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Effect of Controlled Drainage for Alleviating Soil Problem

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Authors' contributions

This work was carried out in collaboration between all authors. Author AS designed the study of controlled drainage for alleviating soil problem and wrote the first draft of the manuscript. Authors IM and SV read and approved the final manuscript.

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ABSTRACT

Water logging induced salinity is a common problem in many command areas of irrigation projects. Controlled drainage is the next level of logical step towards improving water management in irrigated agriculture and reducing the environmental impact on subsurface drainage flow. The experiment was carried out during 2015 under irrigated condition, to study the effect of controlled drainage for alleviating water logging and soil salinity. The design of experiment was spilt plot design. The main plot treatments were taken at 4 levels of spacing (S_1=7.5 m, S_2 = 10 m, S_3 =12.5 m, S_4 =15 m) and subplot treatments were taken at 2 levels of drain depth and drain diameter (D_1 = 75 cm, D_2 = 60 cm; d_1 = 75 mm, d_2 = 63 mm). The result showed that the treatments of 75 cm (D_1) of drain depth areas showing more depth to water table in all days of observations. The drain discharge rates were high in 7.5 m (S_1) spacing when compared to all other spacing due to the influence of more area of contributing drain pipes (0.44 cm/day). The average paddy yield in the

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system installed field was 3.58 t/ha and the control plot was 2.2 t/ha. The results showed that the treatments of 7.5 m drain spacing at 75 cm depth with 75 mm diameter ($S_1D_1d_1$) recorded high value in drainage coefficient and depth to water table. From the economic viability, it was observed that the 15 m drain spacing at 75 cm drain depth with 75 mm diameter ($S_4D_1d_1$) were economically viable with the highest profit than the other treatments.

Keywords: Controlled drainage; drainage; hydraulic conductivity; observation wells; salinity.

1. INTRODUCTION

Nowadays, water logging induced soil salinity adversely affected agricultural lands and creating doubts about the sustainability of irrigated agriculture. Subsurface drainages have been experimented in India for the last 130 years. The first ever subsurface drainage experiment to reclaim salt affected land was conducted by [1]. Stone drains and tile drains were laid out to reclaim the lands. In spite of usage of collars in laying these drains, silting problem was noticed. The recorded evidence of environmental degradation due to water logging was in the first decade of the last century. Increasing incidences of Malaria in the Amristar city scared the people to migrate to safer areas. Subsurface drainage through tube wells was implemented to tackle the problem of water logging. [2] had compiled works the global level works on drainage and reported that salinity affects 10 to 16 per cent of all irrigated lands while the annual rate of land loss due to water logging and salinity was about 0.5 million hectares per year. However, artificial drainage can increase nutrient losses by leading to higher outflows volumes and by limiting the potential for nutrients to be absorbed by the soil. Recently, controlled drainage has been identified as a potential management method in humid areas to reduce nitrate loading of surface water. Studies demonstrated significant reduction of nitrate in drainage water from controlled drainage system as a result of reduced drainage flow and lower concentration in a shallow ground water [3]. For controlled drainage to become effective soil surface must be nearly flat, so that only very few structures in the drainage system are needed to control the water table depth over large areas. The system is preferred to fulfill the advantages are water can be held in the soil and outlet ditch and supplied to the crop through the existing drainage system without modifying that system, except to add an outlet control structure, labor and maintenance costs are low and the water table can be regulated to suit varying condition and weather patterns. Hence the present research had been proposed to fulfill the following objectives are

1. To design and install hydraulically efficient controlled drainage system in an experimental area.
2. To evaluate the functional and hydraulic performance of the system with reference to drainage coefficient, water table fluctuation and salinity reduction.

Amelioration of water logging and salinity in an experimental area can be achieved by following objectives.

2. MATERIALS AND METHODS

The experiment was laid out and conducted during 2015 under wetland ecosystem, to study the effect of controlled drainage for alleviating problem soil on sandy loam soil, at 10°56' 34.05" N latitude and 78° 49'34" E longitude with mean altitude of 72.2376 m above the mean sea level at Eastern Farm A Block, Agricultural Engineering College and Research Institute Kumlur. Topography of the experimental plot was uniform and levelled. The project site has a serious problem of water logging and salinity due to seepage of water from the adjoining lake where water is collected from the kumulur watershed. Most of the fields in the experimental site are connected to natural drain but the drain is at field level and causes back flow. The irrigation channels that exist in the site are used as open drains and field to field carrying drain. Rice based cropping system is prevailing cropping system in this area.

2.1 Methodology

1. Experimental investigation through field data collection.
2. Design of controlled drainage system based on steady state condition.
3. Performance of the controlled drainage system should be based on the results of drain discharge, depth to water table and

quality of drain water constituents such as, EC, pH and ESP.

2.2 Measurement of Saturated Hydraulic Conductivity

Hydraulic conductivity test kid was used to conduct auger hole experiment. Hooghoudt's equation was used to find out the hydraulic conductivity. It will be very much essential for the design of water table management system. From standard Hooghoudt's equation,

$$K_s = \frac{2.3\,aS}{(2d+a)\Delta t} log_{10} \frac{yo}{y1}$$

Where,

K_s = Saturated hydraulic conductivity
a = Radius of the auger hole
d = Depth of the hole below ground level
s is defined by ad /0.19
y_0 and y_1 over a particular time interval the initial and final water level.

2.3 Design Consideration of Controlled Drainage System

2.3.1 Subsurface drainage system

- Layout of the system
- Spacing and Depth of lateral drain
- Collector diameter and Slope
- Inspection chamber/sump

2.4 Design of Lateral Drain Spacing

Drain spacing could be computed by several formulae developed from the theories of ground water flow substituting the appropriate soil and other parameters. Broadly speaking the drainage spacing formulae are based on a) steady state flow and homogeneous b) non-steady state flow conditions, a steady-state flow conditions. For the present study as the profile in the experimental site is homogeneous and isotropic, Hooghoudt's equation was used for computing the drain spacing

$$q = \frac{4kh+(2d_e+h)}{L^2} \quad [4]$$

where,

q = Drainage co-efficient or drain discharge rate per unit surface area, m/d
K = Hydraulic conductivity of the soil, m/d
d_e = Equivalent depth, m
h = Height of water table above the water level in the drain, m
L = Drain spacing, m.

2.5 Design Diameter of Drain Pipe

Wessling's equation for uniform flow in smooth pipes and corrugated pipes derived from Manning's equation was used to calculate the size of lateral drain pipes. Size of the lateral

Table 1. Summary of design parameter of controlled drainage system

Area covered	1.5 acre
Hydraulic Conductivity	0.35 m/d
Average Annual Rainfall	864.1 mm
Drainage Coefficient	1.08 cm/d
Water table height above drains at midpoint between drains	0.5 m
Depth to impervious Layer	4 m
Observation well material	PVC
Length of observation well	1.3 – 1.5 m
Depth of observation well	0.6 - 0.8 m
Envelope	Coconut Coir
Size of perforation of drain pipes	8 mm
Size of perforation of observation wells	3 mm
Soil sample analysis	
Soil texture	Sandy Loam
Soil pH	9.1
EC	3.28 dS/m
ESP	33 per cent
Crop parameters	
Controlled Drainage	Paddy: BPT 5204

pipe required to carry the design flow rate is given by

$$Q = 80\,(d_L)^{2.714}\, i^{-0.572}$$

d_L = Diameter of lateral pipe
Q = Discharge m^3 /day
L = Spacing of drain (m)
i = Slope lateral pipe (fraction)

2.6 Design of Controlled Drainage System Based on Steady State Condition

Initial drainage coefficient =
Depth of irrigation x Apparent specific gravity x drainable porosity
= 5 cm x 1.45 x 0.15
= 1.0875 cm/day
= 0.0108 m/day

Equivalent depth:

$$q = \frac{8KDh + 4Kh^2}{L^2}$$

Where

K = Hydraulic conductivity (m/day)
D = Depth to impervious layer (m)
h = Height of water table above the water level in the drain (m)
L = Spacing of drain (m)
q = Drainage coefficient (m/day)

$$L^2 = \frac{(8x0.35x4x0.5) + 4x0.35x0.5^2}{0.0108}$$

L = 23.45 m
L = 23 m
D < L/4 = 1 < 23.45/4 = 5.86

$$d_e = \frac{D}{\frac{8D}{\pi L}\ln\frac{D}{u} + 1}$$

u = Π x 0.036
= 0.113

$$d_e = \frac{4}{\frac{8x4}{3.14x23.45}\ln\frac{4}{0.113} + 1}$$

d_e = 1.58 m

Hooghoudt's equation for steady state condition:

$$L^2 = \frac{4Kh(2d_e + h)}{q}$$

Where

d_e = equivalent depth (m)

$$L^2 = \frac{4x0.35x0.5(2x1.58 + 0.5)}{0.0108}$$

L = 15 m

Diameter of drain pipe:

Q = length of field x width of field x drainage coefficient
i = 0.3% 0.003

Wesslings equation:

$$Q = 89(d_l)^{2.716} x(i)^{-0.572}$$

Spacing = 7.5 m
Q = 0.0108x7.5x30
Q= 2.43 m^3/day

$$2.43 = 89(d_l)^{2.716} x(0.003)^{-0.572}$$

d_L = 82 mm

similarly,

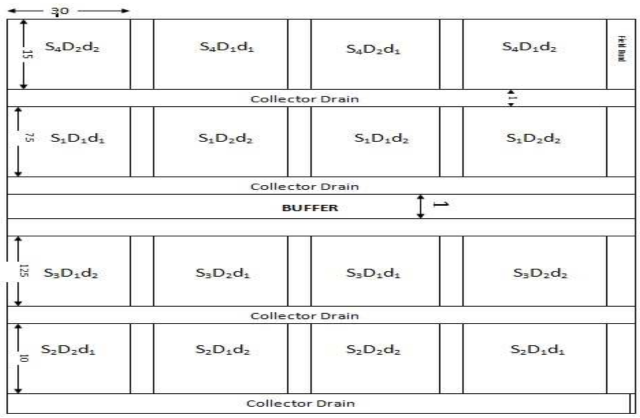
spacing = 10.0 m; d_L = 91 mm
spacing = 12.5 m; d_L = 99 mm
spacing = 15.0 m; d_L = 106 mm

Table 2. Design: Split plot design

Main plot treatments: (at 4 levels of drain spacing)	Subplot Treatments:(at 2 levels of depth and diameter)
S_1 = 7.5 m spacing between drains	D_1d_1= Depth of drain at 75 cm + 75mm diameter
S_2 = 10 m spacing between drains	D_1d_2= Depth of drain at 75 cm + 63mm diameter
S_3 = 12.5 m spacing between drains	D_2d_1= Depth of drain at 60cm + 75 mm diameter
S_4 = 15.0 m spacing between drains	D_2d_2= Depth of drain at 60cm + 63mm diameter

(Due to commercial available and reduce cost we can used 75 mm and 63 mm drain diameter PVC pipes)

2.7 Design Layout



All dimensions in m

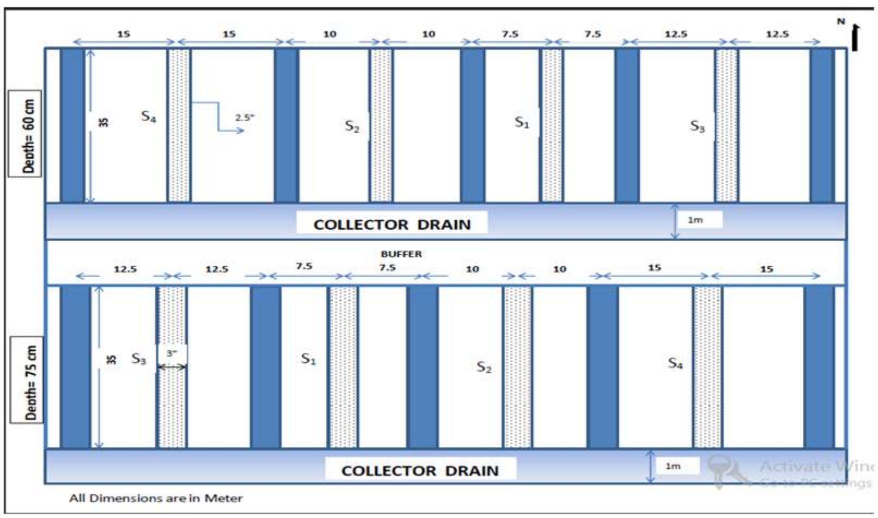


Fig. 1. Layout of controlled drainage system in an experimental area

2.8 Drain Envelope Material

Increasing use of plastic pipes and considering the cost of transport gravel material, synthetic materials are commonly used. But in the present study, to avoid more synthetic material in the soil, and earlier experience in Tamil Nadu research, as the locally available coconut coir was wrapped around the pipes which were found more durable when placed in soil water system.

2.9 Construction of Controlled Drainage System

Laying of drain pipes and back filling were done manually. After marking and staking of the proposed layout, trenches were dug with a DIGGING machine having bucket width of 40 cm. with the help of staff gauges and dumpy level the depth of cut was monitored throughout the digging operation to ensure proper gradient in the laterals and collector lines. Cleaning and smoothening was done manually along the bottom of lateral and collector lines to attain proper surface conditions for laying the pipes. Before placing the lateral pipes on the trenches, zero sized chips are placed along the bed to act as filter to a thickness of 2.5 cm. Lateral pipes were wrapped firmly with two layers of coconut coir fibre envelope materials manually. One end of the lateral was closed with an end plug and other end was fixed with rigid PVC pipe and connected to the inspection chamber. The pipes were lowered smoothly and were placed

Plate 1. Constuction of control drainage system

in the trenches. Above the laterals also, 1 inch thick zero sized metal chips were placed. Care was taken to see that no damage was caused to the pipes while backfilling was done with minimum soil disturbance compared to before trenching. Controlled drainage a device to the fix level of ground water to the delimit depth in the different treatments. In this instance, the drainage system will be managed to control the flow and water table depth in the course of time in response to the irrigation management and deep percolation. Controlled drainage devices were installed at different treatments. The system consists of 3 inch vertical pipe of 60 and 75 cm height. The riser was connected at the bottom to the lateral inside the manhole. The watertable is controlled at the required level using stop-log.

2.10 Installation of Observation Wells

The eighteen number of observation wells were installed to observe the fluctuation of watertable and collecting ground water samples for chemical analysis. The observation wells were installed using PVC pipes with a 5 cm diameter and 1.5 m length. Tubes were perforated at the lower end and covered with permeable materials and screen to allow easy movement of groundwater to the tubes and to avoid the clogging by clay and fine particles.

3. RESULTS AND DISCUSSION

The results of the experimental findings obtained from the present study have been discussed in following heads.

3.1 Water Level Fluctuations

The depth to watertable was found very close to the ground level from 0.1 m to 0.15 m and it went up to 0.5 m during early harvesting stage of paddy stage. Observation wells installed beyond 75 m showed deeper water tables ranging from 0.1 to 0.3 m during early harvesting stage of paddy.

3.2 Hydraulic Performance Studies of Controlled Drainage

Immediately after transplanting of paddy nursery continuously for a period three days at every 2 hours, the observation of both drain discharge and depth to water table midway between drains were recorded interval during day time. To know the recession of controlled flow and decline in observation well reading i.e fall in water table height/ rise in water table with the decreased flow were recorded and were plotted for both the drain depth and for all spacing combination. The water table steadily declined and attained the value below drains and similarly drainage coefficient was also reduced after few hours.

Table 3. 7.5 m spacing/ 75 cm drain depth

Elapsed time	Drainage coefficient (cm/d)	Depth to watertable (m)
9.00 am	0.44	0.32
11.00 am	0.43	0.32
1.00 pm	0.43	0.33
3.00 pm	0.42	0.33
5.00 pm	0.42	0.35

Table 4. 10.0 m spacing/75 cm drain depth

Elapsed time	Drainage coefficient (cm/d)	Depth to watertable (m)
9.00 am	0.34	0.25
11.00 am	0.33	0.27
1.00 pm	0.33	0.28
3.00 pm	0.32	0.28
5.00 pm	0.31	0.29

Table 5. 12.5 m spacing/75 cm drain depth

Elapsed time	Drainage coefficient (cm/d)	Depth to watertable (m)
9.00 am	0.31	0.21
11.00 am	0.29	0.22
1.00 pm	0.29	0.22
3.00 pm	0.28	0.23
5.00 pm	0.28	0.24

Table 6. 15.0 m spacing/75 cm drain depth

Elapsed time	Drainage coefficient (cm/d)	Depth to watertable (m)
9.00 am	0.25	0.17
11.00 am	0.25	0.18
1.00 pm	0.24	0.18
3.00 pm	0.23	0.19
5.00 pm	0.23	0.19

Table 7. 60 cm depth /7.5 m spacing

Elapsed time	Drainage coefficient (cm/d)	Depth to watertable (m)
9.00 am	0.42	0.27
11.00 am	0.41	0.28
1.00 pm	0.41	0.28
3.00 pm	0.41	0.29
5.00 pm	0.38	0.30

Table 8. 60 cm depth /10.0 m spacing

Elapsed time	Drainage coefficient (cm/d)	Depth to watertable (m)
9.00 am	0.31	0.22
11.00 am	0.30	0.22
1.00 pm	0.30	0.22
3.00 pm	0.29	0.23
5.00 pm	0.29	0.24

Table 9. 60 cm depth /12.5 m spacing

Elapsed time	Drainage coefficient (cm/d)	Depth to watertable (m)
9.00 am	0.29	0.18
11.00 am	0.26	0.19
1.00 pm	0.26	0.19
3.00 pm	0.25	0.20
5.00 pm	0.25	0.21

Table 10. 60 cm depth /15.0 m spacing

Elapsed time	Drainage coefficient (cm/d)	Depth to watertable (m)
9.00 am	0.23	0.14
11.00 am	0.22	0.15
1.00 pm	0.22	0.16
3.00 pm	0.22	0.16
5.00 pm	0.21	0.17

3.3 Performance Evaluation of Controlled Drainage System

The drain discharge was more in lower spacing than higher spacing. Similarly season proceeded towards harvesting the drain discharge also reduced. More reduction of water table depths were found during early harvest and harvesting stages. The discharge values were considered as unsteady state discharges; might values are operated and continuously opened. The valves were opened intermittently depending upon the field submergence in the present investigation of rice crop. The treatments under 75 cm of drain depth areas showing more depth to water table in all days of observations.

3.4 Drain Discharge v/s Drain Spacing

The drain discharge rates revealed that in 7.5 m spacing the maximum and minimum discharge rates were 0.43 cm/day to 0.29 cm/day, the discharge rate of 10.0 m spacing were 0.34

cm/day to 0.24 cm/day, the discharge rate of 12.5 m spacing were 0.22 cm/day to 0.21 cm/day and the discharge rate of 15.0 m spacing were 0.27 cm/day to 0.19 cm/day respectively. The drain discharge rate was high in 7.5 m spacing when compared to all other spacing due to the more influence of area of contributing drain pipes.

3.5 Drain Spacing v/s Water Table

The depth to water table levels was monitored from the observation from the observation well network. At 75 cm depth the maximum and minimum water table for 7.5 m, 10.0 m, 12.5 m and 15.0 m spacing were 0.33 m to 0.25 m, 0.20 m to 0.18 m, 0.23 m, respectively at 60 cm depth the corresponding water table for 7.5 m, 10.0 m, 12.5 m and 15.0 m spacing were 0.28, 0.22 m, 0.14 and 0.11 m respectively.

3.6 Soil Salinity and Reaction

The electrical conductivity (EC) value for pre drainage is 3.28 dS/m and 2.78 dS/m in post drainage. This revealed that decrease in the soils salinity values indicated the leaching of the salts. Which indicate that the drains were effective in reducing the soil salinity. The pH of soil values for pre drainage is 9.1 and 8.7 in post drainage. This shows the slight decrease in soil reaction value. The decrease in soil pH was negligible.

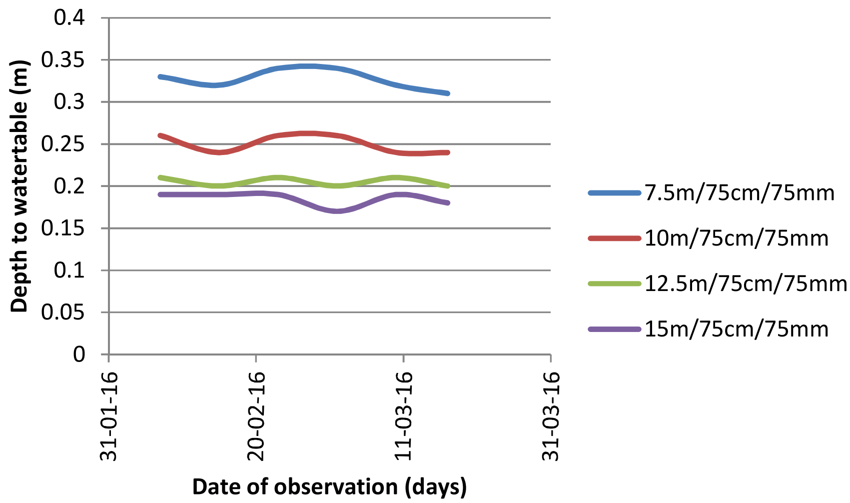


Fig. 2. Drainage coefficient (cm/day) of different spacing at 75 cm depth and 75 mm diameter

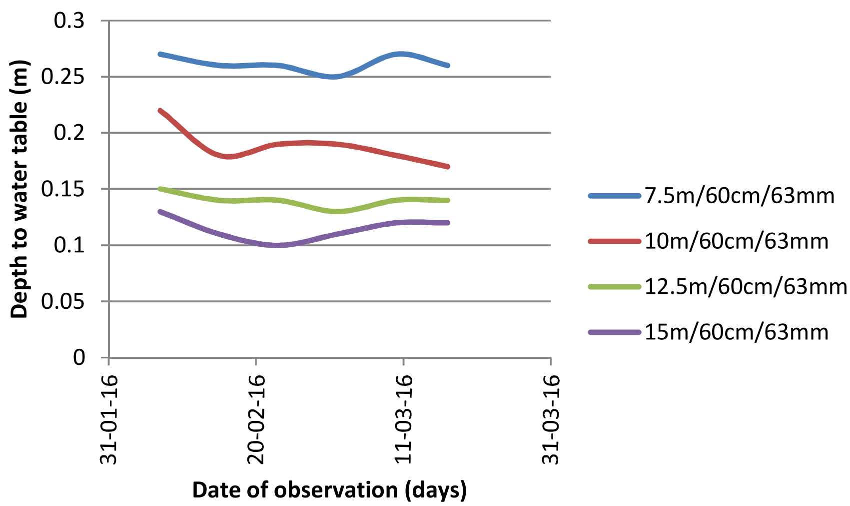


Fig. 3. Drainage coefficient (cm/day) of different spacing at 60 cm depth and 63 mm diameter

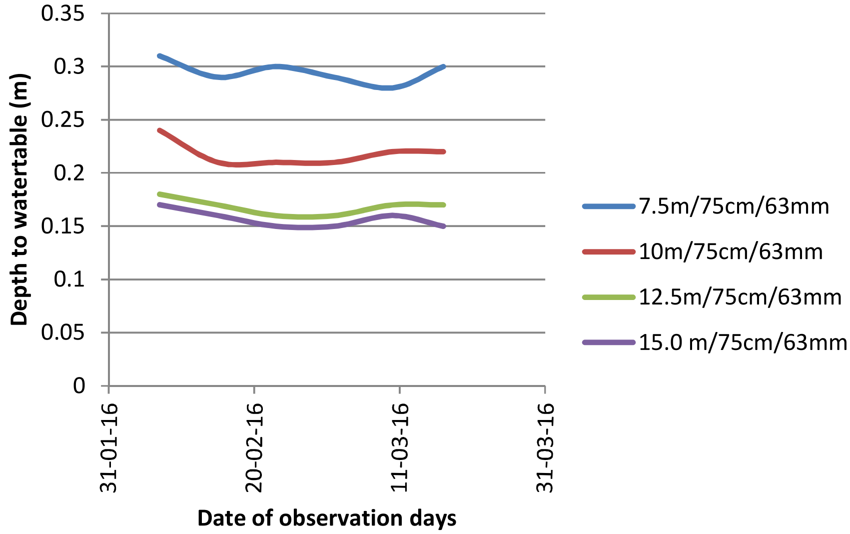


Fig. 4. Drainage coefficient (cm/day) of different spacing at 75 cm depth and 63 mm diameter

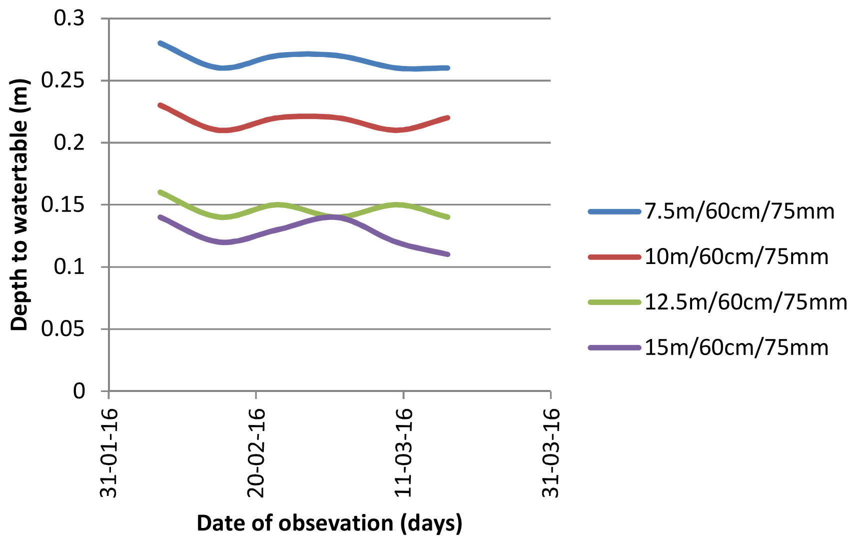


Fig. 5. Drainage coefficient (cm/day) of different spacing at 60 cm depth and 75 mm diameter

3.7 Change in Hydraulic Conductivity

The hydraulic conductivity (k) measurements were determined by inverse auger hole method. These measurements were compared with the pre drainage values. The hydraulic conductivity of pre drainage value was 0.35 m/day where as in post drainage the value was 0.15 m/day. The results revealed that the hydraulic conductivity decreased by 2 per cent when compared to pre drainage. This may be due to reduction in salinity and increase in alkalinity proportion in the drained area [5].

3.8 Paddy (BPT 5204) Yield in Controlled Drainage System

The results revealed that lower most spacing is better for obtaining higher yield levels were less compared to larger spacing for both the drain depth. The average paddy yield in the system installed field was 4.71 t/ha of 7.5 m drain spacing at 75 cm depth with 75 mm diameter ($S_1D_1d_1$) and the control plot was 3.28 t/ha. All the treatments were on par with each other. From the economic viability, it was observed that the 15 m drain spacing at 75 cm drain depth with 75 mm diameter ($S_4D_1d_1$) were economically viable with the highest profit than the other treatments.

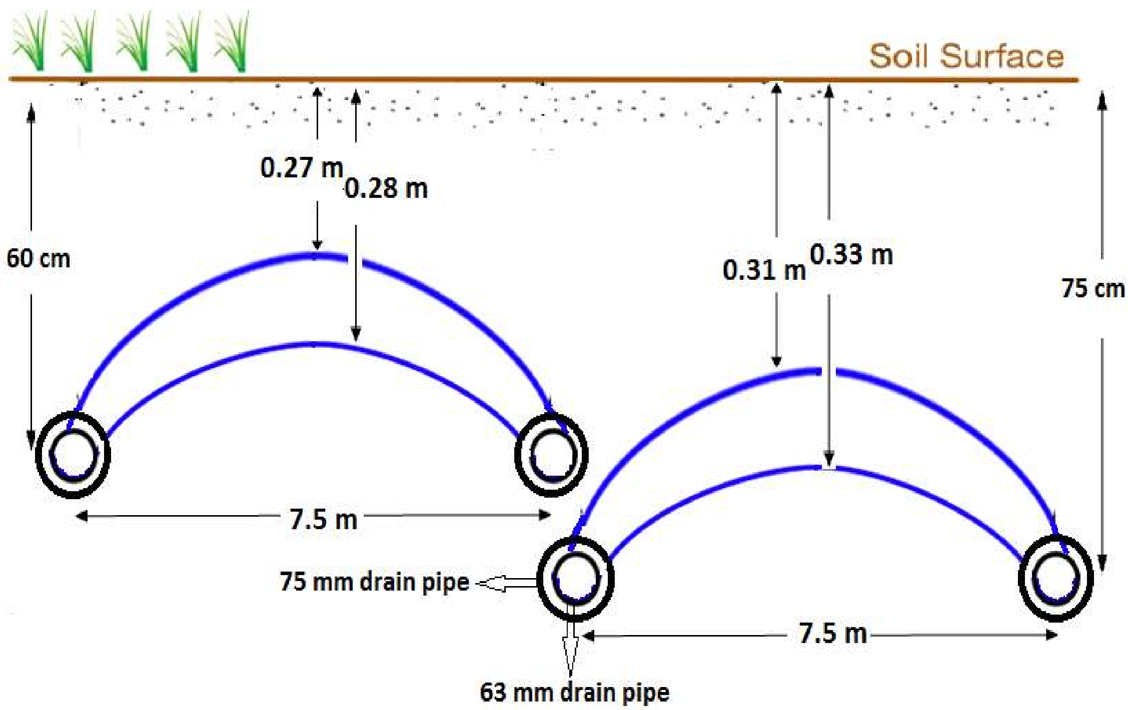


Fig. 6. Depth to water table under controlled drainage mode at 7.5 m drain spacing

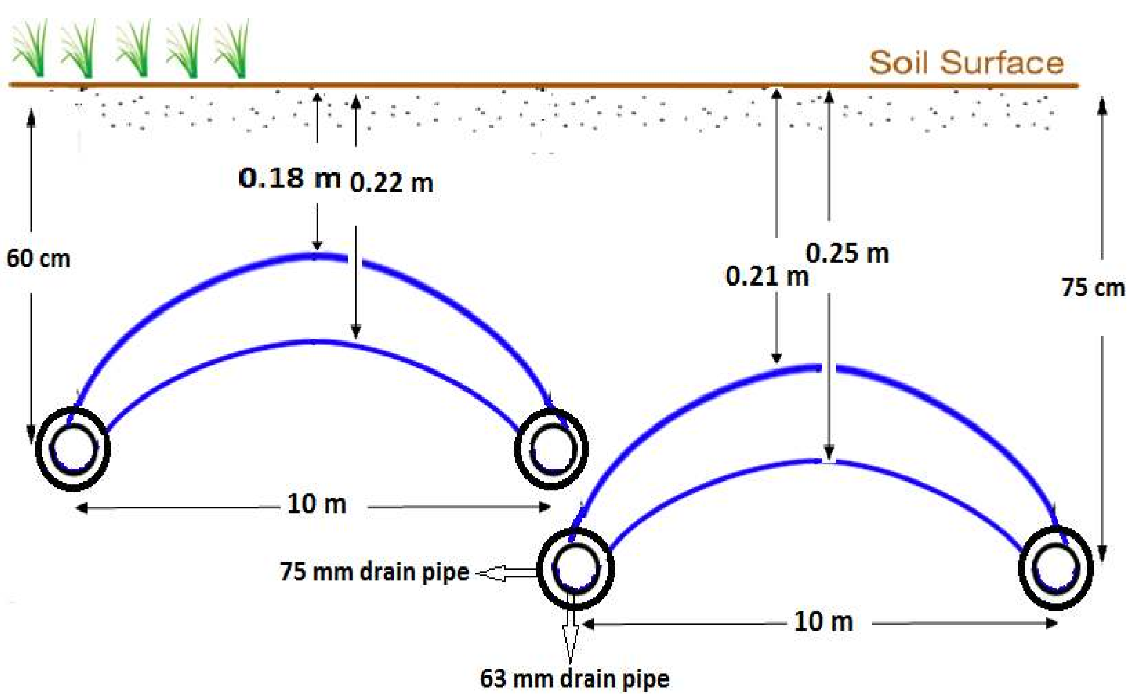


Fig. 7. Depth to water table under controlled drainage mode at 10 m drain spacing

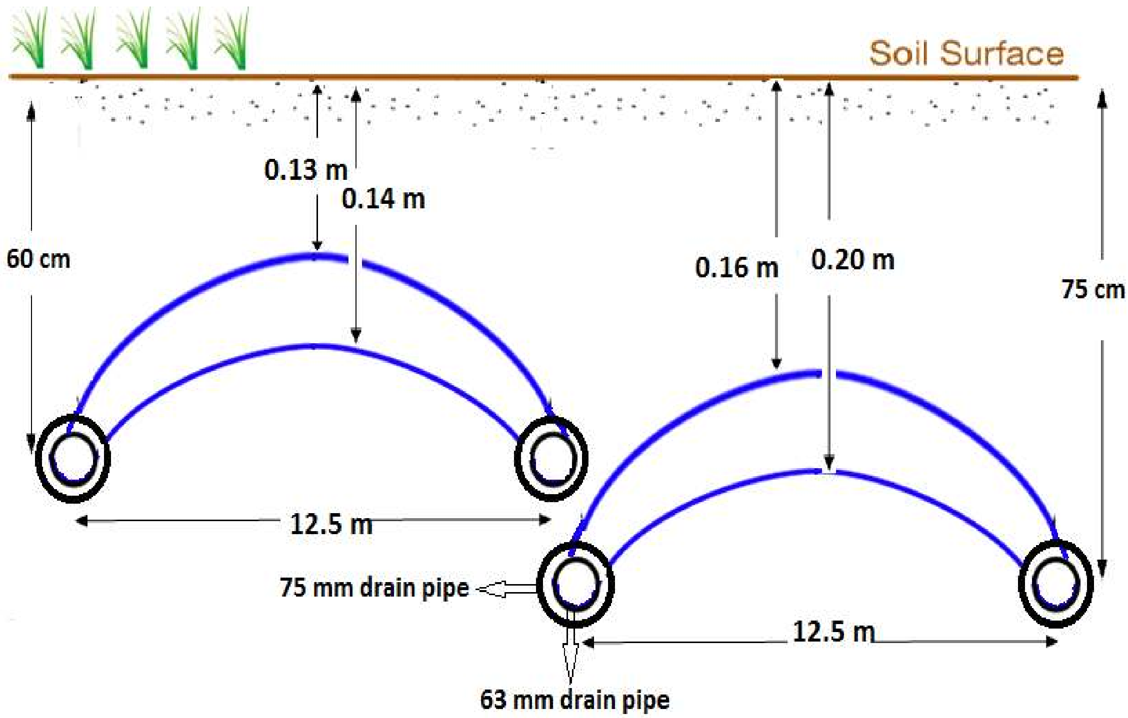


Fig. 8. Depth to water table under controlled drainage mode at 12.5 m drain spacing

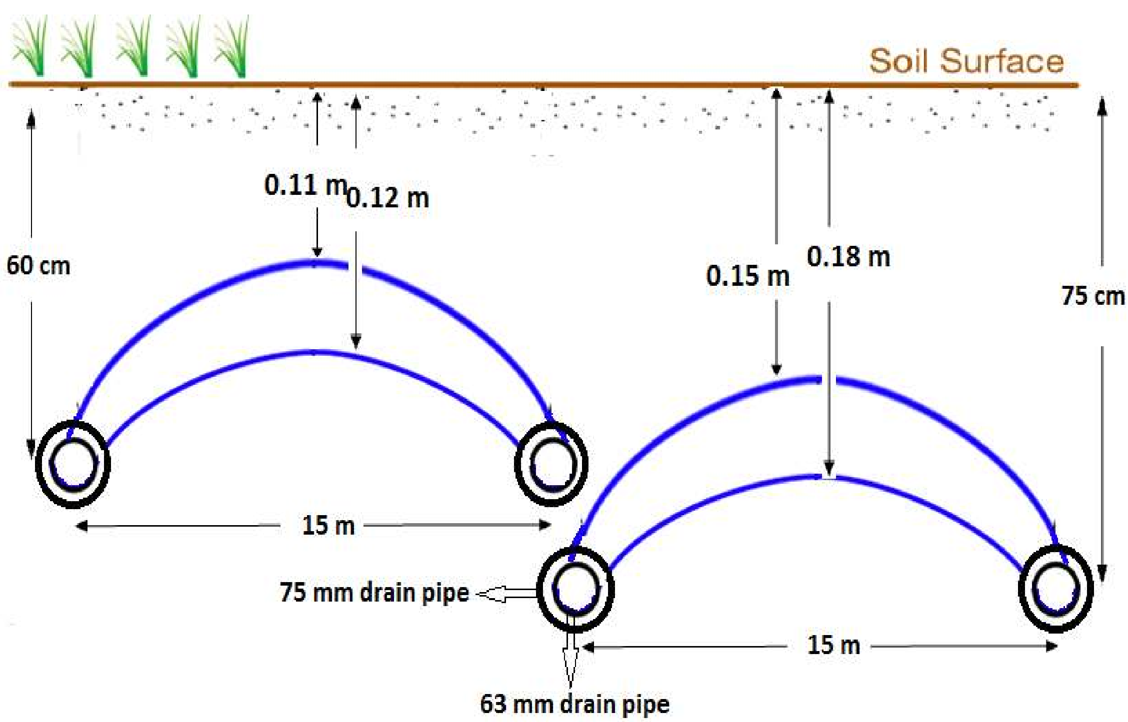


Fig. 9. Depth to water table under controlled drainage mode at 15.0 m drain spacing

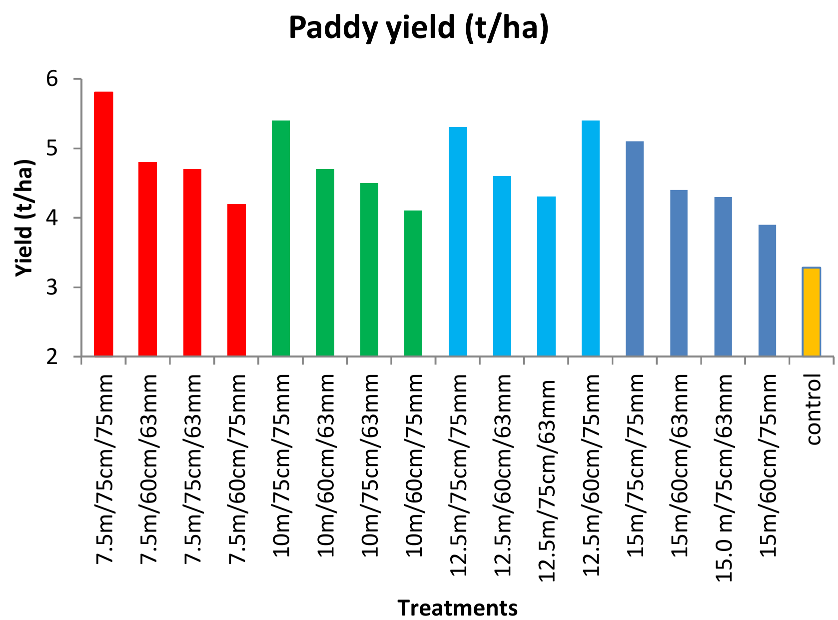


Fig. 10. Grain yield in experimental Plot

4. CONCLUSION

The experiment revealed that the water table steadily declined and attained the value below drains and similarly drainage coefficient was also reduced after few hours. The treatments under 75 cm of drain depth areas showing more depth to water table in all days of observations. The drain discharge rate was high in 7.5 m spacing when compared to all other spacing due to the more influence of area of contributing drain pipes (0.44 cm/day). The electrical conductivity (EC) value for pre drainage is 3.28 dS/m and 2.78 dS/m in post drainage. This may be due to decrease in the soils salinity values indicated the leaching of the salts. The pH of soil values for pre drainage is 9.1 and 8.7 in post drainage. The hydraulic conductivity decreased by 2 per cent when compared to pre drainage. This may be due to reduction in salinity and increase in alkalinity proportion in the drained area. The results showed that the treatments of 7.5 m drain spacing at 75 cm depth with 75 mm diameter ($S_1D_1d_1$) were high in drainage coefficient, depth to water table and crop yield. From the economic viability, it was observed that the 15 m drain spacing at 75 cm drain depth with 75 mm diameter ($S_4D_1d_1$) were economically viable with the highest profit than the other treatments.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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