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Design of Mole Drain Spacing Using Hooghoudt's Equation

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ABSTRACT

There is little literature and guidance available on design of mole drainage spacing, except that an empirical approach for selection of the spacings. In this, context, the present study attempted to apply the Hooghoudt's equation for design of the spacing by considering additional assumptions of preferential flows and radial flow concepts. Further, the bulk density of the soil below mole drains becomes more than the soil slabs above mole drains due to which the soil slab just below the mole drain behaves as a relatively impervious layer and the concept of equivalent depth can be waived in case of mole drains. This has facilitated using the direct depth to relatively impervious layer in the design of spacing using Hooghoudt's equation. The design of the mole drain spacing under the four scenarios revealed that to handle higher drainage co-efficient rates of 55.6 mm d^{-1} and 27 mm d^{-1}, the mole drain spacings in 0.4m depth condition are calculated to be 2m and 3m respectively and in 0.5m mole drain depth condition, they are 2m and 2m only. It can be concluded that the Hooghoudt's equation with additional assumptions facilitated, successful design of mole drain spacing for draining out the rapid flows that occur through the fractures formed due to mole drainage systems installation. It is also found that higher the drainage co-efficient, closer the spacing and deeper the depth, closer will be the spacing, despite 51.4 per cent reduction in drainage co-efficient.

Key Words: *Mole drainage Co-efficient, Return period, SCS-CN method, Sugarcane, waterlogging, Weibul's method*

Agricultural drainage is the removal and disposal of excess waterfrom surface and subsurface slabs of the agricultural fields. The primary source of excess water at a place is rainfall, field to field runoffs and seepage from nearby water bodies.This causes waterlogging. The National Commission on Agriculture, 1976 defined waterlogging as a situation of watertable causing saturation of crop root zone soil, resulting in restriction to air circulation, decline in oxygen and increase in carbon dioxide levels. Scott and Batchelor (1979) defined waterlogging as ponding of water over an area of crop land. The seasonal water logging occurs due to heavy rainfall or splash runoff, frequently super saturating the soils for more than a week period. It is reported that147 mha of land is degraded out of which 14.30 m ha is under waterlogging. Out of this 14.30 mha, 1.66 mha has become wasteland (Maji*et al.,* 2010). The waterlogged soils can be successfully reclaimed using surface, subsurface drainage systems using corrugated perforated PVC pipe, clay tile and mole drains.

The present study is conducted for facilitating mole drainage systems in sugarcane fields in East Godavari district of Andhra Pradesh. Radha *etal.* (2017) reported that waterlogging is one of the serious environmental constraints for optimum growth, yield and juice quality of sugarcane crop. Gomathi *et al.* (2014) reported that waterlogging is a widespread phenomenon that drastically reduces the growth and survival of sugarcane, which leads to 15–45 % reduction in cane yield. Under such conditions, subsurface drainage or mole drainage is considered as a most suitable approach for controlling these waterlogging conditions especially in vertisols. The sugarcane crop is very sensitive to waterlogging conditions, especially, when it crosses 1400 cm-days of sum of excess water index (SEW_{30}).

Ritzema(1994) described that mole drains are unlined circular soil channels which function like pipe drains. Their major advantage is their low cost, and hence they can be installed economically at very close spacings. Their disadvantage is their restricted life, but, their benefit cost ratios are favourable and hence acceptable. It was mentioned that the success of a mole drainage system is dependent upon satisfactory water entry into the mole channel. Ramana*etal.* (2009) conducted a study on mole drainage systems and reported that a mole drains spacings of 2, 4 and 6 m were selected for the study to install at a constant depth of 0.60 m.

Thorough review on mole drainage spacing design revealed that no analytical solutions are available to arrive at the spacing for mole drains, like Hooghoudt's theory. Hooghoudt's theory and equation is used for design of spacing for sub surface drainage systems. This paper deals with application of Hooghoudt's equation with modified assumptions for the design of mole drain spacing to avoid random selection of mole spacing as described in the following chapters.

Study area

The study area is located in the Kapileswarapuram mandal of East Godavari district of Andhra Pradesh (Figure 1.). East Godavari district is one of the agriculturally productive districts of the state, contributing about 10% of the total food production of the State.The soils of Kapileswarapuram mandal are very fine, very deep, imperfectly drained, deltaic black and cracking clay soils with very high available water capacity.

The normal rainfall of district is 1218 mm. More than half of the rainfall is received during southwest monsoon i.e. 758 mm (62 %) while a large portion of the district receives rainfall i.e. 344 mm (38%) from the north-east monsoon also, during October and December.

The rainfall of the study area is in the range of minimum of 498 mm to a maximum of 1814 mm. The long period 25 years (1990-2015) average annual rainfall is 1193 mm and among these, there are 12 years, whose annual rainfall is above recent 25 years average. One day maximum rainfall of the study area is 248.6 mm, whose occurrence matches with the predominant cropping season *kharif*Paddy/ Sugarcane causing waterlogging and failure of crop or reduction in growth and yields, rendering farmers helpless. The rainfall analysis of 26 years of the daily rainfall data (1990-2015)revealed that, this area receives rainfall more than state average (990 mm) for 19 years, less than state average for 7 years and 5 extreme rainfall years with more than 1500 mm annual rainfall. Heavy one-day maximum rainfall of the region underlain by vertisols pose a problem of waterlogging (surface and subsurface) in almost every year.

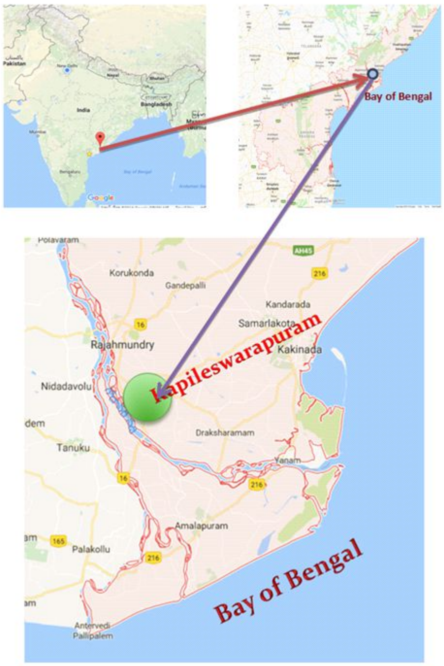
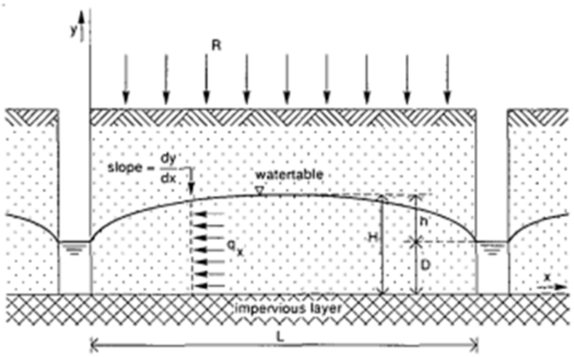


Figure 1. Map of study area, Kapileswarapuram

MATERIAL AND METHODS

Hooghoudt's theory and equation

Most of the drainage equations developed are based on the Dupuit-Forchheimer assumptions. These allow us to reduce the two-dimensional flow to a one dimensional flow by assuming parallel and horizontal stream lines. Such a flow pattern will occur as long as the impervious subsoil is close to the drain. The Hooghoudt's equation is based on these conditions. Hooghoudt's drainage equation (Hooghoudt, 1940) gives a mathematical relation of the parameters involved in the subsurface drainage of flat land by a system of horizontal and parallel ditches or pipe drains without entrance resistance, placed at equal depth and subject to a steady recharge evenly distributed over the area (Figure 2.).



(Source: Ritzema, 1994)

Figure 2. The conceptual diagram of sub-surface drainage phenomena

If the impervious layer does not coincide with the bottom of the drain, the flow in the vicinity of the drains will be radial and the Dupuit-Forchheimer assumptions cannot be applied. Hooghoudt solved this problem by introducing an imaginary impervious layer to take into account the extra head loss caused by the radial flow. Other approximate analytical solutions were derived by Kirkham and Dagan. Kirkham (1958) presented a solution based on the potential flow theory, which takes both the flow above and below drain level into account.The Kirkham Equation can also be used to calculate drain spacings for layered soils (Toksöz and Kirkham, 1971). Dagan (1964) considered radial flow close to the drain and horizontal flow further away from it. Ernst derived a solution for a soil profile consisting of more than one soil layer.

Of the above mentioned equations, Hooghoudt's gives the best results (Lovell and Youngs, 1984). Besides, whichever of the equations is used to calculate the drain spacings, the difference in the results will be minor in comparison with the accuracy of the input data. Therefore, only Hooghoudt's equation is considered to apply the same theory with the following assumptions for mole drain spacing design, as the discharge to the drains is only carried away by the preferential flow paths than as a matrix flow. In this case, the layer above the mole drains get it's hydraulic conductivity increased due to fissures and the subsequent ploughings will enhance the hydraulic conductivity.

The soils of the study area are well developed clay soil with sub angular blocky structure. The clay content and it's plastic limits permitted to install the mole even at 30 % moisture content till 0.4m and 0.5 m depth. Upon drawing of the mole plough in this soil, the cracks (fissures), soil disturbance and leg slot provides the rapid response and hydrological characteristics of these drains in the event of heavy rains and watertable rising. If no such cracks or fissures exist, the effectiveness of the mole drains solely depends on the natural hydraulic conductivity of the layer that exists before successful moling.

The design parameters considering different scenario's were used for designing the mole drain spacing. Very limited approaches are available to design the mole drain spacing, largely. A careful examination and with rational assumptions, a new attempt is made in the present study to design the mole drain spacing using Hooghoudt's steady state equation. It is reported that the isotropic conditions of the soil profile will get converted into anisotropic condition in the soil layers. The equivalent depth concept is not considered here, though the depth to impervious layer is far below the mole drain depth, because, the soil layer above the mole drain will assume a high residual hydraulic conductivity value and the soil slab below the mole drain is compressed and it's porosity and hydraulic conductivity is reduced, which behaves as a relatively impervious layer just beneath the mole drain after moling in the field. This theory eliminates the need for equivalent depth concept to be considered in mole drain design.

The additional assumptions made in this study while designing the mole drain spacing using Hooghoudt's equation are as follows:

1. The flow is largely vertical and convergent through the fissures.
2. The residual hydraulic conductivity after moling is always more than the original hydraulic conductivity of the soil layers before moling.
3. An imaginary relatively impervious layer is present immediately below the mole drain channel.
4. The horizontal and vertical hydraulic conductivity together play equal role in flow through fracture media in mole drained fields.
5. The flow is preferential and steady state and is in dynamic equilibrium.
6. Part of overland flow gets converted into preferential flow.

In the present study, the Hooghoudt's equation used and it terms applied to mole drainage are presented below through the following equation:

$$L = \sqrt{\frac{8 * K_b * D * (D - H) + 4 * K_t * (D - H)^2}{Q}}$$

where,

L = Mole Drain spacing, m
K_b = Hydraulic conductivity of the soil layer below the mole drain level, m/day
K_t = Hydraulic conductivity of the soil layer above the mole drain level, m/day
D = Elevation of the Water level in the mole drain, m
H = Elevation of the watertable midway between the mole drains, m
Q = Drain Discharge (Design Drainage Co-efficient), m/day

Other input parameters used to arrive the above parameters are:

D_{im} = Depth to relatively impervious layer,m
D_d = Mole Drain depth,m
D_{wt} = Depth to watertable to be maintained, m
D = Mole drain diameter, m
H = Height of Water table above the waterlevel in the mole drain (H-D), m
r = radius of the mole drain, m

Mole drain spacing design parameters

The mole drain parameters were determined using standard procedures available as shown in the Table 1.

The present study involves the experimental design with mole drain spacings at two different depths, i.e. 0.4m and 0.5m depths, the design of mole spacing is done separately considering the variable depth. The drainage co-efficient of mole drainage systems was found to be 55.6 mm d^{-1}, which was determined using standard procedures like Weibul's and SCS-CN method (Table 1.). It is also important to consider that the mole drained areas are to be generally complemented with the surface drainage systems, especially in high rainfall areas, whose 1-day maximum rainfall is beyond 100 mm. Under high and low rainfall conditions, the mole drains may have to drain out the total abstraction after overland flow and difference of saturation and field capacity moisture content from the soil slabs respectively. To study the variations of the design spacing due to the drainage co-efficient variations under high and low rainfall regimes, an attempt was made to de-

Table 1.Design input parameters of mole drainage system, Kapileswarapuram

Parameter/Variable	Value	Units	Procedure
Hydro-geological investigations			
Mole Drainage Co-efficient	55.600	mm d^{-1}	Weibul's &
(5 year return period)			SCS-CN methods (1990-2015)
Alternative mole drainage co-efficient	27.000	mm d^{-1}	Difference between saturation and field capacity
Depth to relatively impervious layer	2.100	m	Augering
Avg. Minimum Water table depth (Pre-Drainage and Post-Monsoon)	0.300	m	Observation wells
Avg. Saturated hydraulic conductivity (Before Moling)	0.300	m d^{-1}	Augerhole method
Land slope	0.275	%	Surveying & levelling
Lateral mole slope	0.300	%	Surveying & levelling
Collector line slope	0.500	%	Surveying & levelling
Area	2.000	ac	Surveying & levelling
Mole drain diameter,	75.000	mm	Based on the diameter of the mole plough bullet
Mole drain depth	0.4 & 0.5	m	Effective sugarcane rootzone depth

Table 2. Different scenarios considered for design of mole spacing

Mole drain depth	Scenarios	Description of Scenario
0.4 m	Scenario 1	Abstraction as preferential flow is considered as drainage co-efficient.
	Scenario 2	Difference between saturation and field capacity moisture per cent is considered as drainage co-efficient.
0.5 m	Scenario 3	Abstraction as preferential flow is considered as drainage co-efficient.
	Scenario 4	Difference between saturation and field capacity moisture per cent is considered as drainage co-efficient.

Table 3. Design of Mole drain spacing using Hooghoudt's equation (Steady state condition)

Hooghoudt's Input Parameters	Units	0.4 m mole drain depth		0.5 m mole drain depth	
		Scenario 1	Scenario 2	Scenario 3	Scenario 4
Q	m d^{-1}	0.0556	0.0270	0.0556	0.0270
K_t	m d^{-1}	0.3000	0.3000	0.3000	0.3000
K_b	m d^{-1}	0.3000	0.3000	0.3000	0.3000
H	m	1.7000	1.7000	1.6000	1.6000
D	m	1.6625	1.6625	1.5625	1.5625
h	m	0.0375	0.0375	0.0375	0.0375
D_{im}	m	2.1000	2.1000	2.1000	2.1000
d	m	0.0750	0.0750	0.0750	0.0750
r	m	0.0375	0.0375	0.0375	0.0375
D_d	m	0.4000	0.4000	0.5000	0.5000
D_{wt}	m	0.4000	0.4000	0.5000	0.5000
L, Mole Spacing	m	2.0000	3.0000	2.0000	2.0000

sign the mole spacing considering both the scenarios (Table 2.) under 0.4 m and 0.5 m mole drain depths.

RESULTS AND DISCUSSION

Design of mole spacing

The design of the mole drain spacing under the four scenarios (Table 2.) revealed that to handle higher drainage co-efficient rates of 55.6 mm d^{-1} and 27 mm d^{-1}, the mole drain spacings in both the depth condition are calculated to be 2m and 3m respectively (Table 3.). Higher the drainage co-efficient, closer the spacing.

It can be inferred from the above Table 3. that the influence of drainage co-efficient is much higher on the spacing than the depth of placement of mole drains in vertsols. It is found that a reduction of 51.43 per cent of drainage co-efficient resulted 50 per cent increase in mole drain spacing from 2m to 3m in 0.4m mole drain depth condition. In case of 0.5m drain depth condition, a reduction of 51.43 per cent of drainage co-efficient caused no difference in mole drain spacing, which also infers that deeper the depth, closer must be the spacing.

CONCLUSION

The bulk density of the soil below mole drains becomes more than the soil slabs above mole drains due to which the soil slab just below the mole drain behaves as a relatively impervious ayer and the concept of equivalent depth can be waived in case of mole drains. This has facilitated using the direct depth to relatively impervious layer in the design of spacing in vertisols using Hooghoudt's equation. It is also found that higher the drainage co-efficient, closer the spacing and deeper the depth, closer will be the spacing, despite 51.4 per cent reduction in drainage co-efficient. The design of the mole drain spacing under the four scenarios revealed that to handle higher drainage co-efficient rates of 55.6 mm d^{-1} and 27 mm d^{-1}, the mole drain spacings in 0.4m depth condition are calculated to be 2m and 3m respectively (Table 3.) and in 0.5m mole drain depth condition, they are 2m and 2m only. It can be concluded that the Hooghoudt's equation with additional assumptions facilitated, successful design of mole drain spacing for draining out the rapid flows that occur through the fractures formed due to mole drainage systems installation.

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