

Functional Performance of Parallel Drain Subsurface System in Waterlogged Paddy Field

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Authors' contributions

This work was carried out in collaboration among all authors. Author LK designed and examined the subsurface drainage system and formulates the first draft of the manuscript. Authors MM, AR, MB evaluated the concept and approved the final manuscript. All authors read and approved the final manuscript.

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ABSTRACT

Waterlogging induced salinity is a common problem in many command areas of irrigation projects. Subsurface drainage improves the productivity of poorly drained soils by decreasing the water table, providing greater soil aeration, improving root zone soil salinity and enhancing the crop yield. A pilot study has been conducted to explore the functional performance of the parallel drain subsurface system in waterlogged paddy field by considering the lateral drain spacing and drain depth are the factors influences the soil properties. This experiment was carried out in farmers' field at Sembari village, Lalgudi, Tamil Nadu, India in waterlogged paddy field during October 2020 to February 2021. Treatments of this study consisted the combination of three lateral drains spacing of 7.5 m, 10.0 m and 12.5 m and two drain depths of 60 cm and 80 cm and a control plot. This study investigated the changes in soil properties, depth to water table, drainage coefficient and crop behaviors after installation of the system. Reduction in Soil pH, removal of slats in drain water, lowering the depth to water table and higher drainage coefficient recorded for narrow lateral drain spacing and deeper drain depth treatment has improved the root zone environment for crop

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growth. Paddy has been established very well in terms of plant height and number of tillers per plant in S₁D₂ (7.5 m drain spacing and 80 cm drain depth) treatment which was also reflected in grain yield and straw yield over undrained paddy field yield. Based on the results, it is recommended to install parallel drain subsurface system at 7.5 m drain spacing and 80 cm drain depth in the study area.

Keywords: Waterlogging; parallel drain subsurface system; lateral drain spacing; drain depth; drainage coefficient; water table depth.

1. INTRODUCTION

Paddy is the major crop in the Cauvery commands of Tamil Nadu. Some parts of the commands are suffered by waterlogging, saline and alkalinity problems. When soil is saturated completely with water and cannot hold oxygen between its pores, it develops water logging condition. Increase in the productivity of paddy fields is greatly affected if the soils are water logged. Flat topography, inadequate natural drainage facilities, over-irrigation, flooding or the presence of a permanent or temporary (perched) high water table and excess of water from rainfall during monsoon periods are some of the causes for waterlogging. Poor drainage damages paddy crop and degrades soil quality [1]. The duration and severity of the waterlogging event is influenced by the amount of water entering the system, the topography of the site, soil structure and the water absorbing capacity of the soil [2].

A Working Group constituted by the Ministry of Water Resources identified the problem areas affected by water logging/ salinity/ alkalinity in existing irrigation projects in the country and suggested suitable remedial measures for reclamation adopted in 1991. The norms for identification of waterlogged areas are: Water logged areas due to rise in water table are referred when water is table within 2 meters of the land surface, Potential Areas for waterlogging are water table between 2 to 3 meters below land surface and safe areas when water table below 3 meters of land surface [2]. Some of the water-logging problems are permanent and some others are as seasonal. Thus water-logging is time and place specific as well [3].

An area of 6.73 m ha has been characterized as salt-affected areas in India, out of which 3.77 M ha is alkali and the remaining 2.96 m ha is saline and spread across 11 states in India. Uttar Pradesh having the largest alkali area of 1.35 m ha accounts for 35.75 per cent of total alkali affected area followed by Gujarat (14.36 per cent), Maharashtra (11.21 per cent), Tamil Nadu

(9.41 per cent), Harayana (4.86 per cent) and Punjab (4.02 per cent). These six states are having about 80 per cent of the total alkali lands in India [4]. In Tamil Nadu state, parts of Trichy, Tanjore, Nagapattinam, Tiruvarur, Erode districts are frequently under the problem of waterlogging during North-East monsoon heavy rainfall periods (October to December). At the same time, the above areas are under the realms of water scarcity for a few months (February - May) during canal non supply periods [5]. Alkali soils degrade soil structure, hardens soil surface, reduces infiltration and creates water logging after rainfall or irrigation. Because of this water availability to plant reduces, poor seed germination and root development, as a result it lowers crop yield.

Subsurface drainage is useful method to remove excess water from the soil and to provide favorable conditions for plant production [6]. Subsurface drainage lowers water table, creates a deeper aerobic zone and increases the productivity of poorly drained soils [7]. Subsurface drainage helps to dry the soil faster and improves root zone soil layer condition [8]. Drainage problems at harvest might have important financial consequences for farmers, both because of increased production costs and of a reduction in rice quantity and quality [9]. However, they are needed to be placed at appropriate depths and spacing according to soil types [10]. In India, installation of subsurface drainage system has recorded increase in the yield of rice and cotton of about 69 per cent and 64 per cent [11].

The subsurface drainage system consists of network of perforated PVC pipes and pipes are enclosed with gravel/synthetic filter to prevent clogging and are placed manually in the trenches at a preferred design spacing and depth [12]. The drain spacing generally influences the quickness of lowering water table based on the interruption of rainfall. Therefore, drain spacing and the depth and drain discharge play a decisive function in deciding the fluctuations of

the water table [13]. Under these circumstances, this study is aimed to assess the appropriate lateral drain spacing and drain depth for analyzing the functional performance of parallel drain subsurface system to remove the excess water in the subsurface soil.

2. MATERIALS AND METHODS

2.1 Study Area

Sembarai village is located Lalgudi Taluk, Trichy Dt, Tamil Nadu and receives water from river courses of Cauvery and adjacent to Coleroon. The field is located in 10°53'50.35" latitude and 78°53'53.80" longitude with mean altitude of 56.08 m above mean sea level. The average annual rainfall of the study area is 881 mm out of which 75 percent occurs in the rainy season from October to January. Nature of the soil is sandy loam. The main crop grown in the village is paddy and farmers are having a land holding of less than one ha. Normally, paddy is grown during kharif (June - Sep) and Rabi (Oct - Jan) season. Canal water is released from Mettur Dam every year during June for Kharif and October for Rabi . Crops are also irrigated by ground water pumping from bore wells. Water table is very shallow in canal irrigated regions whereas it is somewhat deeper in other regions. The maximum depth of bore well is upto 60 m and submersible pump is used for irrigation. Ten samples were collected from the village randomly for analyzing the physical and chemical characteristic of the soil before installation of drainage system. Physical and chemical properties of soil before installation of drainage system are presented in Table 1. From the

Table, soils are said to be alkalinity because pH is greater than 8.5, EC is less than 4.0 and Exchangeable Sodium Percentage is greater than 15. Water quality test was also conducted in the Village. Although the quality of irrigation water is good ($EC=1.51 \text{ dS m}^{-1}$) as per [14],

2.1.1 Problems of study area

Because of alkalinity of soil, waterlogging problems develops in the farmer's field. The other causes of waterlogging are mainly by poorly drainable sandy loam soils, seepage from the canal network adjacent to the field, lack of land development, inefficient irrigation practices and inadequate drainage. Inadequate drainage facility causes submergence of paddy crop and hence affecting the yield severely. It was also perceived that salt accumulation problem is exist during summer season. Waterlogging issues were noticed around 60 ha of land in Sembarai village. Depth to water table was measured in the study area during pre-monsoon and it was 0.3 m below ground level.

Farmers are usually suffers from a considerable yield loss due to water logging problem. They apply green manure before cultivation for improving crop yield. Some places farmers tried to remove excess water through open drains. However removal of drain water through open ditch method occupied more land areas and lowering of water table practically was not so easy. Removal of subsurface water can be removed in a best way by installing the parallel pipe subsurface drainage system. Because it lowers ground water table and creates favorable

Table 1. Physical and chemical properties of study area soil

Physical properties	Value	Chemical properties	Value
Bulk Density (g/cc)	1.56	Soil reaction (pH)	8.93
Particle Density (g/cc)	2.60	Electrical conductivity (dS/m)	0.97
Porosity (percent)	49	Exchangeable Calcium[$\text{cmol (p}^+) \text{ kg}^{-1}$]	6.22
		Exchangeable sodium [$\text{cmol (p}^+) \text{ kg}^{-1}$]	5.18
Mechanical		Exchangeable Magnesium[$\text{cmol (p}^+) \text{ kg}^{-1}$]	4.88
Composition		Exchangeable Potassium[$\text{cmol (p}^+) \text{ kg}^{-1}$]	
Sand (percent)		Exchangeable Sodium Percentage (per cent)	0.08
Silt (percent)		Available Nutrients (Kg/ha)	31.66
Clay (percent)		N	
Texture	67.50	P ₂ O ₅	
	22.30	K ₂ O	32.2
	13.20		7
	Sandy		55
	loam		

environment for crop growth. To address the water logging combined with alkalinity problem, a pilot study was conducted during the Oct 2020 to Feb 2021 to study the performance evaluation of parallel drain subsurface drainage system at farmer's field in Sembarai village.

2.2 Parallel Drain Subsurface System

Lowering of water table below the ground surface thereby creating favorable environment by providing perforated PVC pipe wrapped by coir fiber envelope material in the trenches below the ground surface is referred as parallel drain subsurface system. Lateral drain spacing and depth of the drain pipe as well as hydraulic conductivity of the soil determine the rate of removal of drain water from the field. There is a close relationship exists between soil hydraulic conductivity and the spacing and depth of drains. The drain spacing and depth should be considered based on soil type, hydraulic conductivity, the crops to be grown, the desired drainage coefficient and type of drainage system. Water discharges into the perforated pipes placed at a depth below the ground surface for lowering the initial water table to the desired depth of the water table under steady state condition. It's better to place the drain pipes above the heavy layer of soil if there is an abrupt transition from lighter to heavier soil.

A subsurface drainage system consists of lateral drain pipe, inspection chamber, collector drains, main drain and outlet. Different methods of subsurface drainage system can be practiced based on topography of lands. Because of flat lands in the study area, one method of subsurface drainage system called parallel pipes subsurface drainage system including inspection chamber with collector drain was tried in this study. Determination of lateral drain pipe spacing, pipe placement depth and pipe diameter was calculated based on observations of the soil physical parameters before installation and experiment was set.

2.2.1 Determination of lateral drain pipe spacing

Drain spacing can be computed from the theories of groundwater flow substituting the drainage coefficient, hydraulic conductivity, height of water level above water table and other parameters.

The drainage spacing formulae are based on a) steady state flow and homogeneous b) non-steady state flow conditions. For the present study as the profile in the study area is homogeneous and isotropic, steady state flow condition was considered and Hooghoudt's equation as given below was used for computing the lateral drain spacing [15]. Hooghoudt's equation is mainly based on the assumption that flow is radial near the drains pipe because of the curvature nature of drain water flow [16].

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

Where,

S = Lateral Drain spacing, m

K = Hydraulic conductivity of the soil, m/day

h = Height of water level above the water table in the drain, m

D = Depth to impervious layer, m

q = Drainage coefficient or drain discharge rate per unit surface area, m/day

2.2.2 Measurement of hydraulic conductivity

Inverse auger hole method was employed for measuring the hydraulic conductivity before the installation of drainage system. A hole was made in the soil surface to required depth and the hole was filled with water, water was left to drain away freely. The hole was refilled with water repeatedly till the soil around the hole was saturated over a considerable distance and the infiltration has attained to reach steady value. The detailed procedure of measurement of hydraulic conductivity by the inversed auger hole method as explained by [16] was followed. From the test conducted, the hydraulic conductivity was found to be 0.518 m/day.

2.2.3 Computation drainage coefficient before installation

The drainage coefficient is generally expressed as a total depth of water removed from an area in 24 hours. Before installation of drainage system, drainage coefficient was calculated using water balance equation for finding out the drain spacing. Drainage coefficient can be compute by.

Drainage coefficient (q)

= Recharge from rainfall for drainage (20 percent of average rainfall as effective rainfall for drainage)
+ Average deep percolation losses (25 percent of crop water requirement)/crop period

Average rainfall as 20 per cent of effective rainfall and deep percolation losses as 25 percent of crop water requirement was considered in this study. Crop period for Paddy was taken as 134 days. The computed drainage coefficient based on water balance equation was 3.55 mm/day.

2.2.4 Design drain pipe spacing

The designed drain spacing was calculated by taking the height of the water level above water table observed in the study area as 20 cm, depth to impervious layer taken as 4 m and drainage coefficient as 3.55 mm/day and hydraulic conductivity as 0.518 m/day. The designed drain spacing was found to be 31 m. To test the performance of design drain pipe spacing, a trial study was conducted to assess the radial flow towards the drain pipe by installing the 63 mm drain pipe at 30 m spacing and 60 cm depth for a water level of 20 cm above water table. It was observed that the drainage discharge was 0.002 cm/day and flow towards the pipe was found to be very low. Hence, narrow drain spacing of 7.5 m, 10.0 m and 12.5 m was selected by considering the radial flow and nature of field as farmers are having small land holdings [17]

2.2.5 Design drain pipe depth

The depth of drain pipe placement was selected on the basis of crop root zone depth, soil texture and cost of the system. The system has to work at favored depth for culminate the extra water. The depth of drain pipe needs to be more than the depth of root zone of the selected paddy crop so that the surplus water from the root zone of the crop will be eliminated and appreciable the air circulation will be achieved. In this study, placement of drain pipe depth of 60 cm and 80 cm has been favorably chosen for paddy crop.

2.2.6 Design drain pipe diameter

Wessling's equation [16] for uniform flow in smooth and corrugated pipes derived from Manning's equation was applied to calculate the size of the lateral drain pipes. The size of the lateral pipe required to carry the design flow rate is given as below.

$$Q = 89(d_L)^{2.716} \times i^{-0.572}$$

Where

Q = Discharge in the pipe, m³/day = Length (m) X Width of the field (m) X Initial drainage coefficient (m/day)

d_L = Diameter of lateral pipe, m

i = Slope of lateral pipe fraction 0.3 per cent as 0.003

Length of the field as 7.5 m, width of the field as 10 m and initial drainage coefficient as 0.003 m/day) was applied in Wessling's equation and diameter of the pipe was found to be 33 mm. To drain more water in wider spacing, greater pipe diameter which is more than design diameter was selected. The commercially available pipe diameter of 63 mm was selected in this study.

2.3 Experimental Details

Based of design values of lateral drain pipe spacing, placement depth and pipe diameter, a field experiment was carried out to study the functional performance of the parallel drain sub surface system. This experimental design consists of factorial randomized block design with three replications. The factors used in this study were three lateral drain spacing (7.5 m, 10.0 m and 12.5 m) and two drain depth (60 cm and 80 cm). A control plot was also laid to test the crop in undrained condition. Details of treatments for the experiment are furnished below.

1. 7.5 m drain spacing with 60 cm depth of drain (S₁D₁)
2. 10 m drain spacing with 60 cm depth of drain (S₂D₁)
3. 12.5 m drain spacing with 60 cm depth of drain (S₃D₁)
4. 7.5 m drain spacing with 80 cm depth of drain (S₁D₂)
5. 10 m drain spacing with 80 cm depth of drain (S₂D₂)
6. 12.5 m drain spacing with 80 cm depth of drain (S₃D₂)
7. Control plot

2.4 Layout of the System and Crop Details

The parallel pipe subsurface drainage system was installed in an area of 0.144 ha as per the

different treatment combinations. Length and width of the field was 120 m and 12 m. A plot size of the treatment was decided based on lateral drain spacing and length of the plot was taken as 6 m. Each plot was separated by providing buffer pipe of 63 mm diameter at 60 cm and 80 cm depth. The main purpose for providing buffer pipe is that reading of drain discharge and depth to water table recorded at one plot does not to affect the adjacent plot.

The PVC pipes 63 mm are used as lateral drain pipes and collector drain pipes. These pipes were perforated using 6 mm drill bit with the spacing of 2.5 cm between the perforations. PVC pipes were wrapped by two layers of coir fiber envelope material and it was tied with nylon rope.

1 m length and 63 mm diameter PVC perforated pipes were used as the observation wells. They were installed at the midway between drains to measure the depth to water table. There are totally 24 observation wells installed. Each plot contains three lateral drain pipes, one inspection chamber and one collector pipe.

Entire study area was divided into six plots and each plot is again sub divided into three sub plots to accommodate different lateral drain spacing. Inspection chambers carrying the 250 liters of water are provided at the end all the lateral drain

pipes. All the inspection chambers are connected by the collector drain of 63 mm pipe and collector drains are connected to the main drain of 63 mm. Collected water are finally disposed in to a outlet near the odai. Performance of the system is evaluated by measuring the drain discharge from the lateral drain pipe. The slope of the lateral drain pipe was 0.6 per cent and for collector pipe was 0.3 per cent. Layout of the subsurface drainage system in the study area is shown in Fig. 1.

2.5 Functional Performance of Parallel Drain Subsurface System

Functional performance of parallel drain sub surface systems was studied based on (i) soil properties (pH and EC), (ii) depth to water table from the observation wells and (iii) drainage coefficient in terms of discharge collected at the inspection chamber. Soil properties (pH and EC) was measured at different crop growing stages. All the observations of depth to water table and discharge were recorded next day after it was rained during the paddy growing period. Depth to water table was measured using 1 m steel scale in 24 observation wells regularly. The drain discharge from the lateral drain pipes was measured using a bucket, stop watch and a

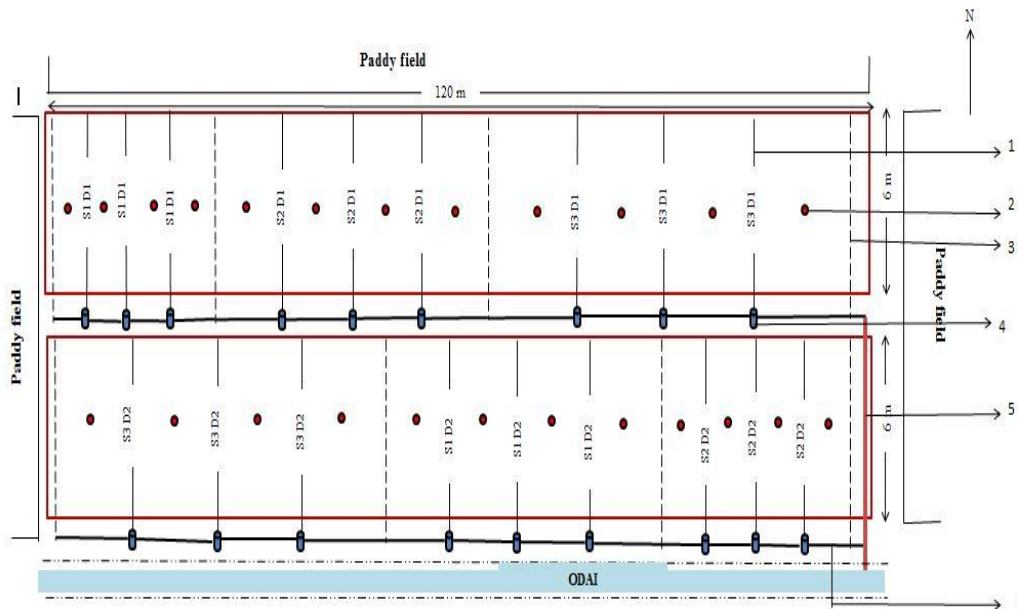


Fig. 1. Layout of subsurface drainage system in an experimental area

1. Lateral drain pipe, 2. Observation well, 3. Buffer pipe, 4. Inspection chamber, 5. Main drain 6. Collector drain

graduated cylinder on volume basis. Drainage coefficient was calculated by dividing the drain discharge with the area of influence of each lateral drain pipe and expressed in the form of cm/day. Area of influence of each lateral drain pipe was calculated by multiplying the length of each lateral drain pipe and spacing between drain pipes.

2.6 Effect of Parallel Drain Subsurface System on Waterlogged Paddy

Paddy crop was transplanted over the parallel pipe sub surface system during Oct 2020 and harvested during Feb 2021. The crop variety was BPT 5204 and paddy was transplanted at 15 X 15 cm spacing. Crop was grown as per the Packages of Practices given in Crop Production Guide, 2019. To study the effect of parallel drain subsurface system on crop performance, biometric observations viz plant height and no of tillers per plant and yield components (grain yield and straw yield) were recorded for different crop growth stages and treatments. Plant height was measured from the bottom near soil surface to tip of the tagged plants. Number of tillers per plant was counted for different crop growth periods and different treatments. The plant height is measured by 1 m steal scale. Number of tillers per plant was counted manually.

3. RESULTS AND DISCUSSION

The results arrived from this study with respect to functional performance and crop performances are discussed here.

3.1 Effect of Parallel Drain Subsurface System on Soil Reaction (pH)

Effect of drain spacing and drain depth with different treatment combinations on soil pH recorded before installation, 30 DAT, 60 DAT, 90 DAT, 120 DAT and after harvest were presented in Table 2. Before installation of subsurface drainage system the soil pH was measured as 9.0. The nature of the soil was found to be alkaline because of presence of base forming cations like Ca^{2+} , Mg^{2+} , Na^+ and K^+ . After installation of the system and noticing the soil pH in different treatment combinations, a remarkable reduction in soil pH was observed in S_1D_2 (7.5 m drain spacing and 80 cm drain depth) treatment when compared with control plot.

From Table 2 among the all treatments, the treatment of S_1D_2 (7.5 m drain spacing and 80 cm drain depth) has recorded lower soil pH value of 8.18 whereas the higher soil pH of 8.77 was recorded in the treatment of S_3D_1 (12.5 m drain spacing and 60 cm drain depth) at 30 DAT. Same pattern was followed for 60 DAT, 90 DAT, 120 DAT and after harvest. It is worth to say that soil pH measured in the control plot for different crop period has shown increasing trend from 9.0 to 9.1 and these values were high when compared to parallel drain subsurface system treatments.

Table 2. Effect of parallel drain subsurface drainage system on soil pH

S.No	Treatment	Before Installation	30 DAT	60 DAT	90 DAT	120 DAT	After harvest
1.	S_1D_1 (7.5 m drain spacing & 60 cm drain depth)	9.0	8.6	8.5	8.53	8.45	8.44
2.	S_1D_2 (7.5 m drain spacing & 80 cm drain depth)	9.0	8.4	8.3	8.27	8.19	8.18
3.	S_2D_1 (10 m drain spacing & 60 cm drain depth)	9.0	8.6	8.5	8.55	8.49	8.47
4.	S_2D_2 (10 m drain spacing & 80 cm drain depth)	9.0	8.8	8.9	8.85	8.77	8.73
5.	S_3D_1 (12.5 m drain spacing & 60 cm drain depth)	9.0	8.9	8.9	8.89	8.80	8.77
6.	S_3D_2 (12.5 m drain spacing & 80 cm drain depth)	9.0	8.7	8.6	8.59	8.51	8.49
7.	Control plot	9.0	9.0	9.0	9.0	9.1	9.1
	SED		0.071	0.098	0.105	0.105	0.100
	CD ($P= 0.05$)**		0.153	0.219	0.234	0.234	0.215

Though all the treatments registered significant reduction in soil pH, closer drain spacing and higher drain depth has recorded higher reduction in soil pH as a result of removal of much ion through drain water compare to higher drain spacing and drain depth. The reduction of soil pH towards the different stages of crop development was mainly due to the removal of some of the base forming cations from the soil by drain water and the elimination of sodium and bicarbonate ions through drain water.

These observations were inlined with the past studies which revealed that the pH of the soil after the implementation of the subsurface drainage system has decreased. [18,19,20] suggested that the reducing in soil pH due to the elimination of sodium and bicarbonate ions through drain water.

3.2 Effect of Parallel Drain Subsurface System on Soil Electrical Conductivity (EC)

Electrical conductivity (EC) of soil was measured before installation, 30 DAT, 60 DAT, 90 DAT, 120 DAT and after harvest for assessing the effect of lateral drain spacing and drain depth with different parallel drain subsurface system and the results are presented in Table 3. Before installation of parallel drain subsurface drainage system the soil EC was measured as 0.97 dS/m. After installation of the system and observing the soil EC in different treatment combinations, a

notable reduction in soil EC was observed in S₁D₂ (7.5 m drain spacing and 80 cm drain depth) treatment.

The treatment of S₁D₂ (7.5 m drain spacing and 80 cm drain depth) has recorded lower soil EC value of 0.35 dS/m whereas the higher soil EC of 0.61 dS/m was recorded in the treatment of S₃D₁ (12.5 m drain spacing and 60 cm drain depth) at 30 DAT. It was also noticed that similar decreasing trend of EC for 60 DAT, 90 DAT, 120 DAT and after harvest.

Soil EC measured in the control plot for different crop period has shown that there is increasing trend from 0.97 to 1.10 dS/m and these values were high when compared to parallel drain subsurface system treatments. Though all the treatments registered significant reduction in soil EC, closer drain spacing and higher drain depth has recorded higher reduction in soil EC as a result of removal of more salts through drain water when compared to higher drain spacing and drain depth.

Before installation of the parallel drain subsurface system, salts were accumulated more at the surface and soil profile over a period due to water logging and alkalinity through the process of high evaporative demands and capillary action. After installation of the system, surface layer salts were partly leached to deeper subsurface layers and partly discharged out by drain water through lateral drains.

Table 3. Effect of parallel drain subsurface drainage system on soil EC (dS/m)

S.No	Treatment	Before Installation	30 DAT	60 DAT	90 DAT	120 DAT	After harvest
1.	S ₁ D ₁ (7.5 m drain spacing & 60 cm drain depth)	0.97	0.54	0.42	0.46	0.43	0.42
2.	S ₁ D ₂ (7.5 m drain spacing & 80 cm drain depth)	0.97	0.45	0.41	0.38	0.36	0.35
3.	S ₂ D ₁ (10 m drain spacing & 60 cm drain depth)	0.97	0.52	0.46	0.39	0.44	0.43
4.	S ₂ D ₂ (10 m drain spacing & 80 cm drain depth)	0.97	0.56	0.52	0.48	0.37	0.36
5.	S ₃ D ₁ (12.5 m drain spacing & 60 cm drain depth)	0.97	0.70	0.68	0.66	0.63	0.61
6.	S ₃ D ₂ (12.5 m drain spacing & 80 cm drain depth)	0.97	0.53	0.52	0.49	0.47	0.46
7.	Control plot	0.97	0.97	0.98	0.98	1.1	1.1
	SED		0.053	0.068	0.057	0.066	0.061
	CD (P= 0.05)**		0.114	0.152	0.129	0.147	0.131

Similar results were observed [18,19,20] mentioned that the decrease in soil EC in the drained field due to elimination of soluble salts through drain discharge water at different lateral drain spacing's. In the existing investigation, an increase in soil EC observed in the control plot due to the application of more fertilizers.

3.3 Effect of Parallel Drain Subsurface System on Depth to Water Table

The pattern of depth to water table from the ground surface at three lateral drain pipes measured next day after rainfall in the observation wells for drain depth of 60 cm and 80 cm is presented in Table 4. Before installation of drainage system, the water table used to be close to the ground surface during the crop period Rabi season (October to January). After installation of the system, water started to flow towards the drain pipe radially and flow is mainly influenced by hydraulic conductivity, soil properties, spacing between the drains, depth of drains, deep percolation and location of impervious stratum.

Initially the depth to water table was 0.3 m from the surface. From the Table 4, it can be observed that depth to water table has fluctuated from 0.29 m to 0.54 m during the crop period for 7.5 m lateral drain spacing and 80 cm drain depth. Due to lesser lateral drain pipe spacing and higher hydraulic conductivity, depth to water table has been lowered notably. Other lateral drain spacing's and drain depth recorded lesser variations in depth to water table. Reasons for decreased level of depth to water table were due to continuous rainfall, drainage problem develops, and water stands at least 20 cm height above surface. The rate of lowering the depth to water table was found to be slow from the next day after rainfall till next rainfall. When there is no rainfall, crops are irrigated by ground water pumping from bore wells, possibilities of lowering of water was minimum as height of water standing over the surface was also very minimum. Srinivasulu et al., [21] have reported that due to the installation of drainage system water table that was very close to the ground surface during the paddy-growing season could be lowered up to 0.25 to 0.4 m below the ground surface at the drain spacing of 30 m and thereby problem of water logging was controlled. Manjunatha et al., [22] have reported that the average water table in the experimental area during Kharif season was shallower than during

Rabi due to monsoon rains. The average water table depth of 50 and 67 cm during Kharif and Rabi in the first year lowered down to, respectively, 62 and 85 cm in the second year but no further change was observed in the third year. Selvaperumal et al., [5] have concluded that the treatments of 7.5 m drain spacing at 75 cm depth with 75 mm diameter recorded 0.28 to 0.33m in variation of depth to water table. Srinivasulu et al., [23] have observed by that deeper groundwater was found to contribute more significantly to the total drain flow compared with shallow groundwater. Maximum and minimum depth of water table was observed as 67 and 63 cm where drains installed at spacing of 30 m and 60 m. Malota & Senzanje, [24] have concluded that reduction in water table depth below the soil surface increases with decrease in drain spacing and constant drain depth.

3.4 Effect of Parallel Drain Subsurface System on Drainage Coefficient

Depth of water to be removed in a day was computed based on drain discharge collected in the inspection chamber and area of influence. The pattern of drainage coefficient at three lateral drain pipes measured next day after rainfall in the inspection chamber for drain depth of 60 cm and 80 cm is presented in Table.5. From the figures, it can be noted that 7.5 m lateral drain spacing and 80 cm drain depth treatment shown the higher variation of drainage coefficient from 0.069 to 0.29 cm/day. As the drain spacing decreased, contributing area per unit perforated area on the drain pipes decreased and hence drain flow in lesser drain spacing increased. The higher drainage coefficient for lesser (7.5m) lateral drain spacing when compared to higher lateral drain spacing was due to reduced flow path of water in soil. The minimum value of drainage coefficient 0.030 cm/day is observed for 12.5 m lateral drain spacing at drain depth of 60 cm.

Similar finding was reported by [25] that heavy texture soil in the hardpan and its low hydraulic conductivity for low drainage volume in the treatments with higher spacing. Christen & Skehan, [26] concluded that the low porosity of the subsoil was responsible for the long draining period and influenced inducing flow in the drain. Srinivasulu et al., [23] concluded in his study that as the lateral drain

Table 4. Effect of parallel drain subsurface drainage system on depth to water table

Treatments	Depth to water table (m)								
	14 DAT (19-11- 2020)	22 DAT (27-11- 2020)	30 DAT (05-12- 2020)	45 DAT (20-12- 2020)	60 DAT (04-01- 2020)	69 DAT (17-01- 2020)	90 DAT (07-02-2021)	120 DAT (10-03- 2021)	After harvest
	20 mm RF on 18-11- 2020	15 mm RF on 26-11- 2020	39 mm RF on 04-12- 2020	15 mm RF on 19-12- 2020	37.5 mm RF on 03- 01-2021	28.8 mm RF on 16- 01-2021	No rainfall	No rainfall	No rainfall
S ₁ D ₁ (7.5 m drain spacing & 60 cm drain depth)	0.32	0.33	0.37	0.26	0.27	0.12	0.31	0.35	0
S ₁ D ₂ (7.5 m drain spacing & 80 cm drain depth)	0.42	0.48	0.42	0.34	0.34	0.29	0.50	0.54	0
S ₂ D ₁ (10 m drain spacing & 60 cm drain depth)	0.31	0.31	0.37	0.24	0.25	0.11	0.29	0.32	0
S ₂ D ₂ (10 m drain spacing & 80 cm drain depth)	0.40	0.46	0.38	0.28	0.32	0.25	0.47	0.50	0
S ₃ D ₁ (12.5 m drain spacing & 60 cm drain depth)	0.29	0.30	0.33	0.21	0.21	0.10	0.28	0.31	0
S ₃ D ₂ (12.5 m drain spacing & 80 cm drain depth)	0.36	0.40	0.34	0.25	0.28	0.20	0.45	0.48	0
SED	0.009	0.012	0.029	0.007	0.007	0.005	0.006	0.004	0
CD ($P = 0.05$)**	0.020	0.025	0.063	0.016	0.016	0.012	0.014	0.009	0

Table 5. Effect of parallel drain subsurface drainage system on drainage coefficient (cm/day)

Treatments	drainage coefficient (cm/day)								
	14 DAT (19-11- 2020)	22 DAT (27-11- 2020)	30 DAT (05-12- 2020)	45 DAT (20-12- 2020)	60 DAT (04-01- 2021)	69 DAT (17-01- 2021)	90 DAT (07-02-2021)	120 DAT (10-03-2021)	After harvest
	20 mm RF on 18-11-20	15 mm RF on 26-11-20	39 mm RF on 04-12-20	15 mm RF on 19-12-20	37.5 mm RF on 03-01-21	28.8 mm RF on 16- 01-21	No rainfall	No rainfall	No rainfall
S ₁ D ₁ (7.5 m drain spacing & 60 cm drain depth)	0.187	0.058	0.109	0.049	0.118	0.098	0.089	0.076	No discharge
S ₁ D ₂ (7.5 m drain spacing & 80 cm drain depth)	0.297	0.079	0.152	0.069	0.145	0.195	0.175	0.158	No discharge
S ₂ D ₁ (10 m drain spacing & 60 cm drain depth)	0.143	0.048	0.099	0.033	0.108	0.088	0.078	0.067	No discharge
S ₂ D ₂ (10 m drain spacing & 80 cm drain depth)	0.273	0.068	0.129	0.065	0.128	0.179	0.165	0.138	No discharge
S ₃ D ₁ (12.5 m drain spacing & 60 cm drain depth)	0.123	0.042	0.089	0.030	0.098	0.054	0.048	0.037	No discharge
S ₃ D ₂ (12.5 m drain spacing & 80 cm drain depth)	0.253	0.058	0.125	0.058	0.118	0.168	0.140	0.127	No discharge
SED	0.004	0.001	0.001	0.002	0.002	0.002	0.003	0.005	
CD ($P=0.05$)**	0.008	0.003	0.003	0.004	0.004	0.005	0.007	0.011	

spacing decreased, the drain discharge increased. Helmers et al., [27] reported that deeper drains increase drainage amounts. Schott et al., [28] recorded 40 per cent of reduction of annual drainage volume at a drain depth of 0.76 m as compared to 1.20 m.

3.5 Effect of Different Parallel Drain Subsurface System on Plant Height

Plant height measured for different crop growth periods and different treatments is presented in Table 6 the growth of the paddy crop was found to be increasing as the crop duration in days increasing. From the Table 6 it can be noticed that the crop height was significantly increased in the different lateral drain spacing and drain depth treatments. The plant height was found to be higher in S₁D₂ i.e. 7.5 m drain spacing and 80 cm treatment drain depth (25.7 cm) and lower in S₃D₁ i.e. 12.5 m drain spacing and 60 cm drain depth treatment (22.3 cm) for 5 DAT.

After 30th days transplanting, average plant height was found to be maximum in S₁D₂ i.e. 7.5 m drain spacing and 80 cm drain depth treatment (56.3 cm) and minimum in S₃D₁ i.e. 12.5 m drain spacing and 60 cm drain depth (47.4 cm). plant height computed after 60th DAT showed that S₁D₂ i.e. 7.5 m drain spacing and 80 cm drain depth treatment (82.3 cm) was registered higher height whereas S₃D₁ i.e. 12.5 m drain spacing and 60 cm drain depth treatment registered lower height of 76.7 cm.

It was found that the crop growth for 90 DAT, 120 DAT and at harvest was found to be equal.

Height of the plant measured in control plot was found to be smallest when compared to other treatments as depth to the water table was present near the soil surface.

Balusamy and Udayasoorian, (2017) reported that the provision of subsurface drainage system in waterlogged saline-alkali soil increased the germination percentage, plant height of maize crop, due to removal of a large amount of soluble salts, waterlogging free condition and increased nutrient availability in drained field, favored the plant growth and development. Same findings were also recorded by [29]. Similarly, Sousa et al., [30] reported that 80 percent increase in plant height after 8 months in drainage system installed field, whereas it was only 50 percent in the un-drained field. A significant positive effect of subsurface drainage on plant height was recorded in this study. This result is supported by the findings of [31,32] also reported higher plants under the 30 cm water table depth compared with those under 15 cm water table and flooded conditions.

3.6 Effect of Different Parallel Drain Subsurface System on Number of Tillers per Plant

Number of tillers per plant was counted for different crop growth periods and different treatments and it is presented in Table.7 From the table it can be well observed that the parallel drain subsurface system has made significant influence in number of tillers per plant when

Table 6. Effect of parallel drain subsurface drainage system on plant height (cm)

SI.No	Treatment	5 DAT	30 DAT	60 DAT	90 DAT	120 DAT	At harvest
1	S ₁ D ₁ (7.5 m drain spacing & 60 cm drain depth)	24.4	51.0	81.7	85.3	85.3	85.3
2	S ₁ D ₂ (7.5 m drain spacing & 80 cm drain depth)	25.7	56.3	82.3	90.3	90.3	90.3
3	S ₂ D ₁ (10 m drain spacing & 60 cm drain depth)	23.6	49.3	79.7	84.0	84.0	84.0
4	S ₂ D ₂ (10 m drain spacing & 80 cm drain depth)	24.7	52.0	82.0	85.0	85.0	85.0
5	S ₃ D ₁ (12.5 m drain spacing & 60 cm drain depth)	22.3	47.4	76.7	79.3	79.3	79.3
6	S ₃ D ₂ (12.5 m drain spacing & 80 cm drain depth)	23.5	48.8	79.0	82.7	82.7	82.7
7	Control plot	21.2	46.1	75.0	76.3	76.3	76.3
	SED	0.219	1.495	1.070	2.879	2.879	2.879
	CD (P= 0.05)**	0.471	3.207	2.296	6.176	6.176	6.176

compared with control. Number of tillers per plant for paddy at different treatments was found to be increasing when the duration of crop in days was increasing. Table.5 showed that there was significant difference in number of tillers per plant in the different lateral drain spacing and drain depth treatments. The number of tillers per plant was found to be maximum in S₁D₂ i.e. 7.5 m drain spacing and 80 cm treatment drain depth (16 Nos.) and minimum in S₃D₁ i.e. 12.5 m drain spacing and 60 cm drain depth treatment (11 Nos.) for 5 DAT.

After 30th days transplanting, average number of tillers per plant was found to be maximum in S₁D₂ i.e. 7.5 m drain spacing and 80 cm drain depth treatment (27 Nos.) and minimum in S₃D₁ i.e. 12.5 m drain spacing and 60 cm drain depth (24 Nos.). Number of tillers per plant computed after 60th DAT showed that S₁D₂ i.e. 7.5 m drain spacing and 80 cm drain depth treatment (37 Nos.) was registered higher whereas S₃D₁ i.e. 12.5 m drain spacing and 60 cm drain depth treatment registered lower of 34 Nos.

Average number of tillers per plant was found to be higher in S₁D₂ i.e. 7.5 m drain spacing and 80 cm drain depth treatment (43 Nos.) and minimum in S₃D₁ i.e. 12.5 m drain spacing and 60 cm drain depth (40 Nos.) for 90th DAT.

It was found that number of tillers per plant for 120 DAT and at harvest was found to be same. Number of tillers per plant in control plot was found to be least when compared with other treatments as depth to the water table was present in the root zone depth. Owusu-Sekyere

[32] reported that increased tiller numbers were observed for the plants under the 30 cm water table depth compared those under the 15 cm water table depth.

3.7 Effect of Parallel Drain Subsurface System on Paddy Yield and Straw Yield

Paddy grain yield was greatly affected by different lateral drain spacing and drain depth treatments. Grain yield recorded for different treatments is presented in Table.8. From the table it can be observed that grain yield in the parallel drain subsurface system treatments was significantly higher than that of control plot. S₁D₂ (7.5 m drain spacing and 80 cm drain depth) treatment has recorded higher grain yield of 5570 kg per ha whereas S₃D₁ (12.5 m drain spacing and 60 cm drain depth) treatment recorded the grain yield of 4740 kg per ha. Control plot has recorded the lesser grain yield of 3300 kg per ha. Grain yield recorded in S₁D₂ (7.5 m drain spacing and 80 cm drain depth) treatment has increased to 22.6 per cent than that of control plot. Yield recorded for narrow lateral drain spacing was more compared to wider spacing at both drain depths. Lowering depth to water table, higher drain discharges and leaching of base forming cations below the root zone has improved the aeration around the root zone thereby created favorable environment to the crop growth. It was reflected in grain yield. Grain yield has showed the positive and significant correlation with plant height, number of tillers per plant and straw yield.

Table 7. Effect of parallel drain subsurface drainage system on number of tillers per plant

S.No	Treatment	5 DAT	30 DAT	60 DAT	90 DAT	120 DAT	At harvest
1.	S ₁ D ₁ (7.5 m drain spacing & 60 cm drain depth)	14	26	36	42	43	43
2.	S ₁ D ₂ (7.5 m drain spacing & 80 cm drain depth)	16	27	37	43	44	44
3.	S ₂ D ₁ (10 m drain spacing & 60 cm drain depth)	12	25	35	41	42	42
4.	S ₂ D ₂ (10 m drain spacing & 80 cm drain depth)	14	26	36	42	43	43
5.	S ₃ D ₁ (12.5 m drain spacing & 60 cm drain depth)	11	24	34	40	41	41
6.	S ₃ D ₂ (12.5 m drain spacing & 80 cm drain depth)	13	25	35	41	42	42
7.	Control plot	10	21	30	38	39	39
	SED	0.230	0.164	0.181	0.274	0.320	0.320
	CD (P= 0.05)**	0.494	0.351	0.388	0.588	0.686	0.686

Table 8. Effect of parallel drain subsurface system on grain yield and straw yield

S.No	Treatment	Grain yield, Kg/ha	Straw yield, Kg/ha
1.	S ₁ D ₁ (7.5 m drain spacing & 60 cm drain depth)	5190	4180
2.	S ₁ D ₂ (7.5 m drain spacing & 80 cm drain depth)	5570	4350
3.	S ₂ D ₁ (10 m drain spacing & 60 cm drain depth)	4870	4050
4.	S ₂ D ₂ (10 m drain spacing & 80 cm drain depth)	5040	4200
5.	S ₃ D ₁ (12.5 m drain spacing & 60 cm drain depth)	4740	3820
6.	S ₃ D ₂ (12.5 m drain spacing & 80 cm drain depth)	4810	4140
7.	Control plot	3300	3000
	SED	0.004	0.005
	CD ($P = 0.05$)**	0.010	0.011

Previous studies have shown that subsurface drainage system has improved crop yield. [33] Aaron Lee M. Daigh et al., 2019 reported that narrow drain spacing of 9 m resulting in significantly higher corn yield during the wet years of 2015. Research conducted by [34] Lal and Fausey (1998) in central Ohio showed that crop yield increased with decreasing subsurface drain spacing. Moustafa et al., [35] found that 39 per cent increase in crop yield with 12.5 m drain spacing and 16 per cent increase in crop yield with 25 m drain spacing when compared with 50 m drain spacing in a clay soil. These results are consistent with other studies conducted on drain spacing and depth [35,36, and 37].

From Table 8 presents the straw yield under different subsurface drainage system. Different lateral drain spacing and drain depth treatments has affected significantly on paddy straw yield. Straw yield recorded in the parallel drain subsurface system treatments was higher than that of control plot. Control plot has recorded the lesser straw yield of 3000 kg per ha. S₁D₂ (7.5 m drain spacing and 80 cm drain depth) treatment has recorded maximum straw yield of 4350 kg per ha whereas S₃D₁ (12.5 m drain spacing and 60 cm drain depth) treatment recorded the straw yield of 3820 kg per ha. Straw yield in S₁D₂ (7.5 m drain spacing and 80 cm drain depth) treatment has increased to 24 per cent than that of control plot. Straw yield recorded for closer lateral drain spacing was higher when compared to wider lateral drain spacing at both drain depths, which reflects as in the grain yield. Darzi-Naftchali et al., [17] has concluded that grain yield, growth characteristics and straw yield of rice were significantly influenced by subsurface drainage system.

4. CONCLUSION

Functional performance of parallel drain subsurface system installed in waterlogged paddy field was assessed through the soil properties, depth to water table, drainage coefficient and crop yield. Post installation of the system higher rate of reduction of soil pH (from 9.0 to 8.18) and removal of salts through drain water measured by EC (from 0.97 dS/m to 0.35 dS/m) has been recorded for S₁D₂ (7.5 m drain spacing and 80 cm drain depth) treatment.

This study explored the effect of lateral drain spacing and drain depth on depth to water table and drainage coefficient (cm/day). Closer lateral drain spacing and deeper drains lowers water table below the root zone and increases drain discharge due to removal of salts through drain water. S₁D₂ (7.5 m drain spacing and 80 cm drain depth) treatment has recorded higher grain yield 22.6 per cent and straw yield of 24 per cent over un-drained field. Plant height and number of tillers per plant was found to be higher. Generally, like this kind of subsurface drainage is an essential economic activity to improve paddy crop production in the study area. Therefore it is concluded that adoption of subsurface drainage increases the profitability of paddy fields and improves self sufficiency in food grain production.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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