Modelling 2D water table and soil moisture distribution in a field installed with sub surface drainage

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Abstract. The present study is part of the development of an environment-friendly water management system based on sub surface drainage technology. It is aimed at creating a multipurpose farmland with expectation of increase in both benefits and productivity. Sub-surface drainage pipes which are installed inside mole-drain, functions as water channel that flows water into the drainage channel. Simulation was run using a 2D numerical soil water flow model based on Richard’s equation. It integrates varying soil textures with aim of figuring the optimum setting of sub-drains in response to soil textures. The depth of sub-drain was established at 40cm beneath the surface for all conditions as it is the current installation available in Indonesia. Our simulation shows the variation of soil moisture and pressure over distance, time and different textures under specified spacing of sub-surface installation.

1. Introduction

Sheetpipe is a sub-surface drainage technology originating from Japan which emerged a few decades ago. This technology uses the benefits brought by the nature of its design, under the form of perforated sheet roll that can easily be installed. The pipes can be installed as shallow as just beneath the plows, so that it is not affected by land preparation, and it can be easily connected to existing drainage channel.

Most of the subsurface drainage in Japan is applied to paddy fields. With the operation of subsurface drainage and relief wells, groundwater level control can be carried out properly. This system is expected to have the effect of: increasing soil permeability, soil physical properties, bearing capacity and trafficability of agricultural machinery and diversified use of paddy fields [1].

The effects of sheetpipe drainage on the suction and volume water content of subsurface layer was studied [2] using miniature experiment box in the laboratory, by comparing the drainage capacity of the sheet pipe with four other pipe-shaped materials for drainage. Sheet pipe was confirmed to be effective for a relatively high storage capacity soil.

Further observation was presented by [3] on drainage performance of a paddy field installed by sheetpipe. It was shown to drain faster, right after a rainfall event. Rainwater immediately infiltrates, water level profile is horizontally flat. Electrical conductivity of the soil was observed to be lower due to the leaching effect, which is an indication of its usefulness to remove matters in swampy land. A...
research conducted by [4] showed that subsurface drain at 0.65m was more effective that at 0.9 depth, and concluded that shallow sub-surface drainage would perform better in lowering water table, and therefore the depth of sheetpipe at 40cm would provide preferable performance on draining water logged land.

The potential of sheetpipe technology for modernization of irrigation was also presented by [5]. The concept was to combine sheetpipe technology with automation technology. This concept however should be carefully design in regard of the physical and hydraulic properties of the land, beside of the realization of hardware and software technology, before can be implemented.

The study is part of the development of an environment-friendly water management system based on sub surface drainage technology. The objectives of this study was to develop a 2D computer model of a farmland with sheetpipe subsurface drainage and to run simulation using the model in order to estimate the distribution of soil moisture and pressure.

2. Material and Methods

The 2D model was built based on the utilisation of sub-surface drainage pipes installed in the interior of mole-drain, that functions as a water channel flowing water to the drainage channel. Simulation was run with 2D numerical soil water flow model based on Richard’s equation, with varying soil textures in order to figure the optimum setting. The depth of sub-drain was given only at 40cm beneath the surface for all conditions as it is the current installation available in Indonesia. A simulation by [6] using numerical which was based Richard’s equation of flow in porous medium, was conducted for variably deeper sub-drain of 65 to 90 cm beneath the soil surface and showed the method was well suited for experimental field conditions and thus would benefit during development stage such as in this study.

Installation of sheetpipe would create mole drains and at the same time sliced the soil column from the surface to the depth of installation and left a crack line open. This was modelled by preparing a gap in the model for the crack, and a circular open boundary form mole drain. The wall of the crack and mole drains were set as seepage faces that would give outward flux from the soil depending on the soil wetness. Left side, right side and bottom side boundaries were set as no flux occur and no surface to atmosphere flux (evaporation) was assigned. Figure 1 shows the computer model setting.

![Figure 1](image)

**Figure 1** Model setting for 2D simulation of water flow in a field with sheetpipe sub drainage.

The simulation was run 50 days in order with an initial pressure of the soil uniform at -1 cm at the surface, and linearly distributed to 100cm at the 100cm depth. An observation point was set up at the middle between two sheetpipe lines 30 cm beneath the surface.

Relation of soil water retention and moisture, and also soil hydraulic conductivity were modelled following van Genuchten model and van Genuchten – Mualem model [7]. The soil hydraulics parameters used for the models for 12 soil textures are enlisted in Table 1. Only simulation with available soil
hydraulics data had been conducted in this stage of research, without physical model or observation experiment.

| Soil Texture          | $\theta_r$ | $\theta_s$ | $\alpha$ (1/cm) | $n$ | $K_s$ (cm/hour) | $I$ |
|-----------------------|------------|------------|------------------|-----|-----------------|-----|
| Clay Loam             | 0.095      | 0.41       | 0.019            | 1.31 | 0.26             | 0.5 |
| Clay                  | 0.068      | 0.38       | 0.008            | 1.09 | 0.20             | 0.5 |
| Loam                  | 0.078      | 0.43       | 0.036            | 1.56 | 1.04             | 0.5 |
| Silt                  | 0.034      | 0.46       | 0.016            | 1.37 | 0.25             | 0.5 |
| Sand                  | 0.045      | 0.43       | 0.145            | 2.68 | 29.7             | 0.5 |
| Sandy Loam            | 0.065      | 0.41       | 0.075            | 1.89 | 4.42             | 0.5 |
| Silty Clay            | 0.07       | 0.36       | 0.005            | 1.09 | 0.02             | 0.5 |
| Silty Loam            | 0.067      | 0.45       | 0.02             | 1.41 | 0.45             | 0.5 |
| Silty Clay Loam       | 0.089      | 0.43       | 0.01             | 1.23 | 0.07             | 0.5 |
| Loamy Sand            | 0.057      | 0.41       | 0.124            | 2.28 | 14.59            | 0.5 |
| Sandy Clay Loam       | 0.1        | 0.39       | 0.059            | 1.48 | 1.31             | 0.5 |
| Sandy Clay            | 0.1        | 0.38       | 0.027            | 1.23 | 0.12             | 0.5 |

3. Result and Discussion

The simulation was run for 12 soil textures enlisted in Table 1 with the same initial condition for every soil texture. Pressure distribution in the soil is depicted in Figure 2, pressure head at the surface of soil column is -1 cm H2O, which is water saturated or very near to saturated in actual condition. The pressure head at the lower layers, the deeper is bigger as pressure in saturated condition will be increased accordingly to depth.

![Figure 2 Initial condition pressure head](image)

Water table exists as the top of saturated zone beneath the soil surface, indicated by pressure head value of 0 cm. Two examples of pressure head distribution from 12 textures simulation, which are loam and clay are shown in Figure 3 and Figure 4. Water table decreased to at the sheetpipe depth and in the convex-shaped soil between two sheetpipes in loam texture (layer with cyan colour, ranged -6.182 to 7.091 cm). Similarly in clay for the depth and shape of water table, however clay has less dark blue colour at the surface which has pressure head range between -32.727 cm to -46.000 cm. Therefore the sheetpipe system in this simulation was able to lower saturated layer to the depth of instalment. Which provided the upper layer of soil dryer condition that would suitable for subsurface aeration and crops root development.
Soil water pressure head is an important indication to water stress in the soil, it decides the availability of water for root water uptake. Its relation to soil moisture is represented by soil water retention curve based on van Genuchten model, priorly mentioned. After simulation of 2 days, the distribution of soil moisture in loam and clay soil are shown in Figure 5 and Figure 6. Colour scale of volumetric water content at the right side of the figure shows narrower range of soil moisture in clay (0.368 – 0.410) compared to loam (0.310 – 0.430), showing that similar pressure head distribution does not mean the same quantity of soil moisture, and thus the quantity of outflows through the sheetpipe will be different for different soil texture.

Criteria of calculating the depth and spacing of sub-drainage was proposed by [8] for steady state Hooghoudt equation. However, installation of sheetpipe had been standardised to 4 m in Japan, which also applied at the experimental sheetpipe plot in Indonesia. The spacing and the depth could be further studied by means of experiment and simulations by using steady state analytic equation on numerical method used in this research.
In order to understand the changes of pressure head in the soil, especially at the point that water state might be critical for root development or activity, an observation point was set. Figure 7 shows the change of water pressure head at observation point for the 12 textures, until 1200 hours of simulation or 50 days. This figure shows the different changes of water pressure head at the farthest horizontal distance from the sheetpipe lines, between two lines and experiencing impact of two drainage directions.

Starting with the same pressure head of around 27 cm, it decreased gradually with different rate. Sand and loamy sand drained the quickest, while silt was slower that loam. Sandy clay was the slowest to reach the stable pressure head around -15 cm with the smoothest curve compared to the other textures. This results shows the variation of time required by different textures for water extraction by sheetpipe drainage, which should be considered in planning water and cultivation management of the land.

![Figure 7](image.png)

**Figure 7** Pressure at observation point (30 cm depth, 200 cm from sheetpipe lines)

It is not convenient to observe only water pressure decrease until they reach equilibrium since it could take considerable time and very small value of pressure. Therefore, outflows from soil through sheetpipe was also observed. However it is also not easy to observe exactly the amount of water flowed through sheetpipe, instead the accumulation of seepage faces’ flux was calculated. Seepage faces represent only crack’s and mole drain’s wall in this simulation and thus the flux out from these walls were the amount of water that would be drained by sheetpipe.

Figure 8 depicts the cumulative seepage flux in the 12 textures. Here, not only the change of flux’ accumulation with time are different, but also the quantity of the flux. It is easier to observe that sand drained the fastest and the curve became ramps and seepage flux is ceased (drainage stop). The other textures were drained slower and time to get seepage flux stop were longer.

Tabel 2 shows the compilation of cumulative seepage flux and seepage stop time for all textures. Sandy clay would need the longest time until the drainage stop, while sand would only need shortest time. Sand and clay required less time until drainage stop, however comparing to the cumulative flux, clay drained quite little quantity of water compared to sand. This values of cumulative drainage flux and drainage time would be very useful in planning drainage management with sheetpipe.

![Figure 8](image.png)

**Figure 8** Depicts the cumulative seepage flux in the 12 textures.
Figure 8 Cumulative seepage flux (sheetpipe’s mole drains’ and crack’s wall)

Table 2 Cumulative Seepage Face’s Flux

| Textures         | Ks (cm/sec) | Cumulative Seepage flux (cm²) | Seepage stop (hours) | Seepage stop (days) |
|------------------|-------------|-------------------------------|----------------------|--------------------|
| Sandy clay       | 0.12        | 771                           | 1189                 | 49.5               |
| Silty clay loam  | 0.07        | 348                           | 929                  | 38.7               |
| Silt             | 0.25        | 929                           | 890                  | 37.1               |
| Clay loam        | 0.26        | 756                           | 698                  | 29.1               |
| Silty clay       | 0.02        | 76                            | 678                  | 28.3               |
| Loam             | 1.04        | 2222                          | 410                  | 17.1               |
| Silty loam       | 0.45        | 1117                          | 411                  | 17.1               |
| Sandy Clay Loam  | 1.31        | 2533                          | 398                  | 16.6               |
| Loamy sand       | 14.59       | 1116                          | 394                  | 16.4               |
| Sandy Loam       | 4.42        | 5130                          | 304                  | 12.7               |
| Clay             | 0.2         | 132                           | 202                  | 8.4                |
| Sand             | 29.70       | 10094                         | 138                  | 5.8                |

4. Conclusion
A model of water flow in soil in a field installed with sheetpipe sub surface drainage had been developed in 2D based on Darcy’s equation and it was used for simulation of water potential and soil moisture in the field. Our results showed that the field’s 4 m spacing sheetpipe of 40 cm depth could have relatively flat water table, except in the vicinity of the sheetpipe which Induces a curving response. Seepage flux through crack and mole drain faces ceased quickest in sand and longest in sandy clay textures.

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