Effect of dune sand mulch on water recharging into root zone using drip lines

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Accepted 13 December, 2012

Surface drip irrigation has been used for agricultural production for more than three decades. Surface drip irrigation (SDI) can maintain sufficient water content in soil for seed germination and emergence, seedling development and plant growth. Insufficient water content in the root zone may cause crop failure. In this study, the effects of Tottori dune sand mulch on drip lines on water recharging into root zone was examined under drip irrigation. Two irrigation levels of 60 and 100% evapotranspiration, and three dune sand mulches of 0, 2 and 5 cm thickness on the drip lines were used in this experiment. The results indicated that water recharging into the root zone under 5 cm dune sand was highest among the three dune sand mulch treatments. The drip lines under the 2 cm dune sand mulch expanded and contracted resulting in protrusion from the sand mulch. An irrigation level of 100% evapotranspiration under the 5 cm dune sand mulch resulted in increase of dry matter yield of sorghum. From this study, it is concluded that to increase water recharging into the root zone (to the depth of 25 cm), the minimum thickness of dune sand mulch on the drip lines was 5 cm.

Key words: irrigation level, root zone, dune sand, surface drip irrigation, water recharging.

INTRODUCTION

Water is one of the most important resources for the growth and development of human life. Water demand for agriculture to meet the increasing demand for food is increasing worldwide. The population of the world benefits from the efficient use of water resources. In order to reduce the severity of water scarcity, water management should be improved. Agriculture has the greatest potential for solving the problem of global water scarcity (Longo and Spears, 2003).

SDI has been used for agricultural production for more than three decades. SDI has higher water use efficiency than other irrigation methods. Surface drip irrigation can keep sufficient water content in the soil and high soil temperature for seed germination and seedling development (Wang et al., 2000).

When the drip lines are covered with sandy soil, the sandy soil surface tends to dry, which would help to reduce soil evaporation. The top 20 cm of sandy soil had lower water content than the deeper soil layers resulting in reduced soil evaporation when drip lines were buried at the depth of 45 cm (Phene et al., 1983; Solomon, 1993).

Lamm and Trooien (2005), and Neelam and Rajput (2007) proposed that placement of drip lines might be practical at depths shallower than 10 cm under sandy soil. Neelam and Rajput (2007) evaluated the effect of placing drip lines at the depths of 0, 5, 10, 15 and 20 cm under sandy loam soil on yield of potato. When drip lines were buried at the depth of 5 cm, movement of water to the soil surface was observed. Their findings showed that sandy loam of 5 cm thickness was not sufficient to effectively restrict soil evaporation.

The effectiveness of vegetative mulches may be limited because their high porosity permits rapid diffusion (Hillel, 1998). In a banana plantation in central Uganda, McIntyre et al. (2000) found that mulching decreased surface soil bulk density and thus led to more rapid recharge of soil.
water. Water recharging is important in supplying adequate water to the root zone, and mulch materials have been used to reduce soil evaporation and to increase infiltration. Ssali et al. (2003) assessed the effects of maize stovermulch on recharging of water into the soil. They found that there was higher water recharging under mulched surfaces than under unmulched surfaces. They attributed the increase in water recharging to the increased infiltration rather than the increased porosity.

Our study hypothesized that Tottori dune sand could be used as a mulch to increase amount of water recharged into the root zone. The objective of this study was to evaluate the effects of dune sand mulch on drip lines on water recharging into the root zone, and to determine the minimum thickness of dune sand mulch.

MATERIALS AND METHODS

Plots and sub-plots

The experiment was carried out in a 154 m² glasshouse at the Arid Land Research Center, Tottori University, Japan (35°32’N; 134°13’E; 23 m above sea level). The length, width and maximum height of the glasshouse were 22, 7 and 4.5 m, respectively. It was unheated and naturally ventilated with a single continuous roof vent. Lateral windows were kept open during daytime. The soil type of the Tottori dune sand was Arenosol (silicious sand, typic Udipsamment) with 96% sand (Qiu et al., 1999).

Soil water pressures (kPa) and the respective soil water contents (m³/m³) were measured using a pressure plate. Undisturbed soil samples were collected from the upper soil layer using 100 cm³ stainless steel cores. The soil water retention curve was determined using the pressure plate laboratory method (Richards, 1948; Klute, 1986). Richards (1948) and Klute (1986) found that the pressure plate method can reliably measure soil water characteristics when undisturbed soil samples are used. The relationship between soil water pressure and volumetric water content of the Tottori dune sand is shown in Figure 1. The field capacity and permanent wilting point of the dune sand were 0.074 and 0.022 m³/m³, respectively, and the corresponding matric potential is -0.006 and -1.5 MPa, respectively (Qiu et al., 1999). Porosity and saturated soil hydraulic conductivity of the dune sand were 0.4 m³/m³ and 2.7×10.4 m/s, respectively (Qiu et al., 1999). Some of the physical properties of the dune sand are summarized in Table 1.

Two plots (Plot A and Plot B), each of 4.80 m long and 1.0 m wide, were used in this experiment as shown in Figure 2. Sorghum (Sorghum bicolor) was planted on Plot A and B on June 16, 2008 at a 50 cm row and 30 cm in-row spacing. After sowing, the drip lines were mulched with dune sand. The sorghum was harvested on October 24, 2008. Fertilizer was applied at the rate of 180 kg/ha N, 45 kg/ha P and 80 kg/ha K just before sowing. Top dressing was done at the rate of 100 kg/ha N at the middle growth stage.

Thickness of mulch

Each of the two plots was further divided into three sub-plots. Three drip lines were arranged on each sub-plot. The drip lines were spaced at 50 cm. The spacing within the drip line was 30 cm. This irrigation system was operated at a pressure head of 14 m.

On the first sub-plot of each plot, three drip lines were not mulched, and are referred to as T0. On the second sub-plot of each plot, the three drip lines were mulched with 2 cm of the dune sand, and are referred to as T2. On the third sub-plot of each plot, the three drip lines were mulched with 5 cm of the dune sand, and are referred to as T5. The section view of the position of the drip lines, sensors and plants under T0, T2 and T5 is shown in Figure 3.

Irrigation level

Two small evaporation pans were placed at random in each sub-plot, and were weighed twice daily, at 08:30 and at 20:30. Irrigation water was applied every other day based on small pan evaporation. Different irrigation levels were applied to Plot A and B. For Plot A, 60% of the estimated evapotranspiration of sorghum was applied and this is referred to as 0.6Ep. For Plot B, 100% of the estimated evapotranspiration of sorghum was applied and this is referred to as 1.0Ep.

Evapotranspiration and amount of irrigation water

Evaporation of the small evaporation pan was converted to the class A pan evaporation by the Agodzo et al. (1997) equation:

\[ E_A = a \times E_S^b \] (1)

Where, \( E_A \) is the class A pan evaporation (mm), and \( a \) and \( b \) are fitting parameters, and \( a = 0.17, b = 1.92 \) and \( E_S \) is the evaporation from the small evaporation pan (mm). Measured \( E_S \) and \( E_A \) (\( E_S \) and \( E_A \) were measured daily at 08:30) were correlated for 10 days at the Arid Land Research Center, Tottori University, Japan. \( E_A \) was measured using a meter rule daily at 08:30. The meter rule measured the depth of water lost in the last 24 h.

The class A pan evaporation was then converted to the potential evapotranspiration by the Doorenbos and Pruitt (1977) equation:

\[ ETo = Kp \times E_A \] (2)

Where, \( ETo \) is the potential evapotranspiration (mm) and \( Kp \) is the pan coefficient (dimensionless). \( Kp = 0.80 \), and was obtained from \( Kp = 0.75 \) as given by Doorenbos and Pruitt (1977) based on location, and adjusted by 7.5% to \( Kp = 0.80 \) for sorghum (\( Kp = 1.075 \times 0.75 = 0.80 \)). The \( Kp \) values relate to evaporation pans located in an open field with no crops taller than one meter (1 m), and depend on general wind and humidity conditions of an area. The \( Kp \) values were therefore, adjusted because the small evaporation pans were placed in a glasshouse (a small enclosure) and surrounded by sorghum. The \( ETo \) from Equation (2) was converted to evapotranspiration of sorghum (\( ETo \)) (mm) by the Doorenbos and Pruitt (1977) equation:

\[ ETo = Kc \times ETo \] (3)

Where, \( Kc \) is the crop coefficient (dimensionless). The Allen et al. (1998) \( Kc \) values of 0.70, 1.10 and 0.55 for early growth stage, middle growth stage and late growth stage, respectively, were used in this experiment. Irrigation time was calculated by the following equations:

\[ T = \frac{A \times 0.6 \times ETo}{Q} \] (4)

\[ T = \frac{A \times 1.0 \times ETo}{Q} \] (5)

Where, \( T \) is the irrigation time (hours), \( ETo \) is the evapotranspiration of sorghum (mm), \( A \) is the area of the wetted horizontal region (assumed circular and of radius of 15 cm) (m²) below the emitters and \( Q \) is the emitter discharge (l/h).
The total amount of irrigation water during the cropping period was 344 mm for 0.6Ep to each mulch treatment. The total amount of irrigation water during the cropping period was 521 mm for 1.0Ep to each mulch treatment.

### Soil water and water recharged into the root zone

Soil water content was measured by ECH₂O capacitance probes (Decagon Devices Inc., Pullman, Washington, USA) installed at depths of 5 and 25 cm. The capacitance probes were calibrated using the method described by Cobos and Chambers (2010). The sensor installation depth of 25 cm was based on Yamamoto and Cho (1978) who reported that the most effective root-water uptake zone in the dune sand under surface drip irrigation was the top 25 cm. Soil water content was not measured at the surface because the dune sand dries quickly. Soil water content was recorded every hour by Em50 ECH₂O data loggers (Decagon Devices Inc., Pullman, Washington, USA).

The data of soil water content at an hour before irrigation and at 12 h after irrigation was selected from the hourly recorded data. The average soil water content was determined from the soil water content at the depths of 5 and 25 cm at one hour before irrigation and at 12 h after irrigation. Soil water content at one hour before irrigation was selected because that represented the amount of water retained in the soil before irrigation. Soil water content at 12 h after irrigation was selected because gravitational water was expected to have drained. In course textured (sandy) soils, the gravitational water drainage is completed within a period of a few hours while in fine textured (clayey) soil; the drainage may take some (2 to 3) days (Brouwer et al., 1985). Water recharged (m³/m³) into the root zone was the difference between the average soil water content at one hour before irrigation and the average soil water content at 12 h after irrigation. Water recharged in mm into the root zone was the product of water recharged in m³/m³ into the root zone and the root zone depth of 20 cm (between the depth of 5 and 25 cm).

\[
R_i = (\theta_{ai} - \theta_{bi}) \times D \times 10
\]

Where, \(R_i\) is the water recharged into the root zone at \(i^{th}\) irrigation (mm), \(\theta_{ai}\) is the average soil water content (m³/m³) at 12 h after irrigation, \(\theta_{bi}\) is the average soil water content (m³/m³) at one hour before irrigation and \(D\) is the depth from 5 to 25 cm (cm).

### Climatic conditions and plant growth

Air temperature and humidity in the glasshouse were measured at the height of 2 m by ESPEC temperature and humidity sensors (ESPEC MIC Corp., Aichi, Japan). These were installed at the centre of the glasshouse. Air temperature and humidity were recorded every hour by ESPEC data loggers (ESPEC MIC Corp., Aichi, Japan). The climatic conditions in the glasshouse are summarized in Table 2. The maximum air temperature is the highest daily air temperature in each month. The minimum air temperature is the lowest daily air temperature in each month. The average humidity is the average of maximum and minimum daily relative humidity in each month.

Three plants were randomly selected from each sub-plot of Plots...
**Figure 2.** Experiment plots.

**Figure 3.** Section view of the position of drip lines and soil moisture sensors under T0, T2 and T5.
Table 2. Climatic conditions in glasshouse.

<table>
<thead>
<tr>
<th>Month</th>
<th>Air temperature (°C)</th>
<th>Average humidity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Maximum</td>
<td>Minimum</td>
</tr>
<tr>
<td>June</td>
<td>31.1</td>
<td>12.4</td>
</tr>
<tr>
<td>July</td>
<td>35.9</td>
<td>16.7</td>
</tr>
<tr>
<td>August</td>
<td>39.5</td>
<td>18.1</td>
</tr>
<tr>
<td>September</td>
<td>33.8</td>
<td>13.7</td>
</tr>
<tr>
<td>October</td>
<td>28.5</td>
<td>9.4</td>
</tr>
</tbody>
</table>

Figure 4. Amount of irrigation water and water recharged under T0, T2 and T5 for 0.6Ep.

A and B for measurement of plant height and dry matter weight. Plant height was measured at the early, middle and late growth stage by a meter rule. Plant height was measured from dune sand surface to the latest leaf. The dry matter weight was measured after drying the samples in an oven at 70°C for 48 h.

RESULTS AND DISCUSSION

Water recharged

The amount of irrigation water and water recharged into the root zone under T0, T2 and T5 for 0.6Ep are shown in Figure 4. The orders of water recharged into the root zone from high to low were T5, T2 and T0. The 5 cm dune sand mulch on drip lines improved the amount of water recharged through the dune sand. A possible explanation for the improved water recharged under 5 cm dune sand mulch could be reduced upward movement of water to the surface. The reduced upward movement of water to the soil surface was due to the dune sand dry layer of 5 cm thickness above the wet layer.

The amount of irrigation water and water recharged into the root zone under T0, T2 and T5 for 1.0Ep are shown in Figure 5. The orders of water recharged into the root zone from high to low were T5, T2 and T0. The 5 cm dune sand mulch on drip lines improved the amount of water recharged through the dune sand to the root zone.

Improved amount of water recharged for 1.0Ep could be for the same reason as for 0.6Ep. Total water recharged into the root zone was the sum of the water recharged calculated after every irrigation event. Mean water recharged into the root zone was the average of the water recharged calculated after every irrigation event.

The total and mean water recharged into the root zone under T0, T2 and T5 for 0.6Ep and 1.0Ep are shown in Table 3. The total amount of water recharged was the highest under T5 for 0.6Ep and 1.0Ep. The 5 cm dune sand mulch on drip lines improved the amount water recharged through dune sand.

The total amount water recharged in the root zone under T0, T2 and T5 for 1.0Ep was higher than those of 0.6Ep. A greater amount of irrigation water was applied at 1.0Ep than 0.6Ep. Applying sufficient amount of irrigation water resulted in higher amount of water recharged into root zone as compared to insufficient amount of irrigation. Under 0.6Ep we practised deficit irrigation which meant insufficient amount of irrigation was replenished. Deficit irrigation reduces the amount of water content in the soil compared to full irrigation.

Plant growth

Average plant heights at the early growth stage, middle
Figure 5. Amount of irrigation water and water recharge under T0, T2 and T5 for 1.0Ep.

Table 3. Water recharge under T0, T2 and T5 for 0.6Ep and 1.0Ep.

<table>
<thead>
<tr>
<th>Symbol of mulch</th>
<th>0.6Ep</th>
<th>1.0Ep</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total (mm)</td>
<td>Mean (mm)</td>
</tr>
<tr>
<td>T0</td>
<td>136</td>
<td>5.9a</td>
</tr>
<tr>
<td>T2</td>
<td>170</td>
<td>7.4b</td>
</tr>
<tr>
<td>T5</td>
<td>212</td>
<td>9.2c</td>
</tr>
</tbody>
</table>

Means followed by different letters are significantly different at P ≤ 0.05; SD is standard deviation.

Table 4. Average plant height under T0, T2 and T5 for 0.6Ep and 1.0Ep.

<table>
<thead>
<tr>
<th>Symbol of mulch</th>
<th>0.6Ep</th>
<th>1.0Ep</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ES(cm)</td>
<td>MS(cm)</td>
</tr>
<tr>
<td>T0</td>
<td>38.9a</td>
<td>117.1a</td>
</tr>
<tr>
<td>T2</td>
<td>41.4a</td>
<td>109.4a</td>
</tr>
<tr>
<td>T5</td>
<td>46.0b</td>
<td>104.9a</td>
</tr>
</tbody>
</table>

Means followed by different letters are significantly different at P ≤ 0.05; ES is early growth stage; MS is middle growth stage; LS is late growth stage.

growth stage and late growth stage under T0, T2 and T5 for 0.6Ep and 1.0Ep are shown in Table 4.

For 0.6Ep, the plant heights under T0, T2 and T5 varied little for the three growth stages. Covering the drip lines with either a 2 cm thickness or a 5 cm thickness of dune sand had no effect on vegetative growth of sorghum. The drip lines were observed to expand and protrude to the surface under 2 cm sandy mulch thus causing non-uniform water distribution along the drip lines. The thin layer of dune sand resulted in higher temperature variations on the drip lines which caused expansion during daytime and contraction during night time. For 1.0Ep, the plant heights under T5 were greater than and significantly different (p = 0.05) from those under T0 and T2. Covering the drip lines with a 5 cm thickness of the dune sand significantly supported the vegetative growth of sorghum. The possible explanation for the support of vegetative growth of sorghum could be that the 5 cm dune sand mulch improved the amount of water recharged into the root zone.

At the early growth stage, the plant heights of 0.6Ep and 1.0Ep did not vary significantly. At the middle growth stage, the plant heights of 1.0Ep were significantly greater (p = 0.05) than those of 0.6Ep. At the late growth
stage, the plant heights of T0, T2 and T5 showed little variation.

An irrigation level of 0.6Ep did not supply sufficient amount of irrigation water to support sorghum growth. The combination of T5 and 1.0Ep resulted in the highest amount of water recharged into the root zone which supported sorghum growth. This combination supplied sufficient amount of irrigation water and improved water recharge to the root zone.

Dry matter yields under T0, T2 and T5 for 0.6Ep and 1.0Ep are shown in Table 5. For 0.6Ep, the dry matter yield under T5 was marginally higher than those of T0 and T2. For 1.0Ep, the dry matter yield of T5 was higher than those of T0 and T2. As shown in Table 5, for 1.0Ep, dry matter yield under T2 was higher than under T0. The dry matter yields under T0, T2 and T5 for 1.0Ep were higher than those of 0.6Ep. The combination of T5 and 1.0Ep resulted in the highest dry matter yield.

**Conclusion**

Though the 2 cm dune sand mulch also increased water recharged into the root zone, it was not practical as dune sand mulch on drip lines due to protrusion. Based on these results, the minimum thickness of the dune sand mulch should be 5 cm.

Water recharged into the root zone was highest under T5 and 1.0Ep. The combinations of the 5 cm dune sand mulch and a sufficient amount of irrigation water resulted in increased plant height and dry matter yield of the sorghum.

The 5 cm dune sand mulch is a better alternative to subsurface drip irrigation since no special machine is necessary to cover the drip lines by 5 cm of the sand soil. It is easy to remove the drip lines after the growing season.

**REFERENCES**


