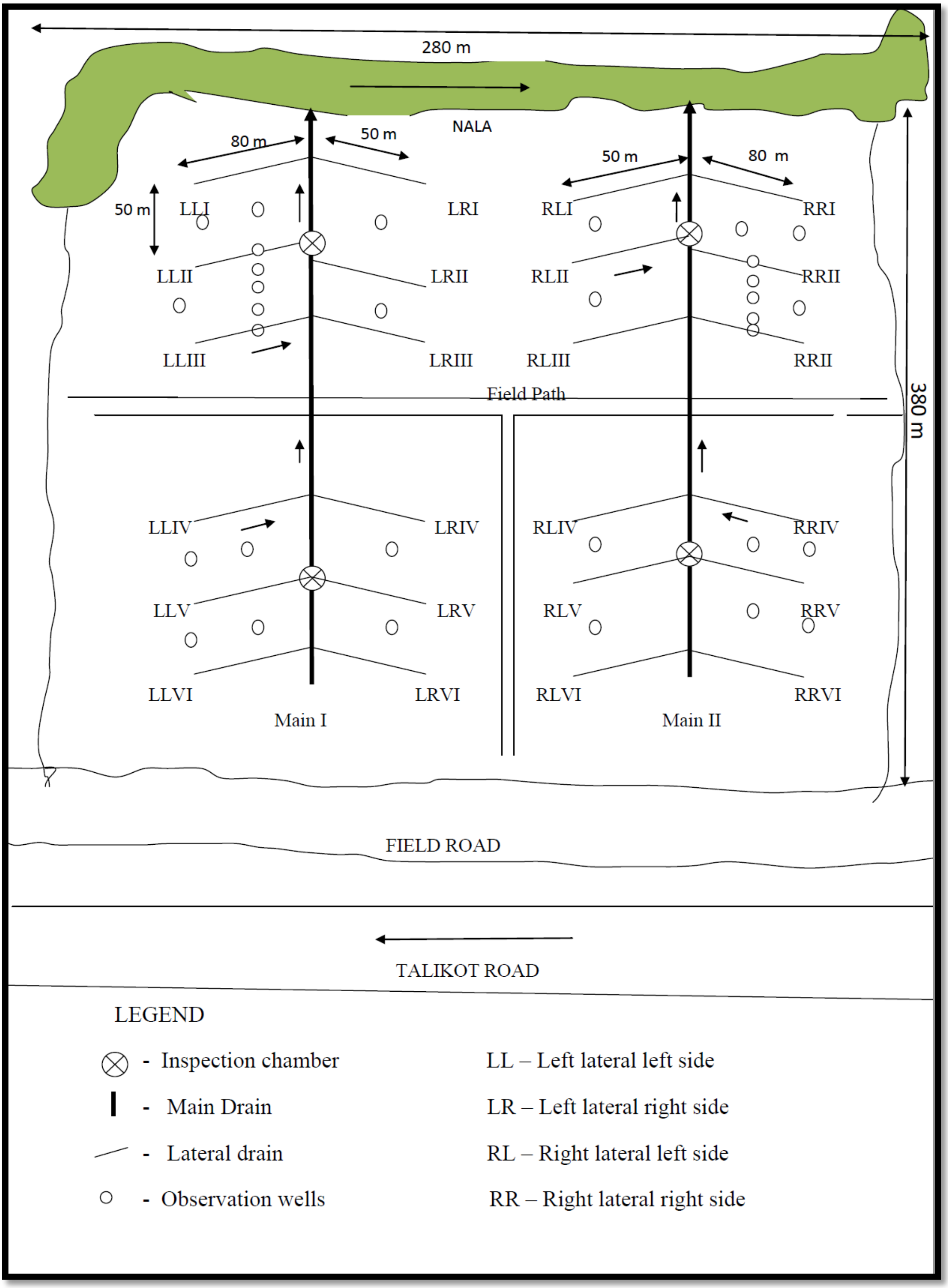

Fig. 3.3 Observation wells installed in study area for performance of subsurface drains and drainage efficiency

3.2.5 Analysis of leachate water quality

The leachate water samples were collected fortnightly during the study period in all the outlets and all the laterals in the inspection chambers and were analysed for water quality parameters of EC, pH, CO_3^{-2}, HCO_3^-, Cl^-, SO_4^- and SAR and ionic composition.

3.2.5.1 Determination of chlorides and sulphates

Mohr's titration is used for the determination of chlorides. Five ml of the sample is taken in a clean 100 ml beaker or a porcelain dish and diluted to about 25 ml with distilled water. After adding 5-6 drops of potassium chromate indicator, t it is titrated against the standard silver nitrate solution with continuous stirring till the first brick-red tinge appearing. Determination of sulphates was done using a spectrophotometer

$$\text{Cl (meq l}^{-1}\text{)} = \frac{\text{N of Silver nitrate X Volume of silvernitrate used X 1000}}{\text{Aliquat taken (ml)}}$$

3.2.5.2 Sodium adsorption ratio (SAR)

The sodium adsorption ratio (SAR) was calculated to indicate the sodium hazard using the following equation:

$$\text{SAR} = \frac{Na^+}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}}$$

Based on the values of SAR, water could be rated into different categories of sodicity according to Richards (1954) as: safe for irrigation: SAR < 10; moderately safe for irrigation: SAR 10 – 18; moderately unsafe for irrigation: SAR 19 – 26 and unsafe for irrigation: SAR > 26.

3.3 Soil Parameters

3.3.1 Preparation of soil samples for chemical analysis

In order to carry out systematic studies, the sampling points were identified on a grid size of 50 m X 50 m in the study area and the GPS readings of these points (30 points) were taken to monitor smoothly the various sampling locations during the study period. The soil samples were collected at different depths of 30, 60, 90 and 120 cm in these grid points before sowing and after harvesting. The soil samples were air dried in the shade, ground in wooden pestle and mortar and passed through 2 mm sieve. The chemical analysis included estimating pH, EC, K, Na^+, Ca^{2+}, Mg^{2+}, RSC and SAR by adopting standard procedures to know the salinity levels, sodium level etc.

3.3.2 Soil reaction (pHs) monitoring and measurement

The pre and post-monsoon soil samples taken at different depths of 0-30, 30-60, 60-90 and 90-120 cm in all the grid points were analysed for soil reaction (pHs) parameter in 1:2.5 soil water suspension using pH meter and the readings were noted. Comparison of soil pHs before sowing and after harvesting of crop was carried out using paired t-test.

3.3.3 Electrical conductivity (ECe)

The pre- and post-monsoon soil samples collected at different depths of 0-30, 30-60, 60-90 and 90-120 cm in all the grid points were analysed for EC parameter to know the effect of subsurface drainage system. The soil samples were air-dried, ground and weighed into 10 g samples. Distilled water was then added to each 10 g soil sample in the ratio of 1:2.5 soil to water. The soil-water mixture was shaken vigorously for five minutes and was left to stand for 24 hr in containers. The EC of the extract was measured using the EC meter and the readings were noted. The comparison of soil EC before sowing and after harvesting of crop was carried out using paired t-test. The ECe was calculated by multiplying the EC value with the factor of 3.65 which was obtained from the previous studies conducted in the UKP command area i.e. ECe = EC*3.65.

3.3.4 Estimation of anions

The carbonates and bicarbonates (CO_3^{2-} and HCO_3^-) were determined by EDTA titrimetric method.

3.3.5 Estimation of cations

The calcium and magnesium concentrations were determined by complex-metric titration using disodium solution of ethylene diamine tetra acetic acid (EDTA) (Schwarzenbach *et al.,* 1946). Sodium (Na^+) was determined by flame photometric method (APHA, 1998).

3.3.5.1 Estimation of sodium (Na^+)

A volume of 10 ml of 1000 ppm sodium standard was diluted to 100 ml in volumetric flask. Then 0, 2, 4, 6, 8 and 10 of the 100 ppm were pipetted out in a working solution into 50 ml volumetric flasks and made up the volume to 50 ml with the distilled water to get 0, 2,4, 6, 8 and 10 ppm standard solutions of Na, respectively. The working standards were aspirted and the instrument was standardised. The soil extractants were also aspirated in a flame photometer and the digital readings were noted. The comparison of soil Na^+ before sowing and after harvesting of crop was carried out using paired t-test. The Na was estimated as follows:

$$\text{Na} = \frac{\text{Concentration X Volume of extractant}}{\text{Weight of soil X Equivalent weight of Na X Aloquot taken}} \text{ X } 100$$

3.3.5.2 Exchangeable calcium (Ca^{2+}) and magnesium (Mg^{2+})

Exchangeable calcium and magnesium of the non-calcareous soils were extracted by using ammonium acetate solution. Similarly, the exchangeable calcium and magnesium of the calcareous soils were extracted with 1 *N* KCl - trietanolamine buffer solution (pH 8.2). Exchangeable calcium and magnesium in these extractants were determined by versanate titration method (Jackson, 1973).

Five ml of extractant was transferred into a porcelain dish, calcium + magnesium in the sample was determined by using buffer solution and titrate against 0.01 *N* ethelene diamine tetra acetic acid (EDTA) in the presence of erichrome black T-indicator, until sample colour changes from wine red to sky blue color. Similarly, blank was carried out in exactly the same manner as explained for soil sample. Blank reading was deducted from sample reading and calcium + magnesium was calculated by using the following formula:

$$\text{(Ca+Mg)} = \frac{\text{(Sample TV} - \text{Blank TV)X N of EDTA X Volume of extractant}}{\text{Weight of sample X Aliquot taken X } 10^6} \text{ X100}$$

Comparison of soil Ca and Mg before sowing and after harvesting of crop has been carried out using paired t-test.

3.3.5.3 Estimation of potassium (K^+)

The measured quantity of 0.0191 g of potassium chloride (KCL) was dissolved in 100 ml of distilled water to get 100 ppm of K stock solution. Working standard of 100 ppm K solution was prepared by diluting 10 ml of 100 ppm K stock solution using distilled water. Then, 0, 0.5, 1.0, 1.5, 2.0 and 2.5 ml of the 100 ppm K stock solution were pipetted out into 50 ml volumetric flasks and made the volume with distilled water to get 0, 1, 2, 3, 4 and 5 ppm of standard solution. The working standards were aspirated and the instrument was standardised, then soil extractants were also aspirated in a flame photometer and the digital readings were noted for estimating K as follows

$$K = \frac{\text{Concentrate X Volume of extractant}}{\text{Weight of soil X Equivalent weight of K X Aliquot taken}} \text{ x } 100$$

The comparison of soil potassium content before sowing and after harvesting of crop was carried out using paired t-test.

3.4 Soil Hydrologic Parameters

3.4.1 Hydraulic conductivity measurement

The *in situ* hydraulic conductivity was determined using post hole auger method on 150 m x 150 m grid basis in the experimental plot. The areal estimates of hydraulic conductivity were computed by reverse technique (drain outflow method) by knowing drain discharge entrance head and available hydraulic head and drain discharge which were measured in the field. These measurements were obtained following the standard procedures using q-h relation as described in Ritzema (ed.), 1994. The sample calculations for determination of hydraulic conductivity by inverse augur hole method and areal hydraulic conductivity are presented in Appendix – III and Appendix – IV respectively.

3.4.2 Infiltration rate measurement

The infiltration rate of the study area was determined using double ring infiltrometer method based on the grid pattern and compared that with that of the pre-drainage situation.

3.5 Inventory of Land Use Cropping Pattern Crop Cutting and Yield Estimation

Due to shortage of irrigation facilities, only one crop was taken up during late *kharif*. The **i**nventory of land use and cropping pattern during late *kharif* 2014 season was carried out in the study area. The crop area cultivated and cropping intensity were noted and crop cutting was done to study the performance of subsurface drainage system. Also the particulars of cropping intensity and crop yields before drainage works were obtained and tabulated.

3.6 Crop Yield

The crop cutting was carried out in a unit area of 4 m x 4 m^2 at six places for paddy crop as per the monitoring plan. The yield of the crop in unit area was measured and was later converted to yield per hectare.

3.7 Economics of Subsurface Drainage System

The economics involving cost benefit analysis of the subsurface drainage system was carried out to know the impact of drainage works on crop production and consequently on the improvement in cost returns and resource use pattern after the drainage. The benefit-cost ratio and also investment payback period were worked out.

3.7.1 Fixed cost

Fixed cost consisted of interest on initial cost and depreciation on the system. The interest calculated on the capital was at the rate of 12 per cent per annum as per the prevailing bank rates. The depreciation on the system was worked out as follows.

$$D = \frac{I - S}{L}$$

where,

D = depreciation per annum, Rs.

I = initial cost of system, Rs.

S = salvage value (10% of initial cost), Rs.

L = economic life period, yr (for SSD system 30 and 50 years were considered).

3.7.2 Operating cost

The operating cost is the amount which is actually paid by the cultivator in cash throughout the crop period for carrying out various agricultural operations. Total operational cost of the system is the operating cost plus interest on operational cost at the rate of 12 per cent.

3.7.3 Total cost

The total cost was calculated as given below.

Total cost = Fixed cost + Operating cost.

3.7.4 Internal rate of return

Internal rate of return (IRR) is a discount or interest rate that makes the net present value (NPV) of all cash flows (both positive and negative) from a particular project or investment equal to zero. IRR calculations rely on the same formula as NPV does.

The following is the formula for calculating NPV:

$$\mathrm{NPV} = \sum_{t_p=1}^{T} \frac{C_t}{(1+r)^t} - c_o$$

where,

C_t = net cash inflow during the period 't_p', Rs.

C_o= total initial investment costs, Rs.

r = discount rate, per cent and

t_p = number of time periods.

To calculate IRR using the formula, one would set NPV equal to zero and solve for the discount rate *r*, which is here the IRR. Because of the nature of the formula, however, IRR cannot be calculated analytically, and must instead be calculated either through trial-and-error or using software programmed to calculate IRR. If IRR in per cent is higher than the required rate of return, then the investment is considered desirable. Generally speaking, the higher a project's IRR, the more desirable it is to undertake the project.

3.7.5 Net present value (also called Net present worth)

The NPV is the present value of the net cash inflows generated by a project including any salvage value (estimated resale value of an asset at the end of its useful life), less the initial investment on the project. The net present value is calculated using a targetted acceptable discount rate. If the net present value, after applying the targetted acceptable discount rate, is positive then the investment is considered desirable. Net present value is expressed in Rs. terms, while internal rate of return is expressed in per cent terms. Both calculations use a targetted return as the basis for evaluation.

3.7.6 Benefit-cost ratio

The benefit-cost ratio (BCR) was worked out as follows:

$$\text{Benefit-cost ratio} = \frac{\text{Gross returns (Rs ha}^{-1}\text{)}}{\text{Cost of cultivation (Rs ha}^{-1}\text{)}}$$

While calculating gross returns the prevailing market rate of Rs. 1200 for 100 kg bag of paddy was considered.

3.7.7 Payback period

The payback period (years or cropping seasons) for the investment for subsurface drainage system was calculated by the following formula:

$$\text{Payback period} = \frac{\text{Total investment} \quad (\text{Rs ha}^{-1})}{\text{Net profit} \ (\text{Rs ha}^{-1})}$$

where,

Net profit = Gross returns – Cost of cultivation.

The calculations for internal rate of return, net present value and benefit-cost ratio for 30 and 50 years life span of SSD system are presented in Appendix - V. The sample calculation for working out the payback period within which the investment on SSD would be repaid is presented in Appendix - VI.

IV. EXPERIMENTAL RESULTS

The results of the various experimental investigations regarding monitoring and evaluation of subsurface drains carried out during the period from August, 2014 to January 2015 under the present project study are presented in this Chapter.

4.1 Analysis of Soil Parameters

4.1.1 Soil reaction

The mean soil reaction **(**pHs) values of the soil samples drawn from different depths at 0-30, 30-60, 60-90 and 90-120 cm at various grid points before the sowing and after the harvesting are presented in Tables 4.1 and 4.2 respectively. The results revealed that the mean pHs values ranged from 8.21 to 8.71 before sowing. The lowest pHs of 7.68 was observed at 0-30 cm depth, while the highest pHs of 9.50 was noticed at 90-120 cm depth. The magnitudes of standard error were found to be 0.0619, 0.0613, 0.0520 and 0.0612 respectively for the above depths of 0-30, 30-60, 60-90 and 90-120 cm, which indicated that there was no much variation in pHs values drawn from same depths at different points. However, it could be noticed from the Table 4.1 that F_{cal} value (12.31*) was more than that of the F_{cri} value (2.68), which implied that there was significant difference between the mean pHs values drawn from different depths. Further, it was observed that the pHs values increased with increasing different depths.

Similarly, the mean pHs values after the harvesting varied from 8.58 to 8.95. The lowest pHs observed was 8.04 at 0-30 cm depth and the highest pHs found was 9.71 at 90-120 cm depth. The standard errors observed were 0.0593, 0.0630, 0.0614 and 0.0584 for different depths of 0-30, 30-60, 60-90 and 90-120 cm respectively, which showed that there were no much variations in pHs of soil samples drawn from particular depths and different points. However, as the F_{cal} value (6.54*) was more than that of the F_{cri} value (2.68), it could be inferred that there was significant difference between the mean pHs values of soil samples drawn from different depths as observed in case of before sowing. Further, it was observed that there was slight increase in pHs at all the depths as compared to the pre-sowing conditions (Table 4.2).

Soil reaction (pHs)				
Soil depth, cm	0-30	30-60	60-90	90-120
Mean	8.21	8.38	8.53	8.71
Standard error	0.0619	0.0613	0.0520	0.0612
Minimum	7.68	7.85	8.03	8.31
Maximum	9.00	9.10	9.30	9.50
F_{cal}	12.31*			

The t_{cal} and t_{cri} values as obtained in comparison of soil pHs before sowing and after harvesting of crop using paired t-test are presented in Table 4.3. A close examination of the same revealed that t_{cal} values (-13.46, -15.56, -11.46 and -10.60 respectively) for the soil

Table 4.1 Soil reaction before sowing in late *kharif* season 2014

Table 4.2 Effect of subsurface drainage on soil reaction after harvesting in late *kharif* season 2014

Soil reaction (pHs)				
Soil depth, cm	0-30	30-60	60-90	90-120
Mean	8.58	8.71	8.81	8.95
Standard error	0.0593	0.0630	0.0614	0.0584
Minimum	8.04	8.18	8.21	8.45
Maximum	9.31	9.54	9.60	9.71
F_{cal}	6.54*			

Table 4.3 Comparison of soil reaction before sowing and after harvesting of crop using paired t-test

Soil reaction (pHs)				
Soil depth, cm	0-30	30-60	60-90	90-120
t_{cal}	-13.46*	-15.56*	-11.46*	-10.60*
t_{cri}	1.699			

samples drawn from 0-30, 30-60, 60-90 and 90-120 cm depths at different grid points before sowing and after harvesting were more than the t_{cri} value (1.699). This indicated that there was significant difference between the mean pHs values of soil samples drawn at different depths before sowing and after harvesting of the crop.

4.1.2 Soil salinity

The mean soil salinity (ECe) values of soil samples taken from different depths of 0-30, 30-60, 60-90 and 90-120 cm at different grid points before sowing and after harvesting of the crop are presented in Tables 4.4 and 4.5 respectively. The mean ECe ranged from 8.84 to 12.09 dS m^{-1} in the soil samples collected before sowing. The lowest ECe observed was 4.56 dS m^{-1} at 90-120 cm depth and the highest ECe of 18.61 dS m^{-1} was found at 0 to 30 cm depth. The standard errors found were 0.54, 0.56, 0.54 and 0.53 for different depths of 0-30, 30-60, 60-90 and 90-120 cm respectively, which indicated that there was much difference in ECe values between the soil samples from same depths and different grid points. It could be seen that F_{cal} value (6.53*) was more than that of the F_{cri} value (2.68), implying that there was significant difference between the mean ECe values of soil samples drawn from different depths. Moreover, it was observed that the ECe decreased with depth in all the grid points; as such, the ECe values were higher in the surface layer (0-30 cm) compared to other lower depths (Table 4.4).

The analysis of salinity of the soil samples observed after harvesting of crop showed that the mean EC values ranged from 7.25 to 12.06 dS m^{-1}. The least ECe was found to be 3.54 dS m^{-1} at 90-120 cm depth and the maximum ECe observed was 15.69 dS m^{-1} at 90-120 cm depth. The standard errors obtained were 0.43, 0.48, 0.49 and 0.56 respectively for different depths of 0-30, 30-60, 60-90 and 90-120 cm, indicating there were differences in the EC values of soil samples drawn from particular depths at different points. Since the F_{cal} value (4.79^{*}) was noticed more than the F_{cri} value (2.68), it could be said that there was significant difference between the mean values of ECe drawn from different depths. Further, the results revealed that as the depth increased the ECe also increased after harvesting of the crop (Table 4.5).

The t_{cal} and t_{cri} values in ECe analysis of the soil samples are presented in Table 4.6. A scrutiny of the same indicated that t_{cal} values (12.46, 12.10, 5.39 and -1.96 respectively) for the soil samples drawn from 0-30, 30-60, 60-90 and 90-120 cm depths at different grid points before the sowing and after the harvesting were more than the t_{cri} (1.699). This showed that

Table 4.4 Soil salinity before sowing in late *kharif* season 2014

Soil salinity (ECe), dS m^{-1}				
Soil depth, cm	0-30	30-60	60-90	90-120
Mean	12.09	11.17	10.16	8.84
Standard error	0.54	0.56	0.54	0.53
Minimum	7.66	5.84	5.073	4.56
Maximum	18.61	17.15	16.86	16.42
F_{cal}	6.53*			

Table 4.5 Effect of subsurface drainage on soil salinity after harvesting in late *kharif* season 2014

Soil salinity (ECe), dS m^{-1}				
Soil depth, cm	0-30	30-60	60-90	90-120
Mean	7.25	8.40	9.41	12.06
Standard error	0.43	0.48	0.49	0.56
Minimum	3.68	4.41	4.74	3.54
Maximum	12.77	14.05	14.96	15.69
F_{cal}	4.79*			

Table 4.6 Comparison of soil salinity before sowing and after harvesting of crop using paired t-test

Soil salinity (ECe), dS m^{-1}				
Soil depth, cm	0-30	30-60	60-90	90-120
t_{cal}	12.46*	12.10*	5.39*	-1.96*
t_{cri}	1.699			

there was significant difference between the mean ECe values of the soil samples drawn before sowing and after harvesting at all depths.

4.1.3 Exchangeable cations of soils

Exchangeable calcium and magnesium were the dominant cations in the soil profiles of different depths of 0-30, 30-60, 60-90 and 90-120 cm.

4.1.3.1 Exchangeable sodium

The sodium (Na^+) values of the soil samples drawn from 0-30, 30-60, 60-90 and 90-120 cm depths at different grid points before sowing and after the harvesting are presented in Tables 4.7 and 4.8 respectively. The results revealed that the mean sodium content values ranged from 7.80 to 10.92 meq/100g before sowing. The lowest sodium was observed to be 4.35 meq/100g at 90-120 cm depth, while the highest was 14.5 meq/100 g noticed at 0-30 cm depth. The standard errors observed were 0.30, 0.26, 0.26 and 0.24 for different depths of 0-30, 30-60, 60-90 and 90-120 cm respectively, which showed that there were variations in the N^+ values at different points of soil samples drawn at same depths. It was noticed that F_{cal} value (24.11*) was more than that of the F_{cri} value (2.68), and therefore it could be concluded that there was significant difference between the mean Na^+ values of soil samples drawn from different depths. Also, it was observed that Na^+ content decreased as the depth increased (Table 4.7).

The exchangeable sodium content of soil observed after the harvesting of the crop revealed that the mean Na^+ ranged from 7.10 to 9.40 meq/100 g. The minimum Na^+ was found to be 4.1 meq/100 g at 90-120 cm depth and the maximum was observed to be 11.5 meq/100 g at 0-30 cm depth. The magnitudes of standard error were 0.20, 0.22, 0.20 and 0.18 respectively for different depths of 0-30, 30-60, 60-90 and 90-120 cm, which indicated that there were differences in the N^+ values of soil samples drawn at particular depths and different points. Further, the F_{cal} value (22.11*) was higher than that of the F_{cri} value (2.68), which showed that there was significant difference between the mean Na^+ values of soil samples drawn from different depths. Moreover, it was noticed that the Na^+ decreased as the depth increased as observed in case of before sowing (Table 4.8).

The t_{cal} and t_{cri} values computed in comparison of exchangeable sodium content of soil before sowing and after harvesting of crop using paired t-test are presented in Table 4.9. The t_{cal} values (11.06, 10.56, 7.50 and 6.13 respectively) of the soil samples drawn from 0-30, 30-60, 60-90 and 90-120 cm depths at different grid points before sowing and after the

Table 4.7 Exchangeable sodium (Na^+) of soil before sowing in late *kharif* season 2014

Na^+ (meq/100 g)				
Soil depth, cm	0-30	30-60	60-90	90-120
Mean	10.92	9.91	8.66	7.80
Standard error	0.30	0.26	0.26	0.24
Minimum	7.47	6.70	5.10	4.35
Maximum	14.50	12.50	10.95	9.85
F_{cal}	24.11*			

Table 4.8 Effect of subsurface drainage on exchangeable sodium (Na^+) after harvesting in late *kharif* season 2014

Na^+ (meq/100 g)				
Soil depth, cm	0-30	30-60	60-90	90-120
Mean	9.40	8.68	7.67	7.10
Standard error	0.20	0.22	0.20	0.18
Minimum	6.57	5.90	5.20	4.10
Maximum	11.50	11.50	9.80	8.75
F_{cal}	22.11*			

Table 4.9 Comparison of exchangeable sodium content of soil before sowing and after harvesting of crop using paired t-test

Na^+ (meq/100 g)				
Soil depth, cm	0-30	30-60	60-90	90-120
t_{cal}	11.06*	10.56*	7.50*	6.13*
$t_{critical}$	1.699			

harvesting were more than t_{cri} value (1.699). This implied that there was significant difference between the mean exchangeable sodium content of soil samples obtained at various depths in different grid points.

4.1.3.2 Exchangeable calcium and magnesium

The values of exchangeable calcium (Ca) and magnesium (Mg) of soil samples drawn from different depths of 0-30, 30-60, 60-90 and 90-120 cm before sowing and after harvesting of the crop are shown in Tables 4.10 and 4.11 respectively. An interpretation of the Table 4.10 revealed that the mean exchangeable calcium and magnesium variations were in the range of 34.68 to 39.76 meq/100 g in the soil samples collected before sowing. Further, the lowest of 27.50 meq/100 g was observed at the depths of 60-90 and 90-120 cm against the highest of 47.50 meq/100 g at 0-30 cm depth. The standard errors observed were 0.53, 0.45, 0.58 and 0.60 for different depths of 0-30, 30-60, 60-90 and 90-120 cm respectively, which revealed that there were much differences in exchangeable calcium and magnesium values at same depths drawn from different points. Moreover, it was noticed that F_{cal} value (15.75*) was more than the F_{cri} value (2.68), hence there was significant difference between the mean exchangeable calcium and magnesium values of soil samples drawn from different depths. Also, it was found that exchangeable calcium and magnesium values decreased with the depth (Table 4.10).

Similarly, the mean exchangeable calcium and magnesium values in case of after harvesting varied from 32.91 to 37.62 meq/100 g. The lowest value was found to be 26.50 meq/100 g at depths of 60-90 and 90-120 cm and the highest observed was 43.50 meq/100 g at 0 to 30 depth cm. The standard errors noticed were 0.51, 0.45, 0.48 and 0.66 respectively for different depths of 0-30, 30-60, 60-90 and 90-120 cm respectively, hence there were much differences in values of exchangeable calcium and magnesium content drawn from particular depths and different points. Since the F_{cal} value (13.48*) was more than the F_{cri} value (2.68), there were significant differences between the mean values of exchangeable calcium and magnesium of the samples drawn from different depths. Further, the exchangeable calcium and magnesium content decreased as the depth increased till 60-90 cm, but increased at 90-120 cm depth (Table 4.11).

The comparative analysis of exchangeable calcium and magnesium content before sowing and after harvesting using paired t values is presented in Table 4.12. A glance of the same revealed that t_{cal} values (7.22, 7.73, 3.48 and 4.86 respectively) for the soil samples

Table 4.10 Exchangeable calcium and magnesium (Ca^{2+}+Mg^{2+}) before sowing in late *kharif* season 2014

Ca^{2+}+Mg^{2+}(meq/100 g)				
Soil depth, cm	0-30	30-60	60-90	90-120
Mean	39.76	37.01	34.68	35.50
Standard error	0.53	0.45	0.58	0.60
Minimum	34.50	32.10	27.50	27.50
Maximum	47.50	44.50	42.50	41.50
F_{cal}	15.75*			

Table 4.11 Effect of subsurface drainage on exchangeable calcium and magnesium (Ca^{2+}+Mg^{2+}) after harvesting in late *kharif* season 2014

Ca^{2+}+Mg^{2+} (meq/100 g)				
Soil depth, cm	0-30	30-60	60-90	90-120
Mean	37.62	34.74	32.91	34.44
Standard error	0.51	0.45	0.48	0.66
Minimum	32.50	29.50	26.50	26.50
Maximum	43.50	39.50	39.00	41.50
F_{cal}	13.48*			

Table 4.12 Comparison of soil exchangeable calcium and magnesium before sowing and after harvesting of crop using paired t-test

Ca^{2+}+Mg^{2+} (meq/100 g)				
Soil depth, cm	0-30	30-60	60-90	90-120
t_{cal}	7.22*	7.73*	3.48*	4.86*
t_{cri}	1.699			

drawn from 0-30, 30-60, 60-90 and 90-120 cm depths at different grid points before sowing and after harvesting were more than t_{cri} (1.699). Thus, it could be concluded that there was significant difference in the mean exchangeable calcium and magnesium content of soil samples drawn before sowing and after harvesting.

4.1.3.3 Exchangeable potassium

The results of exchangeable potassium (K) analysis of soil samples drawn from different depths of 0-30, 30-60, 60-90 and 90-120 cm before sowing and after harvesting are presented in Tables 4.13 and 4.14 respectively. The results revealed that the mean K values before sowing ranged from 0.12 to 0.16 meq/100 g. The minimum K value of 0.01 meq/100 g was found at the depths of 60-90 and 90-120 cm, while the maximum was 0.32 meq/100 g observed at the depth of 0-30 cm. The values of standard error observed were 0.0121, 0.0110, 0.0103 and 0.0092 for different depths of 0-30, 30-60, 60-90 and 90-120 cm respectively, which showed that there were no much variations in the K values of soil samples collected from specific depths and different points. However, it was noticed that as the F_{cal} value (3.90*) was larger than the F_{cri} value (2.68), it could be inferred that there was significant difference between the mean values of exchangeable potassium drawn from different depths. Furthermore, it was seen that K^+ values decreased as the depth increased (Table 4.13).

The mean K values of soil samples observed after the harvesting of the crop ranged from 0.20 to 0.27 meq/l, with the lowest of 0.02 meq/100 g found at 0-30 and 90-120 cm depths and the highest of 0.46 meq/l at the surface layer 0-30 cm. The standard errors were 0.0191, 0.0183, 0.0194 and 0.0191 for different depths of 0-30, 30-60, 60-90 and 90-120 cm respectively. Thus, there was no much difference in the K values of soil samples collected from particular depths and different points. Further, as the observed F_{cal} value (1.008^{NS}) was less than the F_{cri} value (2.68), there was no significant difference between the mean values of exchangeable potassium at various depths. However, the K decreased as the depth increased (Table 4.14).

The comparative analysis of potassium content before sowing and after harvesting using paired t values is given in Table 4.15. A look at the results revealed that t_{cal} value (-5.03, -6.27, -6.71 and -7.17 respectively) of the soil samples drawn from 0-30, 30-60, 60-90 and 90-120 cm at different grid points before sowing and after the harvesting was numerically greater than t_{cri} value of 1.699. Hence, it could be concluded that there was

Table 4.13 Exchangeable potassium (K^+) of soil before sowing in late *kharif* season 2014

K^+ (meq/100 g)				
Soil depth, cm	0-30	30-60	60-90	90-120
Mean	0.16	0.14	0.12	0.12
Standard error	0.0121	0.0110	0.0103	0.0092
Minimum	0.02	0.02	0.01	0.01
Maximum	0.32	0.25	0.23	0.23
F_{cal}	3.90*			

Table 4.14 Effect of subsurface drainage on exchangeable potassium (K^+) after harvesting in late *kharif* season 2014

K^+ (meq/100 g)				
Soil depth, cm	0-30	30-60	60-90	90-120
Mean	0.27	0.25	0.22	0.20
Standard error	0.0191	0.0183	0.0194	0.0191
Minimum	0.02	0.03	0.03	0.02
Maximum	0.46	0.42	0.42	0.40
F_{cal}	1.008^{NS}			

Table 4.15 Comparison of soil exchangeable potassium content before sowing and after harvesting of crop using paired t-test

K^+ (meq/100 g)				
Soil depth, cm	0-30	30-60	60-90	90-120
t_{cal}	-5.03*	-6.27*	-6.71*	-7.17*
t_{cri}	1.699			

significant difference between the mean exchangeable potassium content of soil samples drawn before sowing and after harvesting of the crop.

4.1.4 Exchangeable sodium percentage

The exchangeable sodium percentage (ESP) values of the soil samples before sowing and after harvesting drawn from different depths of 0-30, 30-60, 60-90 and 90-120 cm are shown in Tables 4.16 and 4.17. The data revealed that the mean ESP of soil samples collected before sowing ranged from 17.99 to 21.45. The lowest ESP was observed to be 10.63 at 90-120 cm depth and the highest observed was 27.78 at 0 to 30 cm. The standard error values obtained were 0.49, 0.46, 0.52 and 0.53 respectively for different depths of 0-30, 30-60, 60-90 and 90-120 cm, which revealed that there were many variations in ESP of soil samples drawn from particular depths and different points. Also, since the F_{cal} value (9.21*) was more than the F_{cri} value (2.68), there was significant difference between the mean values of ESP drawn from different depths.

The mean values of ESP of soil samples after harvest ranged from 17.07 to 19.90. The least ESP observed was 9.09 at 30-60 cm depth against the maximum ESP value of 26.62 at 60-90 cm depth. The magnitudes of standard errors observed were 0.41, 0.55, 0.52 and 0.46 for different depths of 0-30, 30-60, 60-90 and 90-120 cm, which showed that there was much difference in ESP of soil samples drawn from particular depths and different points. Further, it was noticed that the F_{cal} value (6.48*) was more than the F_{cri} value (2.68), and hence there was significant difference between the mean values of ESP at different depths. Similar to the case of before sowing, the mean ESP was found to be maximum at the surface layer followed by the lower depths (Table 4.17).

The comparative analysis of exchangeable sodium percentage before sowing and after harvesting using paired t values is depicted in Table 4.18. The data revealed that t_{cal} value (7.46, 5.34, 4.06 and 5.31) for the soil samples drawn from 0-30, 30-60, 60-90 and 90-120 cm depths respectively at different grid points before sowing and after the harvesting was more than t_{cri} value (1.699). This meant that there was significant difference in the mean exchangeable sodium percentage values of the soil samples drawn before sowing and after harvesting.

Table 4.16 Exchangeable sodium percentage of soil before sowing in late *kharif* season 2014

ESP				
Soil depth, cm	0-30	30-60	60-90	90-120
Mean	21.45	21.02	19.90	17.99
Standard error	0.49	0.46	0.52	0.53
Minimum	15.23	14.94	12.34	10.63
Maximum	27.78	26.07	26.63	25.10
F_{cal}	9.21*			

Table 4.17 Effect of subsurface drainage on exchangeable sodium percentage after harvesting in late *kharif* season 2014

ESP				
Soil depth, cm	0-30	30-60	60-90	90-120
Mean	19.90	19.67	18.83	17.07
Standard error	0.41	0.55	0.52	0.46
Minimum	14.15	9.09	12.73	10.03
Maximum	25.38	26.03	26.62	23.30
F_{cal}	6.48*			

Table 4.18 Comparison of soil exchangeable sodium percentage (ESP) before sowing and after harvesting of crop using paired t-test

ESP				
Soil depth, cm	0-30	30-60	60-90	90-120
t_{cal}	7.46*	5.34*	4.06*	5.31*
$t_{critical}$	1.699			

4.2 Analysis of Leachate Water Quality

The water quality aspects in respect of salinity and ionic composition of the leachate from the outlets of the SSD collector main drains and the laterals (at manholes) collected during late *kharif* 2014 are presented in the following sections.

4.2.1 Salinity of the leachate water at the laterals and the outlets

The leachate water samples collected from the subsurface collector main drain outlets and the inspection chambers of different laterals were subjected to fortnightly analysis of salinity (EC) from September 2014 till January 2014 and the data are presented in Table 4.19. Considering all the laterals, the mean leachate salinity (dS m^{-1}) ranged from 7.20 dS m^{-1} during October in lateral RLII to 12.50 dS m^{-1} during November. Individually, the mean leachate salinity (dS m^{-1}) varied from 7.80 to 11.10 in case of LLII, from 7.20 to 11.30 in RLII and from 8.30 to 12.50 in RRII, with their mean salinities of 9.18, 9.20 and 9.94 dS m^{-1} respectively. The values of pooled mean salinity of the laterals during September, October, November, December and January were 8.10, 8.10, 10.50, 10.10 and 10.40 dS m^{-1} respectively with the overall leachate mean salinity of the laterals was 9.44 dS m^{-1}. Upon monthly comparison, the minimum leachate salinity of 8.10 dS m^{-1} was noticed during September, 2015 and the maximum of 10.50 dS m^{-1} was found during November 2014.

Similarly, the maximum leachate salinity was observed in the month of January, 2015 (11.50 dS m^{-1}) in the subsurface collector main drain outlet I and the lowest observed was (7.60 dS m^{-1}) during September, 2014 in the subsurface collector main drain outlet II. Individually, the leachate salinity in the subsurface collector main drain outlet I varied from 8.90 to 11.50 dS m^{-1} with a mean of 10.00 dS m^{-1} while that of the subsurface collector main drain II outlet ranged from 7.60 to 9.60 dS m^{-1} with a mean of 9.36 dS m^{-1}. The values of pooled mean salinity of the outlets during September, October, November, December and January were 8.20, 8.30, 10.50, 10.90 and 10.60 dS m^{-1} respectively with the overall leachate mean salinity of the outlets was 9.68 dS m^{-1}. The mean leachate salinity of the outlet I (10.00 dS m^{-1}) was more compared to that of the outlet II (9.36 dS m^{-1}). Further, it could be noticed that the mean salinity in the outlets increased over the months from September to January.

On comparison, the EC of canal water was very low during the study period with 0.58 dS m^{-1} in September, 2014 and 0.63 dS m^{-1} in December, 2014. Thus, the leachate

Table 4.19 Salinity of leachate from SSD main outlets and laterals during September 2014 - January 2015

SSD main outlet / lateral	Salinity of leachate (EC, dS m^{-1})					
Main outlet	September	October	November	December	January	Mean
I	8.90	9.00	9.90	11.00	11.50	10.0
II	7.60	7.70	11.00	10.90	9.60	9.36
Mean	8.20	8.30	10.50	10.90	10.60	9.68
Laterals						
LLII	8.10	8.20	7.80	10.70	11.10	9.18
RLII	7.80	7.20	11.30	9.90	9.80	9.20
RRII	8.30	8.90	12.50	9.70	10.30	9.94
Mean	8.10	8.10	10.50	10.10	10.40	9.44

salinity was higher by 14 times during September, 2014 and nearly 17 times during December, 2014 compared to that of the canal water.

4.2.2 Ionic composition of leachate water

The results on ionic composition of leachate samples collected fortnightly during the study period from the laterals and the outlets and the EC and pH of the canal water and groundwater are presented in Tables 4.20 and 4.21 respectively. Analysis of the same revealed that the cationic concentration of leachate water collected at the outlets ranged from 19.50-36.50 (Ca^{2+}), 5.00-15.00 (Mg^{2+}), 24.50 to 51.00 (Na^{+}) and 0.30 to 1.10 meq/l (K^{+}) and at the laterals varied from 14.50-42.50 (Ca^{2+}), 6.50-16.50 (Mg^{2+}), 25.50 to 48.50 (Na^{+}) and 0.12 to 1.50 meq/l (K^{+}). Thus, the ionic composition of leachate was dominated by sodium followed by calcium, magnesium and potassium among the cations. The sodium adsorption ratio (SAR) for outlets and laterals was moderate and pH ranged from 7.10 to 9.10 in the outlets and 6.20 to 8.50 in the laterals. The anionic concentration of leachate water collected was dominated by chlorides and bicarbonates followed by sulphates. The anionic concentration of leachate water collected in the outlets ranged from 7.30 to 15.10 (HCO_3^-), 26.47 to 44.50 (Cl^-) and 2.10 to 6.30 (SO_4^-) and in the laterals varied from 7.50 to 13.50 (HCO_3^-), 24.50-37.50 (Cl^-) and 2.50 to 6.50 (SO_4^-) respectively.

The average cationic composition during the entire cropping period for subsurface collector main drain outlet I and outlet II consisted of 27.95 and 27.46 (Ca^{2+}), 11.72 and 10.29 (Mg^{2+}), 32.30 and 31.10 (Na^{+}) and 0.65 and 0.56 (K^{+}) meq/l respectively. Similarly, the mean anionic composition for outlet I and outlet II contained 12.24 and 11.50 (HCO_3^-), 34.64 and 37.55 (Cl^-) and 4.10 and 4.86 (SO_4^-) respectively. The SAR values at the outlets ranged from 5.60 to 10.90 and at the laterals varied from 5.60 to 11.90. The residual sodium carbonate (RSC) values ranged from -34.50 to -19.00 meq/l at the outlets and -34 to -22 meq/l.

4.2.3 EC and pH of groundwater and canal water

The chemical analysis of groundwater revealed that the average EC values were observed to be 9.50 and 9.43 dS m^{-1} and pH values were 7.70 and 7.58 for the months of September and December respectively. Similarly, for canal water the EC values were 0.58 and 0.63 dS m^{-1} and pH values were 7.10 and 7.15 respectively. It was observed that EC of groundwater was found to be much more as compared to canal water (Table 4.21).

Table 4.20 Ionic composition of leachate from SSD main outlets and laterals during late *kharif* season 2014

Outlets	pH	CO_3^{-2}	HCO_3^-	Cl^-	SO_4^{-2}	Ca^{2+}	Mg^{2+}	K^+	Na^+	RSC	SAR
Main I	8.06	0.00	12.24	34.64	4.10	27.95	11.72	0.65	32.3	-30.57	7.75
Main II	7.94	0.00	11.51	37.55	4.86	27.46	10.29	0.56	31.10	-30.90	7.20
Range	7.1-9.1	0.00	7.3-15.1	26.47-44.5	2.1-6.3	19.5-36.5	5-15	0.3-1.10	24.5-51	-19-(-34.5)	5.6-10.9
Laterals											
LLII	7.56	0.00	9.38	28.05	3.52	26	9.72	0.81	37.27	-27.33	9.06
RLII	8.10	0.00	8.27	33.13	3.8	19.50	10.04	0.76	38	-28.5	8.5
RRII	7.16	0.00	10.13	32.4	3.61	25.10	12.24	0.78	33.27	-27.24	8.81
Range	6.2-8.5	0.00	7.5-13.5	24.5-37.5	2.5-6.5	14.5-42.5	6.5-16.5	0.12-1.5	25.5-48.5	-22-(-34)	5.6 to 11.9

Table 4.21 EC and pH of the canal water and groundwater

Source of water	September, 2014		December, 2014	
	EC, dS m^{-1}	pH	EC, dS m^{-1}	pH
Groundwater	9.50	7.70	9.43	7.58
Canal water	0.58	7.10	0.63	7.15

4.3 Monitoring of Discharge in SSD System

4.3.1 Discharge on weekly basis in SSD collector mains

The standard week wise weighted average discharge and the overall weighted average discharge data in two SSD main drains (collector main I and main II) are presented in Table 4.22 and Fig. 4.1. The analysis of data revealed that the drain discharge in the collector main I and collector main II ranged from 0.17-0.54 and 0.23-0.80 mm d^{-1} respectively. It was observed that the discharge was maximum in main II (0.80 mm d^{-1}) during 46th week (November) while the minimum was observed to be 0.17 mm d^{-1} in main I during 3rd week of January. A similar analysis of weekly overall weighted average discharge considering all the drains together (on pipe drained area basis) indicated a range of 0.21 mm d^{-1} (3rd week of January) to 0.65 mm d^{-1} (51st week, December). Among the mains, the average discharge was 0.38 mm d^{-1} in main I and 0.62 mm d^{-1} in main II, which was higher than that of the main I. Further, considering the whole area for the entire period of study, the overall weighted average discharge of the SSD system was found to be 0.50 mm d^{-1}.

4.3.2 Discharge on weekly basis in SSD laterals

The standard week wise weighted average discharge and the overall weighted average discharge data in three lateral drains (LLII, RLII and RRII) are presented in Table 4.23 and Fig 4.2. The analysis of data revealed that the drain discharge ranged from (0.13-0.54), (0.17-0.89) and (0.15-0.59) mm d^{-1} in laterals LLII, RLII and RRII respectively. It was observed that the discharge was maximum in RLII (0.89 mm d^{-1}) during 46 and 51st week and minimum was (0.13 mm d^{-1}) during 3rd week of January. A similar analysis of weekly overall weighted average discharge considering all the laterals together indicating a range of (0.15-0.63 mm d^{-1}). Among the laterals, the average discharge was 0.34, 0.60 and 0.44 mm d^{-1} in LLII, RLII and RRII with overall mean of 0.44 mm d^{-1}.

4.3.3 Discharge on monthly basis in SSD collector mains

The month wise mean, maximum and minimum discharge of two SSD mains, monthly average discharge of individual drains as well as the monthly average and weighted average discharge considering the pipe drained area as a whole area during the study period are presented in Table 4.24 and Fig 4.3. During the period of study, the discharge ranged from 0.17 to 0.54 mm d^{-1} in main I and from 0.23 to 0.80 mm d^{-1} in main II. While the average monthly discharge over the study period in main I was 0.38 mm d^{-1} and that of main II was 0.61 mm d^{-1}. Considering the entire pipe drained area, the average monthly discharge

Table 4.22 Average weekly discharge of SSD mains in the study area

Drain discharge, mm d^{-1}				
Sl. no.	Standard week	Main I, mm d^{-1}	Main II, mm d^{-1}	Overall weighted weekly average discharge, mm d^{-1}
1	37	0.42	0.79	0.61
2	38	0.35	0.60	0.48
3	39	0.35	0.69	0.53
4	40	0.33	0.61	0.48
5	41	0.44	0.73	0.59
6	42	0.32	0.74	0.54
7	43	0.33	0.65	0.50
8	44	0.37	0.58	0.48
9	45	0.49	0.68	0.59
10	46	0.43	0.80	0.62
11	47	0.47	0.75	0.61
12	48	0.44	0.65	0.55
13	49	0.54	0.58	0.57
14	50	0.49	0.65	0.58
15	51	0.50	0.79	0.65
16	52	0.31	0.52	0.42
17	1	0.23	0.42	0.33
18	2	0.21	0.28	0.25
19	3	0.17	0.23	0.21
	Average	0.38	0.62	0.50

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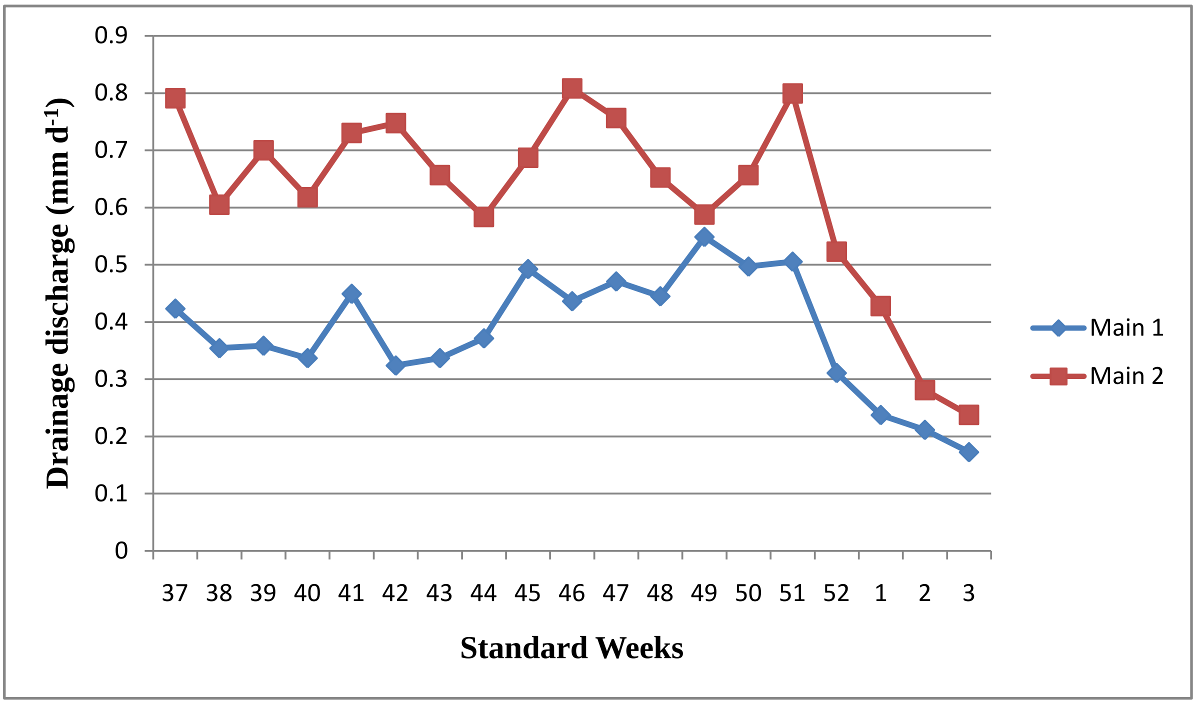

Fig. 4.1 Weekly discharge (mm d^{-1}) in SSD main outlets

was in the range of 0.26 (minimum) during January to 0.60 mm d^{-1} (maximum) during November. It was clear that the average discharge from main I (0.38 mm d^{-1}) was less when compared to that of main II (0.61 mm d^{-1}) through the study period. Upon considering the entire drainage area and the cropping period, the overall weighted average was found to be 0.50 mm d^{-1}.

4.3.4 Discharge on monthly basis in SSD laterals

The month wise mean, maximum and minimum discharge of three lateral drains, monthly average discharge of individual drains as well as the monthly average and weighted average discharge considering the pipe drained area as a whole area during the study period are presented in Table 4.25 and Fig.4.4. during the study period, the discharge in laterals drains were ranged from (0.13-0.54), (0.17-0.89) and (0.15-0.59) mm d^{-1} in laterals LLII, RLII and RRII respectively, while the average monthly discharge in laterals LLII, RLII and RRII were 0.34, 0.60 and 0.44 mm d^{-1}. The weighted average maximum flow was noticed during November (0.56 mm d^{-1}) and minimum during January (0.22 mm d^{-1}). It was clear that average of RLII was more compared to other two laterals throughout the study period

4.4 Leaching and Removal of Salts

The month wise quantities of salts removed from the fields in the study area by the influence of subsurface drainage system are presented in Table 4.26. The results revealed that under the main drain I, the maximum salts removed was 0.94 t ha^{-1} during December month, while the minimum was 0.44 t ha^{-1} in the month of January. Similarly, in case of main II, the maximum removal of salts (1.36 t ha^{-1}) was observed during November month and the minimum (0.63 t ha^{-1}) was noticed in January. The monthly average salts removed in main I was 0.64 t ha^{-1}, while that of the main II was 1.04 t ha^{-1}, which was greater than that of the main I. Further, the total amount of salts removed from the main drains I and II were 3.22 and 5.20 t respectively, thus the salt load removed in main II was higher than that of the main I by 61.49 per cent. In all, a total of 8.42 t of salt load was removed out from the entire study area during the cropping period in 2014-’15.

4.5 Water Table Investigation for Performance of SSD System

The particulars of water table depth below ground level (bgl) observed in the middle of pipe laterals (viz., LLII, LLI, LLIII, RRI, RRII and RRIII) in positions at L/2 distance and 2L/3 distance (Figures 4.5 and 4.6) on fortnightly basis are presented in Tables 4.27 and 4.28.

Table 4.23 Average weekly discharge of SSD lateral drains in the study area

Drain discharge, mm d^{-1}					
Sl. no.	Standard week	LLII	RLII	RRII	Overall weighted weekly average discharge
1	37	0.45	0.58	0.59	0.53
2	38	0.35	0.43	0.49	0.42
3	39	0.41	0.63	0.56	0.52
4	40	0.26	0.50	0.43	0.38
5	41	0.19	0.71	0.49	0.43
6	42	0.26	0.78	0.40	0.44
7	43	0.35	0.65	0.56	0.50
8	44	0.41	0.58	0.44	0.46
9	45	0.45	0.84	0.45	0.54
10	46	0.54	0.89	0.56	0.63
11	47	0.50	0.84	0.51	0.58
12	48	0.45	0.58	0.49	0.50
13	49	0.41	0.52	0.43	0.44
14	50	0.37	0.63	0.49	0.48
15	51	0.35	0.89	0.54	0.55
16	52	0.26	0.54	0.49	0.41
17	1	0.19	0.41	0.26	0.27
18	2	0.19	0.35	0.20	0.23
19	3	0.13	0.17	0.15	0.15
	Average	0.34	0.60	0.44	0.44

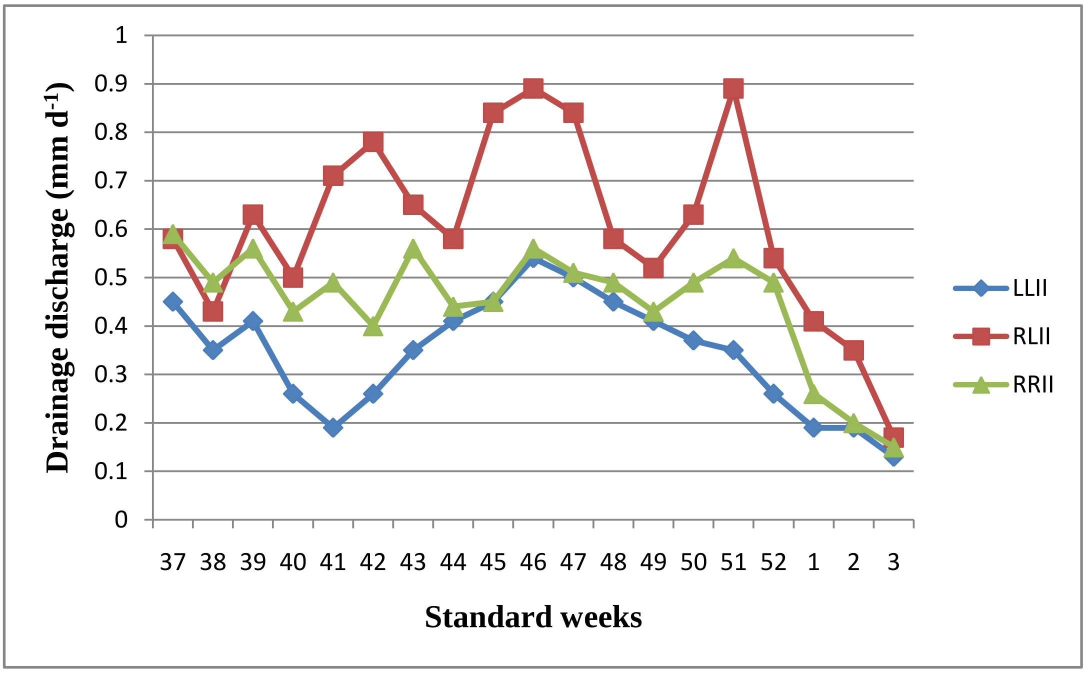

Fig. 4.2 Weekly discharge (mm d^{-1}) in SSD laterals

Table 4.24 Monthly discharge in SSD mains during September 2014 - January 2015

Monthwise drain discharge, mm d^{-1}							
Drain no.	Particulars	September	October	November	December	January	Average
	Mean	0.37	0.37	0.46	0.47	0.21	0.38
Main I	Max	0.42	0.44	0.49	0.54	0.23	
	Min	0.33	0.32	0.43	0.31	0.17	
Main II	Mean	0.68	0.68	0.73	0.64	0.32	0.61
-	Max	0.79	0.74	0.80	0.79	0.42	
	Min	0.61	0.58	0.65	0.52	0.23	
	Average	0.53	0.53	0.60	0.56	0.26	0.50
	Weighted average	0.53	0.53	0.60	0.56	0.26	0.50

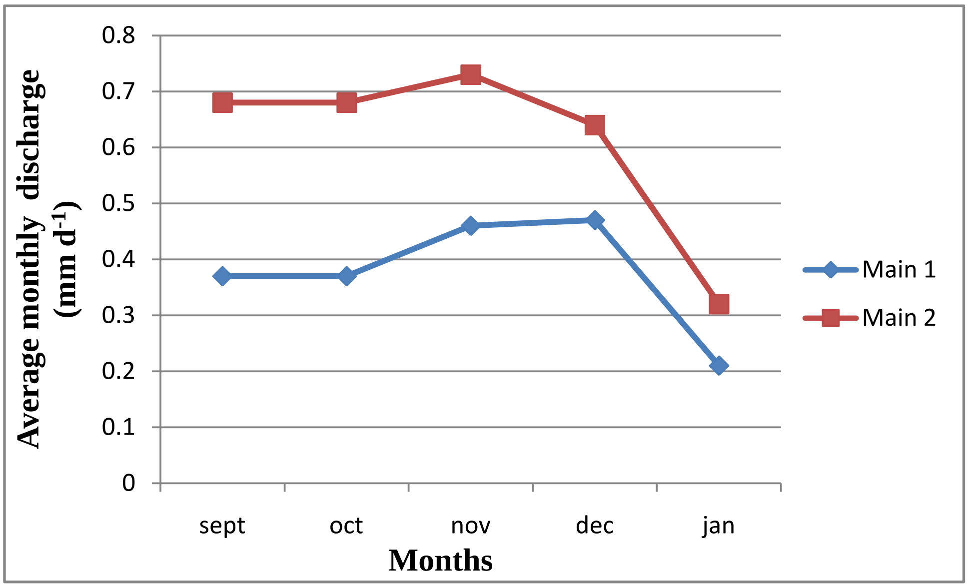

Fig. 4.3 Monthly average discharge (mm d^{-1}) in SSD main outlets

Table 4.26 Average salts removed in SSD system during September 2014-January 2015

Monthwise total salts removed (t ha^{-1})							
Drain no.	September	October	November	December	January	Monthly average	Total
Main I	0.52	0.54	0.78	0.94	0.44	0.64	3.22
Main II	1.08	0.97	1.36	1.15	0.63	1.04	5.20
Total	1.60	1.51	2.14	2.09	1.07	1.68	8.42

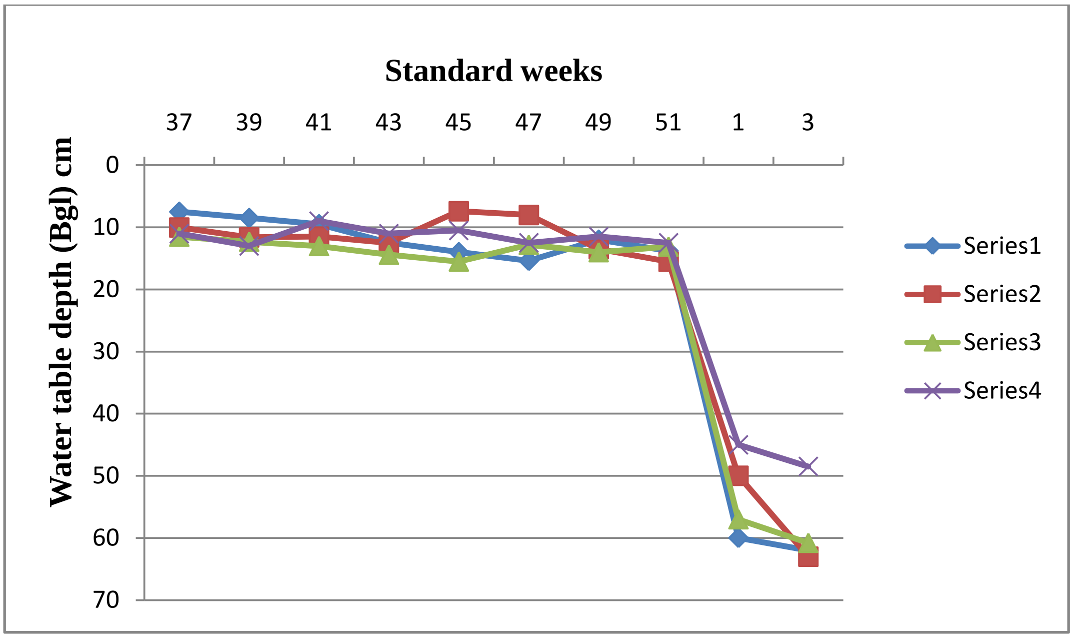

Fig. 4.5 Fortnightly water table depth (bgl, cm) in SSD area at L/2 distance

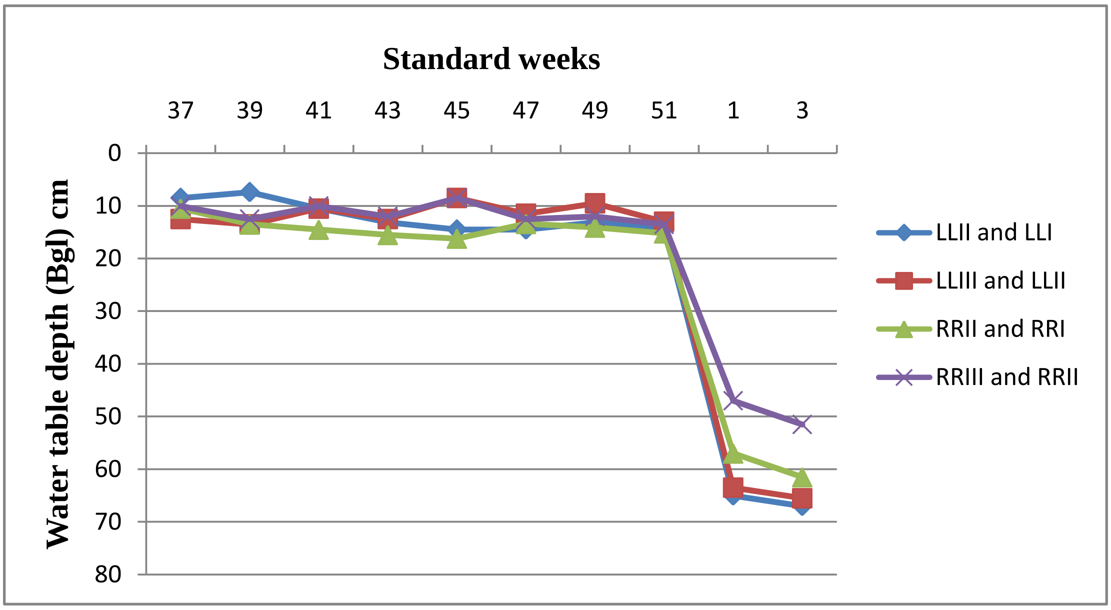

Fig. 4.6 Fortnightly water table depth (bgl, cm) in SSD area at 2L/3 distance

Table 4.27 Fortnightly water table depth in the middle of SSD laterals at L/2 distance

Standard weeks	Water table depth (bgl, cm)									
	37	39	41	43	45	47	49	51	1	3
LLII and LLI	7.5	8.5	9.5	12.5	14.0	15.4	12.0	13.8	60.0	62.0
LLIII and LLII	10.0	11.6	11.5	12.5	7.4	8.0	13.5	15.5	50.0	63.0
RRII and RRI	11.5	12.3	13.0	14.4	15.5	12.8	14.0	13.1	57.0	60.8
RRIII and RRII	11.0	13.0	9.0	11.0	10.5	12.5	11.5	12.5	45.0	48.5

Table 4.28 Fortnightly water table depth in the middle of SSD laterals at 2L/3 distance

Standard weeks	Water table depth (bgl, cm)									
	37	39	41	43	45	47	49	51	1	3
LLII and LLI	8.5	7.4	10.5	13.1	14.5	14.5	13.1	14.3	65.0	67.0
LLIII and LLII	12.5	13.5	10.5	12.5	8.5	11.5	9.5	13.0	63.5	65.5
RRII and RRI	10.5	13.5	14.5	15.5	16.2	13.4	14.1	15.2	57.0	61.5
RRIII and RRII	10.0	12.5	10.0	12.0	8.5	12.5	12.0	13.5	47.0	51.5

It was observed that at L/2 distance, the water table depth (bgl) ranged from 7.50 to 62.00, 7.40 to 63.00, 11.50-60.80 and 9.00 to 48.50 cm between LLII and LLI, LLIII and LLII, RRII and RRI and RRIII and RRI respectively. Similarly, at 2L/3 distance, it varied from 7.40 to 67.00, 8.50 to 65.50, 10.50 to 61.50 and 8.50 to 48.50 cm (bgl).

The average water table depths (bgl) between LLII and LLI during the study period at L/2 and 2L/3 positions were 11.65 and 12.01 cm, between LLIII and LLII at the same positions were 11.25 and 11.43 cm, between RRIII and RRII were 13.30 and 14.10 cm and between RRII and RRI were 11.40 and 11.37 cm respectively.

4.6 Water Table Investigation for SSD System Efficiency

The data pertaining to drainage efficiency in terms of water table depth (bgl) noticed in the series of observation wells placed between the pairs of laterals (LIII-LLII and RRIII-RRII) are presented in Tables 4.29 through 4.30. The results revealed that the average water table depths at mid points (25 m) in L/2 position were 11.25 and 13.30 (bgl) between laterals LLIII-LLII and RRIII-RRII respectively. It was observed that water table (bgl) was comparatively deeper at the above laterals at 21.70 and 23.60 cm (bgl) between LLIII-LLII and 22.70 and 23.00 cm between RRIII-RRII (bgl) laterals respectively as compared to that of the mid way between the laterals as given above (Figures 4.7 and 4.8).

4.7 Analysis of Soil Hydrologic Parameters

4.7.1 *In-situ* measurement of soil hydraulic conductivity

The *in-situ* hydraulic conductivity (K) was determined in the study area and the K-values are presented in Tables 4.31 and 4.32. The results revealed that the hydraulic conductivity before installation of subsurface drainage ranged between 0.053-0.085 m d^{-1}. The arithmetic mean (AM) of hydraulic conductivity for the area was 0.067 m d^{-1}, while the geometric mean (GM) of hydraulic conductivity was 0.066 m d^{-1}, which was lower than that of the AM. The combined average K of AM and GM was 0.067 m d^{-1}. Further, after installation of SSDs the hydraulic conductivity of the soil ranged from 0.065-0.096 m d^{-1}. The arithmetic mean (AM) of hydraulic conductivity for the area was 0.078 m d^{-1}. The geometric mean (GM) of hydraulic conductivity was 0.076 m d^{-1}, which was lower than that of the AM. The combined average K of AM and GM was 0.077 m d^{-1}.

Table 4.29 Monthly average water table depth in observation wells between laterals LLIII and LLII in SSD system at L/2 distance for drainage efficiency

Sl. no.	Month	Position	Distance in between laterals, m				
			0	12.5	25.0	37.5	50.0
			Water table depth (bgl, cm)				
1	September	L/2	20.7	15.8	10.8	14.3	21.8
2	October	L/2	25.3	16.3	12.0	15.1	24.3
3	November	L/2	19.0	13.1	7.7	13.9	24.2
4	December	L/2	21.7	19.4	14.5	17.0	24.3
		Average	21.7	16.1	11.25	15.1	23.6
5	January	L/2	85.8	77.7	56.5	73.8	91.6

Table 4.30 Monthly average water table depth in observation wells between laterals RRIII and RRII in SSD system at L/2 distance for drainage efficiency

Sl. no.	Month	Position	Distance in between laterals, m				
			0	12.5	25.0	37.5	50.0
			Water table depth (bgl, cm)				
1	September	L/2	21.0	15.2	11.9	15.9	20.1
2	October	L/2	23.3	16.8	13.7	17.5	23.2
3	November	L/2	22.3	18.1	14.2	18.9	24.1
4	December	L/2	24.3	17.6	13.6	18.0	24.4
		Average	22.7	16.9	13.3	17.6	23.0
5	January	L/2	85.3	75.7	58.9	73.0	85.4

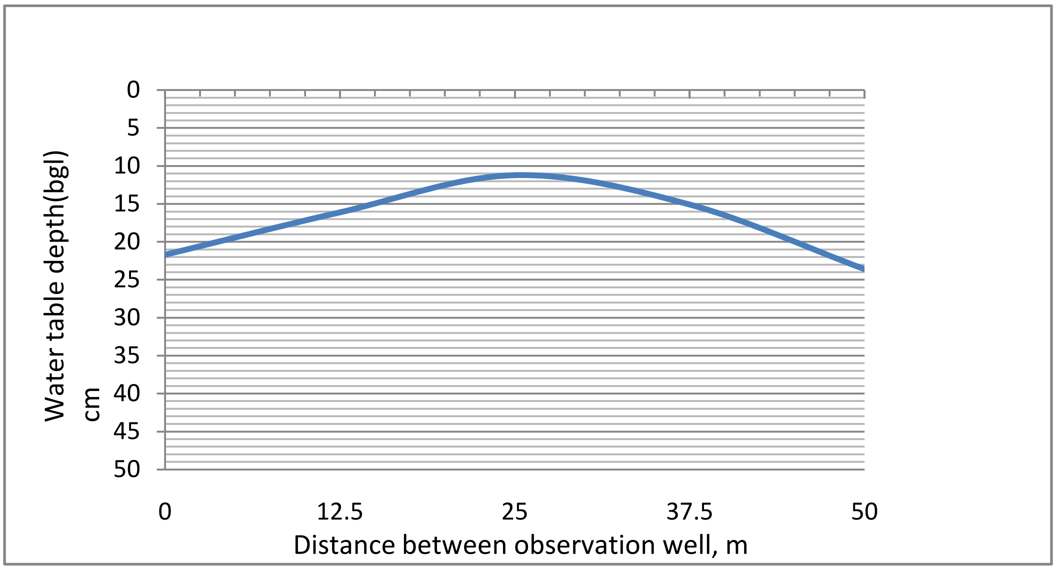

Fig. 4.7 Position of average water table depth (bgl, cm) between laterals LLIII and LLII at L/2 distance

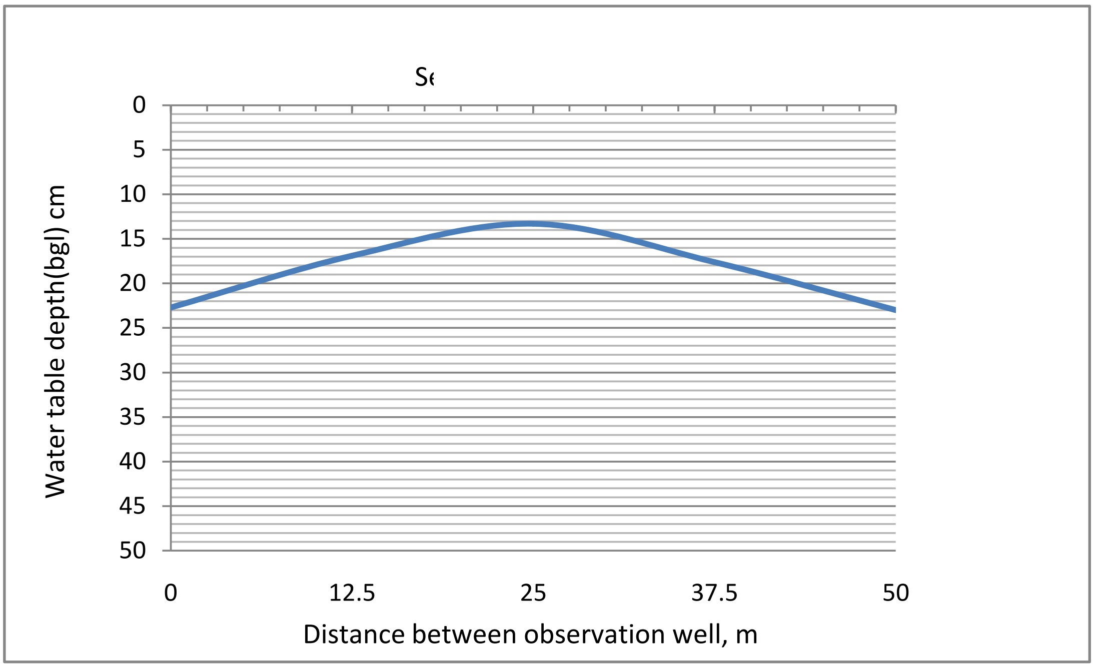

Fig. 4.8 Position of average water table depth (bgl, cm) between laterals RRIII and RRII at L/2 distance

Table 4.31 *In-situ* hydraulic conductivity measured in the study area before installation of subsurface drainage

Grid no.	Hydraulic conductivity (K), m d^{-1}	Arithmetic mean (AM), m d^{-1}	Geometric mean (GM), m d^{-1}	Average of AM and GM, m d^{-1}
1	0.064	0.067	0.066	0.067
2	0.053			
3	0.085			

Table 4.32 *In-situ* hydraulic conductivity measured in the study area after installation of subsurface drainage

Grid no.	Hydraulic conductivity (K), m d^{-1}	Arithmetic mean (AM), m d^{-1}	Geometric mean (GM), m d^{-1}	Average of AM and GM, m d^{-1}
1	0.073	0.078	0.076	0.077
2	0.065			
3	0.096			

4.7.2 Areal hydraulic conductivity of SSD system

The areal estimates of hydraulic conductivity (K) using Hooghoudt's equation, arithmetic and geometric means with their ranges for the SSDs along with 90 confidence limits are presented in Table 4.33. The results indicated that the areal hydraulic conductivity (K) ranged from 0.510-1.340, and 0.680-1.700 m d^{-1} in the areas between the laterals of LLIII-LLII, and RRIII and RRII with the AM and GM K values of 0.810-0.770 and 1.160-1.120 m d^{-1} respectively. Whereas, the overall K by considering the whole SSD system ranged between 0.51 and 1.70 m d^{-1} with AM and GM values of 0.985 and 0.945 m d^{-1} respectively. The hydraulic conductivity at 90 per cent confidence limits between LLIII-LLII and RRIII-RRII varied from 0.690 to 0.920 and 1.030 to 1.280 m d^{-1} with the overall value of 0.690-1.280 m d^{-1}. The areal estimates of K were nearly 15 times higher than that of the *in-situ* estimates of K.

Similarly, the areal estimate ranges of hydraulic conductivity below the drain level (only K_b) by Hooghoudt's equation between the pairs of pipe drains (PSSDs) with arithmetic and geometric mean values and 90 per cent confidence limits are shown in Table 4.34. The data revealed that K_b values ranged from 0.640-1.690 and 0.870-2.140 m d^{-1} for the areas between the laterals of LLIII-LLII and RRIII and RRII respectively. The corresponding arithmetic and geometric mean values of K_b were 1.020 and 0.980 and 1.460 and 1.420 m d^{-1} respectively. Considering the whole system, K_b varied between 0.640 and 2.140 m d^{-1}, with the AM and GM K_b values of 1.240 and 1.200 m d^{-1} respectively. The K_b at 90 per cent confidence limits between LLIII- LLII and RRIII and RRII ranged from 0.880 to 1.680 and 1.310 to 1.620 m d^{-1} with the overall range of 0.880 to 1.620 m d^{-1}. The areal estimates of K_b were nearly 16 times greater than that of the *in-situ* estimates of K.

4.7.3 Infiltration rate of soils

The basic infiltration rate was measured during June, 2014 before sowing using double ring infiltrometer in the study area and the results of infiltration rate are presented in Tables 4.35 and 4.36. The results of infiltration showed that the infiltration rates ranged from 2.00 to 4.50 mm h^{-1} with AM and GM values of 2.75 and 2.63 mm h^{-1} respectively. Further, after harvesting of the crop the rate ranged from 2.20 to 4.70 mm h^{-1} with AM and GM values of 2.90 and 2.79 mm h^{-1}.

Table 4.33 Areal hydraulic conductivity in SSD system

Sl. no.	Areal hydraulic conductivity, K (m d^{-1})				
	Between pipe SSDs	Range	Arithmetic mean (AM)	Geometric mean (GM)	90 per cent confidence limits
1	LLIII and LLII	0.510-1.340	0.810	0.770	0.690 < K > 0.920
2	RRIII and RRII	0.680-1.700	1.160	1.120	1.030 < K > 1.280
3	Average	0.510-1.700	0.985	0.945	0.690 < K > 1.280

Equation $q = \frac{2\pi dKh' + \pi Kh'h^*}{L^2}$

q = drain discharge, m d^{-1}

K = hydraulic conductivity, m d^{-1}

d = equivalent depth, m

h' = available hydraulic head (h-he), m

h = elevation of the water table midway between drains, m

h*= h+he, m

L = drain spacing, m

he = entrance head, m.

Table 4.34 Areal hydraulic conductivity below drain level in SSD system

Sl. no.	Areal hydraulic conductivity, K_b (m d^{-1})				
	Between pipe SSDs	Range	Arithmetic mean	Geometric mean	90 per cent confidence limits
1	LLIII and LLII	0.640-1.690	1.020	0.980	0.880 < K > 1.680
2	RRIII and RRII	0.870-2.140	1.460	1.420	1.310 < K > 1.620
3	Average	0.640-2.140	1.240	1.20	0.880 < K > 1.620

Equation $K_b = L^2 b/2\pi d$

$b = q/h'$

d = equivalent depth, m

L = spacing, m

K_b= hydraulic conductivity below drain level, m d^{-1}

h' = available hydraulic head, m.

Table 4.35 Infiltration rate in the study area before SSD system

Grids	Infiltration rate mm h^{-1}	Average infiltration rate, mm h^{-1}	GM of infiltration rate, mm h^{-1}
1	4.50	2.75	2.63
2	2.00		
3	3.00		
4	2.50		
5	2.00		
6	2.50		

Table 4.36 Infiltration rate in the study area after SSD system

Grids	Infiltration rate mm h^{-1}	Average infiltration rate, mm h^{-1}	GM of infiltration rate, mm h^{-1}
1	4.70	2.9	2.79
2	2.20		
3	3.10		
4	2.5		
5	2.20		
6	2.70		

Table 4.37 Land use pattern of the study area before and after the installation of subsurface drainage system

Sl. no.	Crop / land use	Before installation of SSD		After installation of SSD	
		Area, ha	Yield, q ha^{-1}	Area, ha	Yield, q ha^{-1}
1	Paddy (cropped area)	2.10	41.00	4.03	62.00
2	Uncultivated	8.55	-	6.62	-
3	Total area	10.65	-	10.65	-

4.8 Land Improvement and Crop Performance Studies

The performance of subsurface drainage works installed in the ARS farm, Malnoor was studied by monitoring the cropping pattern and cropping yield in the selected study area. The land use pattern of the study area before and after the installation of drainage system is shown in Table 4.37. It was observed that out of 10.65 ha land, earlier only 2.10 ha was utilised for the purpose of cultivation due to perpetual waterlogging and salinity problems caused by unscientific practices of land and water after the advent of irrigation in mid 1980s before the acquisition of land by the ARS. However, as a result of the drainage work, the land conditions improved. After the installation of the SSD system, the cropped area increased from 2.10 to 4.03 ha. The post-drainage yield also increased to 62.00 q ha^{-1} as compared to pre-drainage yield of 41.00 q ha^{-1}, which meant an increase of 51.21 per cent.

4.9 Economics of Subsurface Drainage System

The total returns, cost of cultivation, net returns, NPV, BCR, IRR and payback period after the implementation of the subsurface drainage system are presented in Table 4.38. It could be observed that the total cost of cultivation was found to be Rs. 40,000 ha^{-1}, while the NPV, IRR and B:C ratio were Rs.1,88,887, Rs.101 per cent and 1.46 respectively for 30 years of SSD life period. By considering all the investment and returns, the BCR was found to be above the acceptable limits and payback period obtained was 2 cropping seasons. Similarly, the NPV and IRR were Rs. 2,20,832 and Rs.104 per cent with a B:C ratio of 1.55 for the life span of 50 years. This meant that the installation of the subsurface drainage was found to be profitable even though the investment was very high.

The late *kharif* 2014 was the first cropping season after the installation of SSDs and there was considerable improvement in land conditions and paddy yield. Therefore, it could be expected the yield levels of crops would go still high in the succeeding cropping seasons and also the total returns, net returns, NPV, BCR, IRR and payback period would improve further.

Table 4.38 Economics of SSD system under the present study

Years	Total returns, Rs. ha^{-1}	Total cost of cultivation, Rs. ha^{-1}	Net returns, Rs ha-1	NPV, Rs ha^{-1}	BCR	IRR (%)	Payback period (seasons)
30	74,400	40,000	34,400	1,88,887	1.46	101	2
50	74,400	40,000	34,400	2,20,832	1.55	104	2

V. DISCUSSION

The results obtained from the present study conducted at the Agricultural Research Station, Malnoor regarding monitoring and performance evaluation of the existing SSD system are discussed in this Chapter.

5.1 Analysis of Soil Parameters

5.1.1 Soil reaction

The perusal of the data indicated that though there was slight increase in the soil reaction (pHs) value of soil sample drawn from 0-30, 30-60, 60-90 and 90-120 cm depths from 8.21 to 8.71 before sowing to 8.58 to 8.95 after harvesting of the crop, it was not significant for the same depths (Tables 4.1 and 4.2). However, there was significant difference in the mean pHs values between different depths. There was no pronounced effect of SSD system alone in reducing the soil pHs. Before sowing the soil from 0-60 cm depth showed saline-sodic characteristics and from 60-120 cm depth exhibited sodic characteristics, but after the harvesting, the entire depth of soil from 0-120 cm became sodic. In such cases, gypsum also should have been applied as amendment particularly to sodic soils, which would have reduced the sodicity of the soils considerably. Therefore, gypsum needs to be applied to the sodic portion of the affected area to quicken the process for complete reclamation of land. In both the situations of before the sowing and after the harvesting, the pHs increased with the depth. These observations were in line with the past studies which revealed that the pHs of the soil after the implementation of the subsurface drainage system increased (Barker *et al.*, 2001; Mathew *et al*., 2001 and Babu *et al*., 2010).

5.1.2 Soil salinity

The mean soil salinity (ECe) values before sowing ranged from 8.84 to 12.09 dS m^{-1} for different depths of 0-30, 30-60, 60-90 and 90-120 cm, with the surface layer consisting of higher ECe and it decreased with depth. Whereas, the situation was reversed after the harvesting wherein the ECe values were lowered to 7.25 to 12.06 dS m^{-1} with surface layer consisting of higher value and it increased as the depth increased (Tables 4.4 and 4.5). There was reduction in ECe by 7.38 to 66.75 per cent in 0-90 cm depth, while it increased by 36.43 per cent in 90-120 cm depth. This could be due to the fact that the salts got accumulated more at the surface layers in pre-drainage situation over a period of time due to development of waterlogging and salinity by excess flow of water along with salts and by the processes of high evaporative demands and capillary action. After the installation of SSDs, the paddy crop was taken up for cultivation. Due to this, the surface layer salts were partly leached to deeper subsurface layers due to impounding of water by rainfall and irrigation and by infiltration and deep percolation processes and were partly discharged out by drainage water through the laterals and the collector drains.

Manjunath *et al*. (2004) noted that the average salinity in the top soil of the study area decreased from an initial value of 8.40 ± 0.80 to 2.60 ± 0.40 dS m^{-1} during *kharif* 1998 and further to 2.10 ± 0.50 dS m^{-1} during *rabi* 1998–1999. The harmful salts that were brought in by the irrigation water were also reduced to a level ranging from 1.20 to 35.40 dS m^{-1} (Babu *et al.*, 2008), which meant that subsurface drainage system was efficient in the reduction of soil salinity. The ECe of soil was the highest in April and lowest in October 2003 (Kamble *et al.*, 2006). The results of the present study were in agreement with similar findings of Patra *et al*. (2000a) and Babu *et al*. (2010).

5.1.3 Exchangeable cations of soil

5.1.3.1 Exchangeable sodium

The soil exhibited higher exchangeable sodium content in the surface layer than that of the deeper layers due to higher evaporation and capillary rise of dissolved sodium in the summer season. With the ponding of water after the transplanting of the paddy crop, part of the sodium was dissolved in the water and drained away (Tables 4.7 and 4.8). Though the drains were found working well, but not found much efficient in the reduction of the sodium concentration from the soil. This could be attributed to the fact that gypsum was not applied. There might be likely chance of reduction in sodium content in the upcoming years with the application of gypsum. The magnitudes of reduction in sodium content were recorded as 13.10 and 12.60 per cent at 60-90 and 90-120 cm drainage depths respectively (Jadho *et al.*, 2009).

5.1.3.2 Exchangeable calcium and magnesium

The content of both exchangeable calcium and magnesium was more during pre-sowing conditions and after the harvesting of the crop there was slight reduction in the same (Tables 4.10 and 4.11) due to leaching effect and draining of water from the field. This was in line with the findings of Mathew *et al*. (2001).

5.1.3.3 Exchangeable potassium

The results of mean exchangeable potassium **(**K^+) values revealed that there was an increase in the potassium content in the soil after harvesting of the crop by 66.67 to 68.75 per cent as compared pre-sowing conditions (Tables 4.13 and 4.14). This might be due to the excess application of the fertilizers to the field, even though smaller amount of potassium was leached out through the drains. These results were in confirmation with findings of Jadho *et al.* (2009)

5.1.4 Exchangeable sodium percentage

The exchangeable sodium percentage (ESP) content was higher at the surface depths (21.45 to 21.02) compared to that of the subsurface layers (19.90 to 17.99) before sowing and after harvesting (19.90 to 19.67 and 18.83 to 17.07). However, there was reduction in ESP at all the depths after the harvesting (7.23 to 5.11%) as compared to pre-sowing conditions. Also, there was significant difference between the mean values of ESP at different depths (Tables 4.16 and 4.17). The reduction in ESP was due to the SSD system, which helped in leaching of salts. However, the reduction was not considerable without the application of gypsum as it was to needed to be applied to tackle the sodicity conditions. With application of the gypsum in the following season(s), it is expected that the reclamation process would be complete by significant reduction in ESP. As explained earlier under soil salinity section, the build-up of ESP was due to the problems of waterlogging and salinity/sodicity. After the provision of SSDs, the salts from the upper layers pushed downwards by leaching to deeper layers and onto the lateral drains. These results were in agreement with that of the studies which revealed that the ESP reduced after the implementation of the subsurface drainage system (Pradeep *et al.,* 2005; Kamble *et al.,* 2006).

5.2 Analysis of Leachate Water Quality

5.2.1 Salinity and ionic composition of leachate from SSD main outlets and laterals

The ionic composition of the leachate collected from the outlets of the collector mains and the manholes of the laterals was dominated by sodium followed by calcium, magnesium and potassium among the cations and by chlorides followed by bicarbonates sulphates in case of anions. Further, that the ionic concentration of leachate was much more than the canal water (Table 4.20). Particularly, the leachate with the salinity (EC) range of 7.20 - 12.50 dS m^{-1} was 8 to 12 times higher than the canal water with EC of 0.70 to 1.10 dS m^{-1}. This is true because that initially, after the installation of SSDs due to leaching of salts, the leachate quality would be very poor and the quality would improve over time depending on the intensity of salinity of the soil and the crop and irrigation management practices. The results of mean EC of 9.68 dS m^{-1} in the collector mains and 9.44 dS m^{-1} in the laterals implied that the reclamation process might take few seasons or couple of years so that the leachate quality would come in equilibrium with the canal water. The concentration of the leachate was found to be nearer to severe conditions or of highly poor quality, hence it was not good for utilization for the purpose of irrigation. The pH of the leachate varied from 7.10-9.10 in the collector mains and from 6.20-8.50 in the laterals in the study area during the monitoring period.

The mean pH of leachate reduced from 8.01 to 7.67 due to SSD system during November 1998 to May, 1999 in the Upper Krishna Project command area (Barker, 2000). These results were corroborated by the study of Girish (2003). Tahir and Nasir 2008 noticed that the average pH of drain outflow was in the range of 8.10-8.11, whereas irrigation water was slightly alkaline in the range of 7.38.

5.2.2 EC and pH of groundwater and canal water

The reaction of both groundwater (pH 7.70 and 7.58) and canal water (pH 7.10 and 7.15) was neutral with during September and December 2014 respectively. But the mean EC of groundwater was very high with 9.47 dS m^{-1} and found to be more than 15 times higher than that of the canal irrigation water with mean EC of 0.61 dS m^{-1}. This also explained the reasons for rendering higher salinity in the soil. The groundwater salinity could be expected to reduce by leaching of salts when cultivation of crops is taken up continuously in the following seasons.

The root zone salinization was found to occur by capillary fringe of brackish groundwater (Yadav *et al.*, 1999). Subramany (1989) also observed that groundwater reaction was neutral in the UKP command area. Groundwater reaction was neutral with mean pH values of 7.49 and 7.62, 7.45 and 7.57 during January 1997 and 1998 and June 1997 and 1998, respectively and EC was observed to be very high at several locations (Shirahatti *et al.*, 2006).

5.3 Monitoring of SSD Discharge

The average weekly drain discharge varied from 0.38 mm d^{-1} in the collector main I to 0.62 mm d^{-1} in the collector main II, with the overall weighted average discharge of the SSD system was 0.50 mm d^{-1} (Table 4.22). This magnitude of drain discharge could be categorized as low drainage discharge / coefficient. The drain discharge was low due to lower rate of hydraulic conductivity and sodic nature of the soil (0.067 mm d^{-1}). The discharge could be increased in the following seasons by application of gypsum and organic manure to the soil. Further, the drain discharge was higher in main II by 63.15 per cent over that of main I. This could be attributed to the fact that the influencing area of the main II is located at lower elevation comparatively than that of the main I area, thereby it could intercept some flow from the influencing area of main I. The lower discharge was found in the month of January (3st week) mainly due to no water flow in the canal and also as the crop had matured and no irrigation was given to the crop.

The average monthly drain discharge in the collector main I was 0.38 mm d^{-1} and that of the collector main II was 0.61 mm d^{-1}, which was 63.15 per cent more than that of the main I. The overall weighted average was 0.50 mm d^{-1} considering the whole study area (Table 4.24). The monthly discharge during the study period was found to be almost equal during September to December 2014, as this period coincided partly with the crop season and the rainy period except January 2015 during which no irrigation was supplied and no rainfall was received since by the end of first week, the crop was harvested (Table 4.24).

The average weekly drain discharges in laterals LLII, RLII and RRII were 0.34, 0.60 and 0.44 mm d^{-1} in the RRII, with the overall weighted average discharge of 0.44 mm d^{-1} (Table 4.23). Further, the drain discharge was more in RLII lateral (0.60 mm d^{-1}) by 26.67 and 43.33 per cent over RRII (0.44 mm d^{-1}) and LLII (0.34 mm d^{-1}) respectively. This magnitude of drain discharge could be categorized as low drainage discharge/coefficient. The drain discharge was low due to lower rate of hydraulic conductivity and sodic nature of the soil. The discharge could be increased in the following seasons by application of gypsum and organic manure to the soil. The discharge was observed to be more in RLII this could be attributed to the fact that the influencing area of the main II is located at lower elevation comparatively than that of the main I area, thereby it could intercept some flow from the influencing area of main I. The lower discharge was found in the month of January (3rd week) mainly due to no water flow in the canal and also as the crop had matured and no irrigation was given to the crop.

The average monthly drain discharge in the laterals were 0.34, 0.60 and 0.44 mm d^{-1} in LLII, RLII and RRII respectively. The lateral RLII registered 78.79 and 34.09 per cent higher discharges over LLII and RRII respectively. The mean monthly lateral discharges from September 2014 to January 2015 were 0.46, 0.46, 0.56, 0,47 and 0.22 mm d^{-1}, while the overall weighted average monthly discharge was 0.44 mm d^{-1}. The weighted average drain discharge was more in main outlets since the discharges of laterals not connected to the inspection chambers also joined to the mains and poured their discharges into them. Their discharges could not be measured since they were joined directly to the mains without the inspection chambers.

The results were similar to the findings of Manjunath *et al.* (2004) and Babu *et al.* (2010). Manjunath *et al.* (2004) noticed that, after the transplanting of the paddy crop, the higher drain discharge was recorded with maximum of 0.60 mm d^{-1} during the September month in 1998 and 1999, which coincided with the monsoon season and the paddy crop in the fields. Even with this low drain discharge, their study area comprising of waterlogged and salt-affected lands in the Tungabhadra command area, Karnataka could be reclaimed.

5.4 Leaching and Removal of Salts

The amount of salts removed from the field by the influence of subsurface drainage system to the natural drain was more in SSD main II (5.20 t ha^{-1}) by 61.49 per cent than SSD main I (3.22 t ha^{-1}) due to high drain discharge that carried away more salts through the main II as compared to the main I (Table 4.26). This outgoing salt load over a period of time depending of cropping and irrigation practices would help in reducing the soil salinity and thereby facilitate restoration of soil production capabilities. The findings of the following studies were in line with that of the results of the present investigation.

Srikanth *et al*. (2004) in their study of salt and water balance in SSD executed area in Upper Krishnan Project (UKP), Karnataka assessed the salt loads as 0.98 and 1.09 t during *kharif* and *rabi* seasons respectively which were disposed through the drainage system. Srinivasulu *et al.* (2006) estimated the total quantity of salts disposed through subsurface drainage systems during the three consecutive years during 1999 to 2002 as 567.21 and 197.92 t at the rate of 81.03 and 39.58 t ha^{-1} through pipe and open drainage systems, respectively. Kuligod *et al*. (2009) computed the quantities of salts carried away in SSD system in UKP command area. A study by Babu *et al.* (2010) revealed that the salts at the rate of 7.30 t ha^{-1} were leached during first year 2006-’07 after installation of subsurface drainage, which gradually reduced to 1.87 t ha^{-1} during 2007-’08 and 2.75 t ha^{-1} during 2008-’09, which was expected.

5.5 Water Table Investigation for Performance of SSD System

The monitoring and measurement of water table depth in the middle of pipe laterals (*viz.*, LLII, LLI, LLIII, RRI, RRII and RRIII) on fortnightly basis was found to follow the elliptical pattern with the water table comparatively at deeper depth directly over the lateral drainage line (21.7 – 24.3 cm, bgl) than the water table nearer to the ground level at the centre in between the lateral lines at L/2 and 2L/3 positions of the lateral length (11.2 – 13.3 cm, bgl) after irrigation and/or rainfall (Figures 4.5 and 4.6 and Tables 4.27 and 4.28). However, the water table depth was shallower which needs to be still lowered below at least by 20-30 cm even for conducive growth of paddy crop. Based on these observations, presently it seemed that the spacing of 50 m was inadequate. With application of gypsum and FYM and cultivation and cultivation of crops for few more seasons, the performance of the drains could be correctly assessed.

Further, as revealed by the past studies, the root zone salinity is more harmful for paddy than shallow water table conditions. Once the soil salinity is reduced to below the threshold salinity level, even with shallow water table conditions, paddy could grow well, provided the groundwater is of good quality. For growing other crops, the water table should be lowered to 0.90 - 1.00 m (bgl). Generally after the installation of SSDs, paddy being high water consumptive use crop is grown for quickening the process of leaching of salts. That way, paddy was grown in the study area during the first season after the laying of SSDs. It is expected that by application of gypsum and cultivation of crops in the following few seasons, the soil salinity would be expected to go down. After the salinity has reduced, light-irrigated crops could be taken up, which would lower the water table.

5.6 Water Table Investigation for SSD System Efficiency

The monthly average water table depths (bgl) noticed in the midway between the pairs of laterals (LIII and LLII, LII and LI, RRIII and RRII and RRII and RRI) at L/2 position along the laterals were 11.2, 11.6, 13.3 and 11.4 cm, bgl (Figures 4.7 to 4.8). The performance of the SSD system was inefficient as the water table could not be lowered much to the desired level. The water table depth between the laterals LLII-LLI and RRII-RRI was found to be at ground level near the laterals LLII and RRII respectively, due to more seepage of water from upland area and alomost continuous ponding of water in the field for paddy crop. Further, there was chance of seepage of water into the field from nearby distributary.

Due to all these factors, the drainage system efficiency was found to be low; as a result, the water table remained at shallow depths. The results obtained were in agreement with the similar findings of Barker (2000) and Girish (2003).

5.7 Analysis of Soil Hydrologic Parameters

5.7.1 *In-situ* soil hydraulic conductivity

The *in-situ* hydraulic conductivity ranged from 0.053 to 0.085 m d^{-1} depending on the variations in soil texture in the study area with arithmetic mean of 0.067 m d^{-1}, geometric mean of 0.066 m d^{-1} and combined average of 0.067 m d^{-1}. The minimum values were observed in the upper reach of the area and highest was observed in the lower reach nearer to the nala, where the soil was slightly coarser in nature. The arithmetic and geometric mean values were almost close to each other. The results obtained were similar to the findings of Barker (2000), Girish (2003), Shirahatti *et al*. (2005) and Balakrishnan *et al.* (2005). By doing reverse calculations assuming the depth to impervious layer (D) below the drain as 3 m and elevation of water table midway between and above the drains (h) as 0.75 m, with the drain discharge of 0.50 mm d^{-1}, the drain spacing was worked out as 44 m. With 5 m as depth to impervious layer, the spacing was worked out to be 48 m. That way, the spacing adopted was slightly higher than the computed one. In spite of this, the water table observed was shallow, which could also be attributed to the sodicity of the soil that had reduced the permeability of flow.

5.7.2 Areal hydraulic conductivity of SSD System

The geometric mean estimates of areal hydraulic conductivity were 0.945 (K) and 1.200 m d^{-1} (K_b) and the 90 per cent confidence limits ranged from 0.69 to 1.280 m d^{-1} (K) and 0.880 to1.620 m d^{-1} (K_b) (Tables 4.33 and 4.34). Upon comparison, the hydraulic conductivity below the drain (K_b) was higher than the K by 26.52 per cent indicating that the flow below the drain was pre-dominant. This could be due to the presence of the permeable subsurface strata below drain level through which more amount of seepage could take place. Further, the areas estimates of K were far greater (15 to 16 times) than the *in-situ* measurements of K.

Studies by Balakrishnan *et al.* (2005) showed that the areal estimates of hydraulic conductivity (K) and hydraulic conductivity below drain level (K_b) values obtained by the drain outflow method were far greater (10-13 times) than the point measurements of hydraulic conductivity by post auger-hole method obtained from the investigations. Further, the flow below the drain was found to be dominant. The observation of higher hydraulic conductivity by drain outflow method in comparison with the post-auger hole method measurements was also in agreement with the findings of El-Mowelhi and Van Schilfgaarde (1982); Holsambre *et al.* (1982) and Suryawanshi *et al.* (1991).

5.7.3 Infiltration rate of soils

The infiltration rate was found to be very low as the soil consisted of considerable amount of clay (32-41%). There was only slight increase in infiltration rate by 5.45 per cent due to improvement by SSDs after the harvesting (2.90 mm h^{-1}) compared to that before sowing (2.75 mm h^{-1}). Though this change in infiltration rate after the installation of drainage was presently insignificant it could be expected that with continuous cultivation of crops in the following seasons and with application of gypsum and organic matter, there would be considerable improvement. Similar, findings were observed by Barker (2000), Girish (2003) and Srikant *et al*. (2004).

5.8 Land Improvement and Crop Performance Studies

Though the entire study was not put under cultivation immediately after the installation of SSDs due to some constraints or of low priority within the activities of the ARS farm, Malnoor, the cropped area of 2.10 ha under paddy crop prior to SSD situation almost doubled to 4.03 ha in the post drainage *kharif* season (Table 4.37). This meant that the cropping intensity of 19.72 per ecnt before the drainage works increased to 37.84 per cent after the installation of SSDs. Due to the affliction of waterlogging and salinity, most of the area was not cultivated earlier. However, it is expected that in the following seasons more area could be brought under cultivation of crops as the soil conditions would improve by the process of reclamation in due course. The installation of SSD system resulted in improvement of paddy yield to 6.20 t ha^{-1} compared to 4.10 t ha^{-1} before the drainage works, thus there was increase in yield by 51.21 per cent. As it was the first year after the installation of the SSDs, the yield could be expected to improve considerably during the succeeding seasons with appropriate and better cropping and irrigation management practices.

Generally, most of the studies carried out on subsurface drainage system in reclamation of waterlogged and salt-affected lands with or without the application of amendments depending on the nature of the problems showed that the deteriorated soil conditions of EC, pH, ESP, water table, groundwater quality and crop area and yield improved considerably. The extent and period of reclamation and process and restoration of soil production capabilities depended on the appropriate cropping and water management practices. The returns on crop yields before and after the drainage system were compared and land utilisation was intensified after the installation of drainage, as a sizeable area of formerly fallow land was brought under cultivation (Shekhawat, 2007). The grain yield data collected from 62 grid points indicated a steady increase from 2005 to 2008. The average grain yield obtained during *kharif* 2005, 2006, 2007 and 2008 were 2.90, 3.80, 4.50 and 4.90 t ha^{-1} respectively (Babu *et al.,* 2008). Increase in grain yield due to subsurface drainage was reported in previous studies of Balakrishnan (2000), Barker (2000), Mathew *et al*. (2001), Girish (2003), Satyanarayana and Boonstra (2007) and Ritzema *et al*. (2008). The yield of soybean at subsurface drainage treatment was higher than that from the open ditch drainage (Jung *et al*., 2010).

5.9 Economics of the Subsurface Drainage System

The performance of subsurface drainage system was valued both in terms of economic returns. However, it is important that a technically feasible proposal should be financially viable and socially acceptable for successful adoption. The economic analysis of subsurface drainage was done by considering the gross returns, cost of cultivation, discounted cost, discounted returns and net discounted returns. The initial cost of installation was found to be much higher but over a period of time the cost could be recovered. The drainage installation influenced in increased net returns and B:C ratio NPV and IRR were 1.46, Rs. 1,88,887 and 101 per cent respectively with a payback period of 2 cropping seasons considering the life of SSD system as 30 years. Similarly for 50 years of SSD life, the BCR, NPV and IRR were 1.55, Rs. 2,20,832 and 104 per cent respectively. Thus, the SSD system was found to be worth investing and profitable venture in reclamation of waterlogged and salt-affected lands.

The late *kharif* 2014 being the first cropping season after laying of SSDs and there was good improvement in land conditions and paddy yield. Further, as observed in this part of the region, the paddy yields are achieved as high as 9-10 t ha^{-1}, with the application of amendment of gypsum and FYM as well as better land, water and crop management practices, considerable improvement in yield levels of crops could be definitely expected in the succeeding cropping seasons and also the total returns, net returns, NPV, BCR, IRR and payback period.

The introduction of subsurface drainage proved to be beneficial for the most expensive (composite pipe drainage) systems with the B:C ratios varying between 1.20 and 3.20 (Ritzema *et al.*, 2008), while (Shekhawat, 2007) obtained a B:C ratio of 2.44. It was observed that the B:C ratio was found to be 4.03 for the drainage adoptive farmers and 2.37 for non-adoptive farmers (Patra *et al.,* 2000a). The B:C ratio of SSD system with mono-crop of late *kharif* paddy was estimated at 1.24. (Babu *et al.,* 2010). The results under the present investigation obtained were also in line with the findings of Reinders *et al*. (2014).

Though the initial investment was found to be higher especially for the marginal, small or poor farmers, it is worth investing in SSD projects since it was found to be much beneficial in improving the crop yields and the farm returns and also the invested amount could be recovered in a few seasons. Further, as the waterlogging and salinity problems are of generally contiguous and serious nature resulting in lands becoming unproductive or under productive or even barren in severe cases as well as huge amount was spent in creation of irrigation potential, the Centre and State Governments should come forward in taking up large scale reclamation projects for restoration of production capabilities of affected lands and for improving the economic livelihood of the farmers at large.

VI. SUMMARY AND CONCLUSIONS

Phenomenal irrigation development in India since independence, has greatly contributed to "Green Revolution". However, the same attention has not been given to land drainage. This coupled with unscientific practices of land and water management have caused the twin menacing problems of waterlogging and salinity in irrigation command areas. These problems have led to degradation of agricultural lands considerably and reduction in crop yields, thereby hinder the sustainability of irrigation systems and even pose question for the investment in irrigation sector. The state of Karnataka is no exception to this, and considerable extent of irrigation command areas were affected by these problems. After the advent of irrigation in the UKP command area, the problems of waterlogging and salinity are on the rise at alarming rate. Towards tackling these problems, subsurface drainage systems (SSDs) are being taken up in the command area. Similarly, the SSDs were installed in few blocks comprising of waterlogged and salt-affected areas for reclamation in the farm of ARS, Malnoor under the UAS Raichur near Hunsagi, Shorapur taluk, Yadgir district during 2013-'14. The study area is located within the UKP command and under the present study, subsurface drainage system installed in an area of 10.65 ha in G-block in the above farm was taken up for performance evaluation during the first season. Accordingly, the soil physico-chemical parameters, drain discharge, leachate quality, water table depth, crop area and crop yield improvement in the post-drainage situation due to execution of subsurface drains were monitored during late *kharif* 2014-'15 and compared to the pre-drainage conditions as well as the economics of the subsurface drainage system was worked out.

The following conclusions are drawn based on the results obtained in the present investigation on performance evaluation and impact of subsurface drains:

- There was no significant change in pHs before sowing (8.21 to 8.71) and after harvesting of the crop (8.58 to 8.95) for the same depths, but it increased with depth. However, there was significant difference in the mean pHs between different depths. Before sowing the soil at 0-60 cm depth showed saline sodic characteristics and 60-120 cm depth exhibited sodic characteristics, but after harvesting, the entire depth of 0-120 cm became sodic. Therefore, gypsum needs to be applied for complete reclamation of land.

- The soil salinity (ECe) was higher at the surface layer before sowing (12.09 to 8.84 dS m^{-1}) and decreased with soil depth and it was *vice-versa* after harvesting (7.25 to

12.06 dS m^{-1}). There was significant difference in ECe between different depths in both the cases. Due to impact of SSDs after harvesting of crop, the ECe reduced significantly by 66.75 and 32.97 per cent at 0-30 and 30-60 cm depths, but it increased significantly by 36.43 per cent at 90-120 cm depth respectively.

- The exchangeable sodium percentage (ESP) decreased with depth with higher values at the surface layers (21.45 to 21.02) compared to that of the subsurface layers (19.90 to 17.99) before sowing and after harvesting (19.90 to 19.67 and 18.83 to 17.07) respectively and there was significant difference between them. Though there was reduction in ESP at all depths after the harvesting (7.23 to 5.11%) as compared to pre-sowing conditions, it was still not considerable to desired level without the application of gypsum.

- The concentrations of calcium and magnesium significantly reduced in the soil after the harvesting (32.91 to 37.62 meq/100 g) as compared to pre-sowing conditions (34.68 to 39.76 meq/100 g) by 3.00 - 6.50 per cent at different depths and these values decreased with depth due to leaching of salts through SSDs.

- The potassium content decreased with depth and increased significantly by 66.60 - 83.30 per cent from the pre-sowing conditions (0.12-0.16 meq/100 g) to post-drainage situation (0.20-0.27 meq/100 g), which was due to application of fertilizers to the field.

- The soil exhibited higher exchangeable sodium content in the surface layers than that of the deeper layers and it decreased significantly by 9.85-16.50 per cent from the pre-sowing situation (7.80-10.92 meq/100 g) to after harvesting of crops (7.10-9.40 meq/100 g) at different depths due to leaching of salts. However, the sodium content still has to be reduced by application of gypsum to restore soil production capabilities.

- The ionic composition of leachate was dominated by sodium, while the anionic concentration of leachate was dominated by chlorides and bicarbonates. The leachate salinities with mean EC of 9.68 dS m^{-1} in collector mains and 9.44 dS m^{-1} in laterals were 15 to 16 times higher than the canal water (0.61 dS m^{-1}) and hence found not fit for irrigation. The pH of the leachate showed neutral reaction, which varied from 7.10-9.10 and 6.20-8.50 in collector mains and laterals respectively against 7.10-7.15 in canal water.

- The reaction (pH) was neutral in both groundwater (7.64) and canal water (7.13), while the mean salinity of groundwater was very high with the EC of 9.47 dS m^{-1} as compared to canal water EC of 0.61 dS m^{-1}. The EC of groundwater was nearly 15 times higher than that of the canal irrigation water, which also explained the reasons for rendering higher salinity in the soil.

- The average weekly discharges were 0.38 and 0.62 mm d^{-1} in SSD collector mains I and II (higher by 63.16% over that of main I) respectively, with the overall weighted average drain discharge of 0.50 mm d^{-1}. The same in SSD laterals ranged from 0.34 to 0.60 mm d^{-1} with the overall weighted average discharge of 0.44 mm d^{-1}. This magnitude could be categorized as low drain discharge and attributed to lower rate of hydraulic conductivity (0.067 m d^{-1}) and sodic nature of the soil.

- The average monthly discharges were 0.38 and 0.61 mm d^{-1}in SSD collector mains I and II (37.70% more than that of main I) with the overall weighted average drain discharge of 0.50 mm d^{-1}. The same in SSD laterals varied from 0.34 to 0.60 mm d^{-1} with the overall weighted average drain discharge of 0.44 mm d^{-1}.

- The total amount of salts removed from the field by the influence of subsurface drainage system to the natural drain during the study period was 8.42 t. The magnitude of salt load removed was higher in SSD main II (5.20 t) by 61.49 per cent than SSD main I (3.22 t) due to more drain discharge. Despite this, still much more salt load has to be removed for achievement of full land reclamation.

- The water table in between the laterals followed elliptical pattern with its position deeper directly over the SSD lateral line (21.7-24.3 cm, bgl) compared to water table nearer to the ground level at the centre (11.2-13.3 cm, bgl) at L/2 and 2L/3 positions of the lateral lengths after irrigation and/or rainfall. As the water table remained shallower, the performance / drainage efficiency of the SSD system could be considered as low. Thus, the water table needs to be still lowered below at least by 20-30 cm for conducive growth of paddy crop and 60-70 cm for light-irrigated crops.

- The *in-situ* hydraulic conductivity (K) ranged from 0.053 to 0.085 m d^{-1} with same arithmetic mean, geometric mean and combined K average of 0.067 m d^{-1} before sowing, and improved slightly (14.92%) after the harvesting to 0.065-0.096 m d^{-1} with similar arithmetic mean, geometric mean and combined K average of 0.077 m d^{-1}. The computed drain spacing of 48 m by reverse calculations was slightly lower than that of the spacing adopted (50 m). With this spacing, shallower water table observed could be attributed to reduction in permeability of flow due to soil sodicity.

- The geometric mean estimates of areal hydraulic conductivity obtained by q-h (discharge *vs* head) relation were 0.945 for entire depth (K) and 1.20 m d^{-1} for below the drain (K_b) and the 90 per cent confidence limits ranged from 0.69 to 1.280 m d^{-1} (K) and 0.88 to 1.620 m d^{-1} (K_b). Thus, the hydraulic conductivity below the drain (K_b) was higher than the K by 26.52 per cent indicating that the flow below the drain was pre-dominant. Further, the areas estimates of K were far greater (15 to 16 times) than the *in-situ* measurements of K. As these areal estimates of K were obtained based on the monitoring of existing SSD project, they could be more reliable and recommended for adoption in the design of future SSD projects to obtain realistic results.

- The infiltration rate was very low due to considerable amount of clay (32-41%) and it improved slightly (by 5.45%) due to SSD system after the harvesting (2.90 mm h^{-1}) compared to that before sowing (2.75 mm h^{-1}). Though this change was presently insignificant, it could improve further by continuous cultivation of crops and application of gypsum and organic matter.

- Despite the fact that the entire study was not put under cultivation immediately after the installation of SSDs due to some reasons, the cropped area of 2.10 ha under paddy crop in pre-drainage situation almost doubled to 4.03 ha in the post-drainage late *kharif* season, which meant that the cropping intensity of 19.72 per cent increased to 37.84 per cent. As a result of SSD system, paddy yield improved by 51.21 per cent from 4.10 to 6.20 t ha^{-1}. This being the first season after the installation of the SSDs, the yield could be expected to improve considerably during the succeeding seasons.

- Any technically feasible SSD proposal needs to be financially viable and socially acceptable for the successful adoption. As per the economic analysis of subsurface drainage system under the present study, the cost of SSD system, cost of cultivation, gross returns and net returns per ha were Rs. 67,081, Rs. 40,000, Rs.74,400 and Rs. 34,400 respectively. The B:C ratio, NPV, IRR and payback period were 1.46, Rs. 1,88,887, 101 per cent and 2 cropping seasons for 30 years of life period of SSD system. Similarly, the same were 1.55, Rs. 2,20,832, Rs.104 per cent and 2 cropping seasons for the life span of 50 years for SSD system. This meant that the subsurface drainage work was found to be worth investing and profitable even though the investment was huge. As the paddy yields of 8-9 t ha^{-1} and even more are common in this region, with the application of gypsum as well as better resource management practices, considerable improvement in yield levels of crops and also the total returns, net returns, NPV, BCR, IRR and payback period could be definitely expected in the succeeding cropping seasons.

Suggestion for Future Work

The study needs to be continued with application of gypsum and FYM and monitored for assessing the impact of SSD system during *kharif* and *rabi* seasons for few more years on soil physico-chemical and hydrologic parameters and crop yield.

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APPENDIX - I

Rainfall data in the study area

Mean monthly rainfall data in the study area during 1991 to 2014

Month	Mean rainfall (mm) during 1991-2014
January	5.4
February	1.6
March	11.1
April	17.4
May	47.7
June	68.8
July	53.9
August	92.1
September	125.8
October	96.4
November	20.1
December	6.8
Total	**547.1**

Monthly rainfall data in the study area during the period of investigation

Month	Rainfall (mm) during 2014-'15
September, 2014	128.8
October, 2014	45.2
November, 2014	0.0
December, 2014	0.0
January, 2015	11.0
Total	**185.0**

APPENDIX - II

Sample calculation for computation of weighted average subsurface drain discharge

Weighted average drain discharge

$$q_w = \frac{\sum a_i q_i}{\sum a_i}$$

where

q_w = weighted average drain discharge, mm d^{-1}

a_i = area of influence, ha and

q_i = drain discharge, mm d^{-1}

Weighted average discharge in drains

Sl. no.	Drains	Drain discharge, mm d^{-1}	Influencing area, ha	Weighted average weekly drain discharge, mm d^{-1}
1	Main I	0.42	2.01	0.61
2	Main II	0.79	2.02	

Weighted average discharge $(q_w) = \dfrac{\left(\frac{0.42}{1000}\right) \text{X } 20100 + \left(\frac{0.79}{1000}\right) \text{X } 20200}{40300}$

=0.61 mm d^{-1}.

The areas of influence of SSD laterals are given below:

Area of influence of laterals

Sl. no.	Influencing area, m^2
LLII	4,000
RLII	2,500
RRII	4,000

APPENDIX - III

Sample calculation for determination of hydraulic conductivity by inverse augur hole method

Depth of hole = 90 cm

Diameter of the hole = 20 cm

log (h_o+1/2(r)) =1.97

log (h_t+1/2(r)) = 1.87

t = 9900 s

t_o = 300 s

Hydraulic conductivity (K) is computed by:

$$K = 1.15 \times r \times \frac{\left[\left(\log(h_o + \frac{1}{2}r\right) + \left(\log(h_t + \frac{1}{2}r\right)\right]}{t - t_o}$$

where,

t = time since the starting of measurements, s

h_t = height of water column in the hole at time ‘t’, cm

h_o = height of water column at time ‘t_o’, cm

$K = 1.15 \text{ X } 0.10 \text{ X } \frac{1.970 - 1.877}{9900 - 300}$

K= 0.00011 cm s^{-1}

K = 0.096 m d^{-1}.

APPENDIX - IV

Sample calculation for estimation of areal hydraulic conductivity

Areal hydraulic conductivity is determined using the following formula

$$q = \frac{2\pi d h' + \pi K h' h^*}{L^2}$$

Rearranging we have

$$K = \frac{qL^2}{\pi h'(2d+h^*)}$$

Data given:

q = drain discharge, m d^{-1}

K = hydraulic conductivity, m d^{-1}

h' = available hydraulic head (h-he), m

h = elevation of the water table mid way between drains, m

h*= h+he, m

d = depth to impervious layer, m

L = drain spacing, m

he = entrance head, m

For the values of q = 0.000518 m d^{-1}; L = 50 m; h'=0.10 m; h*= 1.642 m and d= 3.209 m

$$K = \frac{0.000518 \text{ X } 50^2}{3.142 \text{X} 0.10(2\text{X}3.209+1.642)}$$

K= 0.510 m d^{-1}.

APPENDIX - V

Calculations for internal rate of return net present value and benefit-cost ratio (30 years life span of SSD system)

Year	Total cost, Rs.	Gross returns, Rs.	Net returns, Rs.	Discounted factor	Discounted cost, Rs.	Discounted returns, Rs.	Discounted net returns, Rs.
1	107081	74400	-32681	0.893	95608.0	66428.6	-29179.5
2	40400	74400	34000	0.797	32206.6	59311.2	27104.6
3	42812.43	74400	31587.57	0.712	30473.0	52956.5	22483.4
4	41200	74400	33200	0.636	26183.3	47282.5	21099.2
5	41600	74400	32800	0.567	23605.0	42216.6	18611.6
6	44012.43	74400	30387.57	0.507	22298.1	37693.4	15395.3
7	42400	74400	32000	0.452	19179.6	33654.8	14475.2
8	42800	74400	31600	0.404	17286.2	30048.9	12762.7
9	45212.43	74400	29187.57	0.361	16304.1	26829.4	10525.3
10	43600	74400	30800	0.322	14038.0	23954.8	9916.8
11	44000	74400	30400	0.287	12648.9	21388.2	8739.3
12	46412.43	74400	27987.57	0.257	11912.9	19096.6	7183.7
13	44800	74400	29600	0.229	10267.0	17050.6	6783.6
14	45200	74400	29200	0.205	9248.8	15223.7	5974.9
15	47612.43	74400	26787.57	0.183	8698.6	13592.6	4894.0
16	46000	74400	28400	0.163	7503.6	12136.3	4632.7
17	46400	74400	28000	0.146	6757.9	10835.9	4078.0
18	48812.43	74400	25587.57	0.130	6347.5	9674.9	3327.4
19	47200	74400	27200	0.116	5480.2	8638.3	3158.1
20	47600	74400	26800	0.104	4934.5	7712.8	2778.3
21	50012.43	74400	24387.57	0.093	4629.1	6886.4	2257.3
22	48400	74400	26000	0.083	3999.9	6148.6	2148.7
23	48800	74400	25600	0.074	3600.9	5489.8	1889.0
24	51212.43	74400	23187.57	0.066	3374.0	4901.6	1527.6
25	49600	74400	24800	0.059	2917.6	4376.5	1458.8
26	50000	74400	24400	0.053	2626.0	3907.5	1281.5
27	52412.43	74400	21987.57	0.047	2457.8	3488.9	1031.1
28	50800	74400	23600	0.042	2127.0	3115.1	988.1
29	51200	74400	23200	0.037	1914.0	2781.3	867.3

30	53612.43	74400	20787.57	0.033	1789.5	2483.3	693.8
				Total	410417.9	599305.7	188887

Net present value = Rs. 1,88,887 Internal rate of returns = 101 per cent

Benefit-cost ratio = 1.46.

Calculations for internal rate of return net present value and benefit-cost ratio (50 years life span of SSD system)

Year	Total cost, Rs.	Gross returns, Rs	Net returns, Rs.	Discounted factor	Discounted cost, Rs.	Discounted returns, Rs.	Discounted net returns, Rs.
1	107081	74400	-32681	0.892	95608.0	66428.5	-29179.5
2	40000	74400	34400	0.797	31887.8	59311.2	27423.5
3	42012.4	74400	32387.57	0.711	29903.6	52956.4	23052.8
4	40000	74400	34400	0.635	25420.7	47282.5	21861.8
5	40000	74400	34400	0.567	22697.1	42216.5	19519.5
6	42012.4	74400	32387.57	0.506	21284.8	37693.3	16408.6
7	40000	74400	34400	0.452	18094.0	33654.7	15560.8
8	40000	74400	34400	0.403	16155.3	30048.9	13893.6
9	42012.4	74400	32387.57	0.360	15150.1	26829.3	11679.3
10	40000	74400	34400	0.321	12878.9	23954.8	11075.9
11	40000	74400	34400	0.287	11499.0	21388.2	9889.2
12	42012.4	74400	32387.57	0.256	10783.5	19096.6	8313.1
13	40000	74400	34400	0.229	9167.0	17050.5	7883.6
14	40000	74400	34400	0.204	8184.8	15223.7	7038.9
15	42012.4	74400	32387.57	0.18	7675.5	13592.6	5917.1
16	40000	74400	34400	0.163	6524.9	12136.2	5611.4
17	40000	74400	34400	0.145	5825.8	10835.9	5010.2
18	42012.4	74400	32387.57	0.130	5463.3	9674.9	4211.7
19	40000	74400	34400	0.116	4644.3	8638.3	3994.1
20	40000	74400	34400	0.103	4146.7	7712.8	3566.1
21	42012.4	74400	32387.57	0.092	3888.7	6886.4	2997.8
22	40000	74400	34400	0.082	3305.7	6148.6	2842.9
23	40000	74400	34400	0.073	2951.5	5489.8	2538.3
24	42012.4	74400	32387.57	0.065	2767.9	4901.6	2133.8
25	40000	74400	34400	0.058	2352.9	4376.4	2023.5
26	40000	74400	34400	0.052	2100.8	3907.5	1806.7
27	42012.4	74400	32387.57	0.046	1970.1	3488.8	1518.8

28	40000	74400	34400	0.041	1674.8	3115.0	1440.3
29	40000	74400	34400	0.037	1495.3	2781.3	1286.0
30	42012.4	74400	32387.57	0.033	1402.3	2483.3	1081.0
31	40000	74400	34400	0.029	1192.1	2217.2	1025.2
32	40000	74400	34400	0.026	1064.3	1979.6	915.3
33	42012.4	74400	32387.57	0.023	998.1	1767.5	769.5
34	40000	74400	34400	0.021	848.5	1578.1	729.7
35	40000	74400	34400	0.018	757.6	1409.1	651.5
36	42012.4	74400	32387.57	0.016	710.4	1258.1	547.7
37	40000	74400	34400	0.015	603.9	1123.3	519.4
38	40000	74400	34400	0.013	539.2	1002.9	463.7
39	42012.4	74400	32387.57	0.012	505.7	895.5	389.8
40	40000	74400	34400	0.010	429.9	799.5	369.7
41	40000	74400	34400	0.009	383.8	713.8	330.1
42	42012.4	74400	32387.57	0.008	359.9	637.4	277.5
43	40000	74400	34400	0.007	306.0	569.1	263.1
44	40000	74400	34400	0.006	273.2	508.1	234.9
45	42012.4	74400	32387.57	0.006	256.2	453.6	197.5
46	40000	74400	34400	0.005	217.8	405.0	187.3
47	40000	74400	34400	0.004	194.5	361.6	167.2
48	42012.4	74400	32387.57	0.004	182.4	322.9	140.6
49	40000	74400	34400	0.003	155.0	288.3	133.3
50	40000	74400	34400	0.003	138.4	257.4	119.0
				Total	397022.0	617854.6	220832.7

Net present value = Rs. 2,20,833

Benefit-cost ratio = 1.55

Internal rate of return = 104 per cent.

APPENDIX – VI

Sample calculation for payback period

1. Total investment for subsurface drainage system (Rs ha^{-1})

Sl. no.	Particulars	Cost (Rs)
1	Earthwork excavation	15,186
2	Main drains	7,742
3	Alignment of mains	1,549
4	Cost of PVC corrugated pipes	17,610
5	Alignment of laterals	10,483
6	Synthetic fiber filter	10,523
7	Accessories	1,167
8	Guard wall	378
9	Inspection chamber	2,406
10	Miscellaneous	37
	Total	**67,081**
	Interest rate @ 12%	**8,049**

Sl. no.	Particulars	Cost (Rs)
1	Main drains	73
2	Cost of PVC corrugated pipes	27
3	Synthetic fiber filter	188
4	Accessories	189
6	Guard wall	21
7	Inspection chamber	6

2. Depreciation on all the materials utilised for the drainage system

	Total	**506**

3. Investments on the field operations

Investments on the field operations, Rs. = 40,000

Amount of returns from the crop yield, Rs. = 74,400

Depreciation cost = Rs. 506

(The price of Rs. 1,200 was considered per 100 kg bag of paddy, for estimation of gross returns)

Net returns = Rs. 74,400 - Rs.27,556

Sl. no.	Particulars	Cost (Rs)
1	Puddling	8,000
2	Fertilizer	8,000
3	Spraying	7,000
4	Weeding	8,000
5	Harvesting	9,000
	Total	**40,000**

= Rs. 46,844

Payback period = Total investment / Net returns

= Rs. 67,081 / 46,844

= 1.43 (say 2 cropping seasons)

Due to shortage of irrigation facilities and other reasons, cultivation of crop was taken up for one season i.e. late *kharif* 2014 only. This way, the investment on SSD system would be paid back in two cropping seasons.