

Original Research Article

Drainage Investigations for the Design of Water table Management Systems in AEC&RI, Kumulur, Trichy District, Tamil Nadu

Abstract

A water table management system synonymously referred as Controlled Drainage and Subirrigation system or controlled and Reversible Drainage System was designed and executed in Eastern Farm A Block, Agricultural Engineering College and Research Institute Kumlur. This research article reports the pre-drainage investigations carried out in the study area for arriving at certain important design parameters for the design of water table management system for both drainage and subirrigation modes separately. Steady state Hooghoudt equation was used for the design of drainage spacing and similarly the procedure followed by Doty at North Carolina University using Moody Equation and convergence analysis was used for subirrigation mode spacing. The spacing arrived for drainage mode was 15 m to that of subirrigation was 10 m respectively.

Keywords: Controlled Drainage, subirrigation, Hydraulic conductivity and Drainage coefficient

Introduction

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 – 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. Exact quantification of this seasonal waterlogging is not available for the state. Essentially drainage technology is vital to alleviate the waterlogging problem, but at the same time, the same system technically, if used for irrigation through conjunctive strategy of ground water in the above areas, the crop production and productivity could be increased all round the year (2 to 3 crops).

Many researchers studies in the advanced countries were carried out to accomplish dual purposes with water table management system synonymously referred as controlled Drainage and Subirrigation system. Roy L.Fox et.al reported the procedure of subirrigation systems design and requirements [1]. They have evolved criteria for subirrigation, the design dimensions of feeder ditch. Movement of water table for subirrigation conditions was characterized by

numerically solving a non linear differential equation describing unsteady flow above a horizontal impervious layer. Solutions were presented for both initial draining and horizontal water table profiles [2]. Controlled drainage is a method used for the integration of irrigation management with drainage management. It replies the reduction of drainage flow in order to maximize the crop water utilization [3]

Materials and Methods

The experiment was laid out and conducted experiment 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.

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

$$K_s = \frac{2.3 aS}{(2d + a)\Delta t} \log_{10} \frac{y_0}{y_1}$$

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.

Design parameters:

For both subirrigation and subsurface drainage

1. Depth to the lateral pipe
2. Diameter of the lateral pipe
3. Minimum grade of lateral pipe
4. Length of the lateral pipe

For subirrigation

1. Depth to water table at lateral
2. Depth to water table at midpoint

For subsurface drainage

1. Depth to water table at lateral
2. Depth to water table at midpoint
3. Design subirrigation rate
4. Design subsurface drainage rate
5. Saturated hydraulic conductivity

Spacing calculations under drainage system mode operations

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 [4]

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

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

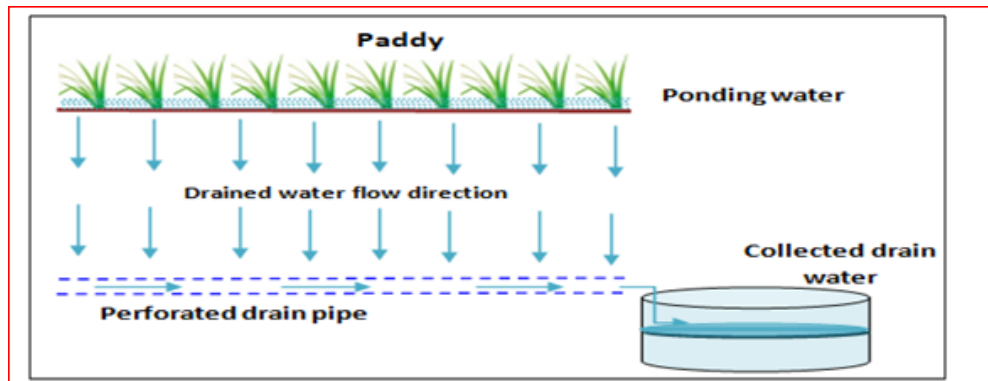


Fig.1 Layout of Subsurface Drainage mode

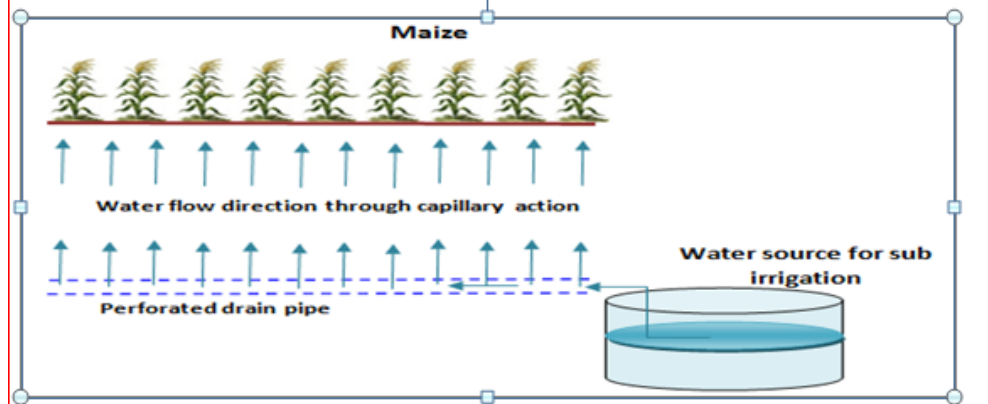


Fig.2 Layout of Subirrigation mode

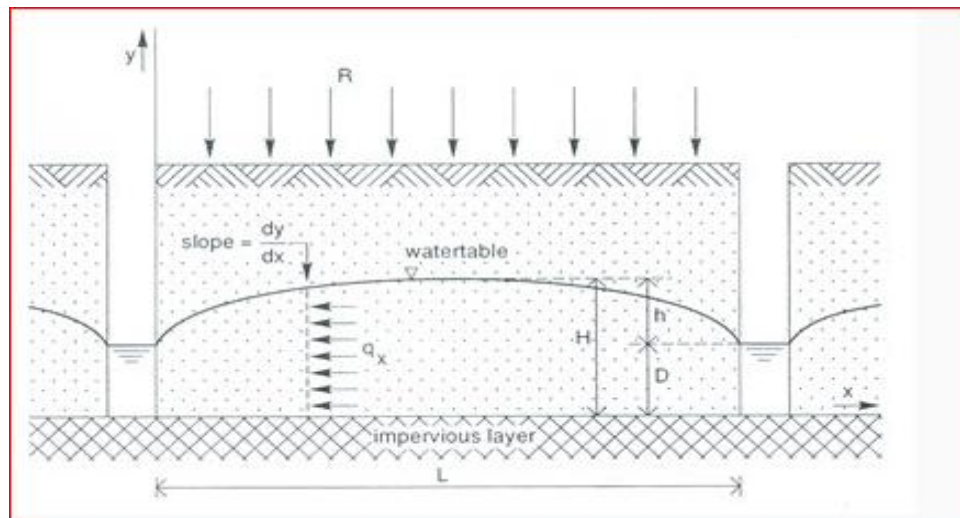


Fig 3.2 Flow to vertically – walled drains reaching the impervious layer. [5]

Water table movement between parallel drains can be predicted by solving Boussinesq equation for the appropriate initial and boundary condition. Boussinesq equation neglects flow in the unsaturated zone and is based on continuity, Darcy's law and the Dupit Forchheimer assumptions

$$f = \frac{\partial h}{\partial t} = K \frac{\partial}{\partial x} \left[h \frac{\partial h}{\partial x} \right] + e \quad \dots Eq.1$$

h = elevation of watertable above the impermeable layer

t = time

x = horizontal position

e = rate of vertical infiltration into the saturated zone ('e' is negative for evaporation or vertical seepage)

K = lateral saturated hydraulic conductivity

f = drainable porosity

Position and shape of the water table during steady state subirrigation can be approximated by making the dupit forecheimer assumption. Water movement in the unsaturated zone is neglected, spacing of drains and could be determined from

$$L = \left(\frac{4 K_s M (2h_0 - M)}{e} \right)^{\frac{1}{2}} \quad \dots Eq.2$$

or

$$L = \left(\frac{4 K_s (h_0^2 - h_1^2)}{e} \right)^{\frac{1}{2}} \quad \dots Eq.3.$$

K_s = Saturated hydraulic conductivity (m/day)

h₀ = Water table height above the drains (m)

h₁ = Water table at midway between drains (m)

e = Evaporation rate (m/day)

Equivalent depth from the drain to the impermeable layer, d_e can be calculated from

$$d_e = \frac{d}{\left[1 + \frac{d}{l} \left(\frac{8}{\pi} \ln \frac{d}{r_e} - 3.4 \right) \right]} \quad \dots Eq.4$$

r_e is the effective drain tube radius which is smaller than the actual radius because the tube wall is not permeable but has only a small percentage of open area
 d is the depth from drains to layer

By taking the suitable corrections for convergence, the final equation for spacing reduces to

$$L = \left(\frac{4 K_s M \left(2h_0' - \frac{h_0'}{h_0} M \right)}{e} \right)^{\frac{1}{2}} \quad \dots Eq.5$$

M = Difference between water table levels = $h_0 - h_1 = h_0' - h_1'$

h_0' equivalent water table elevation = $d_e + y_0$

For both subirrigation trials, the design spacing must be smaller than for drainage spacing. Subirrigation in the transient state water table rise was not analysed in view of cumbersome involved in acquiring the accuracy in parameter estimation for Indian condition. Based on the spacing arrived under both drainage and subirrigation modes, and on the optimum parameters chosen, experimental layout for suiting to the field's natural conditions, following the lines of experimental design, the layout of the water table management system was prepared.

Results and Discussion

The results obtained in the summary of design parameter of controlled drainage and subirrigation system were presented in table [1]. It is evident that the irrigation water is of non saline in nature. Only waterlogging is constraint.

Table 1.

Summary of design parameter of Controlled Drainage system

Area covered	1.5 acre
Hydraulic Conductivity	0.35 m/d
Average Rainfall	864 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
Evapotranspiration rate	5 mm/day
Drainable porosity	15 percent

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
Subirrigation	Maize: COHM6 (hybrid)

138

139 *Steady state spacing under drainage mode for the water table management system*

140 Initial drainage coefficient = Depth of irrigation x Apparent specific gravity x drainable porosity

141 = 5 cm x 1.45 x 0.15

142 = 1.0875 cm/day

143 = 0.0108 m/day

144 *Equivalent depth:*

145
$$q = \frac{8KDh + 4Kh^2}{L^2}$$

146

147 Where

148 K = Hydraulic conductivity (m/day)

149 D = Depth to impervious layer (m)

150 h = Height of water table above the water level in the drain (m)

151 L = Spacing of drain (m)

152 q = Drainage coefficient (m/day)

$$153 \quad L^2 = \frac{(8 \times 0.35 \times 4 \times 0.5) + 4 \times 0.35 \times 0.5^2}{0.0108}$$

$$154 \quad L = 23.45 \text{ m}$$

$$155 \quad \mathbf{L = 23 \text{ m}}$$

$$156 \quad D < L/4 = 1 < 23.45/4 = 5.86$$

$$157 \quad d_e = \frac{D}{\frac{8D}{\pi L} \ln \frac{D}{u} + 1}$$

$$158 \quad u = \Pi \times 0.036$$

$$159 \quad = 0.113$$

$$160 \quad d_e = \frac{4}{\frac{8 \times 4}{3.14 \times 23.45} \ln \frac{4}{0.113} + 1}$$

$$161 \quad \mathbf{d_e = 1.58 \text{ m}}$$

162 *Hooghoudt's equation for steady state condition:*

$$163 \quad L^2 = \frac{4Kh(2d_e + h)}{q}$$

164 Where

165 d_e = equivalent depth (m)

$$L^2 = \frac{4 \times 0.35 \times 0.5 (2 \times 1.58 + 0.5)}{0.0108}$$

$$L = 15 \text{ m}$$

Diameter of drain pipe:

Q = length of field x width of field x drainage coefficient

$$i = 0.3\% \text{ } 0.003$$

3.4 Wesslings equation

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

Spacing = 7.5 m

$$Q = 0.0108 \times 7.5 \times 30$$

$$Q = 2.43 \text{ m}^3/\text{day}$$

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

$$d_L = 82 \text{ mm}$$

similarly,

$$\text{spacing} = 10.0 \text{ m ; } d_L = 91 \text{ mm}$$

$$\text{spacing} = 12.5 \text{ m ; } d_L = 99 \text{ mm}$$

$$\text{spacing} = 15.0 \text{ m ; } d_L = 106 \text{ mm}$$

Design consideration under subirriation mode for the water table management system

$$L^2 = \frac{4K(h_0^2 - h_1^2)}{e}$$

L = Spacing of drain (m)

e = Evaporation rate (m/day)

k = Hydraulic conductivity (m/day)

h_0 = Difference between depth to impervious layer to effective root zone of the crop

h_1 = Difference between depth to impervious layer to height of water table above the water level in the drain

190 Effective root zone of the crop – 0.3 m

191 Evapotranspiration rate – 5 mm/day

$$192 \quad L^2 = \frac{4K(h_0^2 - h_1^2)}{e}$$

193

$$194 \quad h_0 = 4.0 - 0.3$$

$$195 \quad \mathbf{h_0 = 3.7 \text{ m}}$$

$$196 \quad h_1 = 4.0 - 0.5$$

$$197 \quad \mathbf{h_1 = 3.5}$$

$$198 \quad L^2 = \frac{4 \times 0.35(3.7^2 - 3.5^2)}{0.005}$$

$$199 \quad \mathbf{L = 20.07 \text{ m}}$$

200 *Equivalent depth for subirrigation:*

$$201 \quad d_e = \frac{D}{1 + \frac{D}{L} \left(\frac{8}{\pi} \ln \frac{D}{r_e} - 3.4 \right)}$$

$$202 \quad d_e = \frac{4}{1 + \frac{4}{20.07} \left(\frac{8}{3.14} \ln \frac{4}{0.036} - 3.4 \right)}$$

$$203 \quad \mathbf{d_e = 0.39 \text{ m}}$$

$$204 \quad m = h_0 - h_1$$

$$205 \quad m = 3.7 - 3.5$$

$$206 \quad \mathbf{m = 0.2}$$

$$207 \quad L^2 = \frac{4km(2h_0' - \frac{h_0'}{h_0} m)}{e}$$

$$208 \quad h_0' = d_e + h$$

$$= 0.39 + 0.5$$

$$h_0' = 0.89 \text{ m}$$

$$L^2 = \frac{4 \times 0.35 \times 0.2 (2 \times 0.89 - \frac{0.89}{3.7} \times 0.2)}{0.005}$$

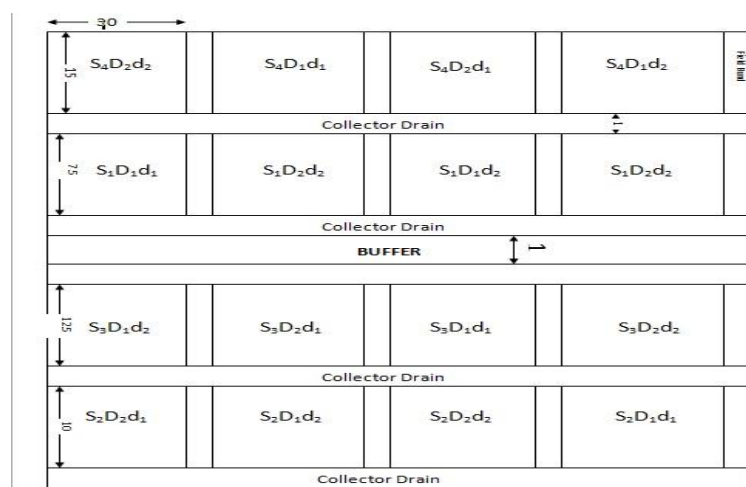
$$L = 10 \text{ m}$$

Table 2. Summary of design parameter of estimated for spacing under subirrigation mode for water table management system

S.No	Design parameters	Specification	
		Controlled draianage	Subirrigation
1.	Hydraulic conductivity	0.35 m/day	0.35 m/day
2.	Draianage coefficient	0.0108 m/day	0
3.	Hydraulic head above the drains	0.5 m	0.5 m
4.	Equivalent depth	1.58 m	0.39
5.	Evapotranspiration rate	5 mm/day	5 mm/day
6.	Effective radius	0.036 m	0.036 m
7.	Drain spacing	15m	10 m

The system of water table management system was installed with the design spacing of 15 m which could be functionally adaptable for both subsurface drainage and subirrigation. It was successfully implemented in the study area (1.5 acre) in Eastern Farm A block at Agricultural Engineering College and Research Institute, Kumulur, Tamil Nadu. The system was efficiently functioning both under subsurface drainage system for rice crop in one season in the year 2015, and subsequently for taking maize crop with subirrigation mode in the consecutive season (2015-2016).

227 *Design Layout:*



228 All dimensions in m

229 *Table 3.*

230 *Design: Split Plot Design*

<i>Main plot treatments: (at 4 levels of drain spacing)</i>	<i>Subplot Treatments:(at 2 levels of depth and diameter)</i>
$S_1 = 7.5$ m spacing between drains	D_1d_1 = Depth of drain at 75 cm + 100mm diameter
$S_2 = 10$ m spacing between drains	D_1d_2 = Depth of drain at 75 cm + 75mm diameter
$S_3 = 12.5$ m spacing between drains	D_2d_1 = Depth of drain at 60cm + 100 mm diameter
$S_4 = 15.0$ m spacing between drains	D_2d_2 = Depth of drain at 60cm + 75 mm diameter

232 *Results for water table management system*

233 The experiment revealed that the water table steadily declined and attained the value below
 234 drains and similarly drainage coefficient was also reduced after few hours. The treatments under
 235 75 cm of drain depth areas showing more depth to water table in all days of observations. The
 236 drain discharge rate was high in 7.5 m spacing when compared to all other spacing due to the
 237 more influence of area of contributing drain pipes (0.44 cm/day). The electrical conductivity
 238 (EC) value for pre drainage is 3.28 dS/m and 2.78 dS/m in post drainage. This may be due to
 239 decrease in the soils salinity values indicated the leaching of the salts. The pH of soil values for
 240

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 100 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 100 mm diameter ($S_4D_1d_1$) were economically viable with the highest profit than the other treatments.

Conclusion

Pre drainage investigation carried out in the study area for arriving at certain important design parameters for the design of water table management system for both drainage and subirrigation modes separately. Steady state Hooghoudt equation was used for the design of drainage spacing and the procedure followed by Doty, at North Carolina University using Moody Equation and convergence analysis was used for subirrigation mode spacing. The spacing arrived for drainage mode was 15 m and to that of subirrigation was 10 m respectively. Considering the feasibility of operation of both subsurface drainage and subirrigation, the spacing of 15 m could be recommended for water table management system of Eastern Farm A Block in AEC &RI kumalur, Tamil Nadu.

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275