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Effects of mulching and sub-surface irrigation on vine growth, berry sugar content and water use of grapevines

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SUMMARY

The objective of efficient water management in vineyards is to save water, increase yield, and improve berry quality. So far, the effects of rice-straw mulching (M) and/or sub-surface seeper hose irrigation (SS) on grapevine's performance and water use are not clear. An experiment was conducted on 'Gros Colman' grapevine (*Vitis vinifera* L.) in a greenhouse using four weighing lysimeters. Four treatments: M combined with SS (MSS); no-mulch combined with SS (SS); no-mulch combined with surface irrigation (S); M combined with S (MS), were compared. Results showed that the higher yield, longer shoot length, and larger berry for MS could be related to the relatively higher moisture at top soil compared to other treatments. MS gave the highest water use efficiency (WUE), followed by MSS and SS, while S was the last efficient among the four treatments. Compared with SS, the berry diameter, fresh yield, WUE, and berry sugar concentration for MS were enhanced by 2.8 mm, 271.5 g/tree, 33% and 15%, respectively. MSS gave a higher berry sugar concentration than MS on most sampling days, which could be attributed to the lower moisture and the higher average soil temperature (*Ts*) in the top soil layer. Mulching combined with surface irrigation (MS) is a useful technique for maximizing water use efficiency.

1. Introduction

Water is the most limiting resource in semi-arid and arid lands. Given current demographic trends and future growth projections, as much as 60% of the global population may suffer water scarcity by the year 2025 (Qadir et al., 2007). Improvements in water use efficiency (*WUE*) of crops are essential under all water scarcity scenarios. The application of mulch is known to be effective in reducing soil evaporation and saving water (Cadavid et al., 1998; Li, 2003). Several mulching materials improved plant biomass as well as the *WUE* of Swiss chard (Zhang et al., 2008). For example, rice-straw mulching increased the *WUE* of Swiss chard by 143% and 10% compared to a no-mulch control and a gravel mulching treatment, respectively (Zhang et al., 2009).

Grapevine, a traditionally non-irrigated crop that occupies an extensive agricultural area in arid and semi-arid regions, plays a very important role in the economic, social and cultural sectors (Santos et al., 2007). In many countries, irrigation was introduced to increase crop yield (Escalona et al., 2003). However, excessive amounts of irrigation water not only results in the waste of water, but also causes nutrient loss and promotes excessive vegetative growth at the expense of fruit production. Appropriate and moderate water stress is beneficial for fruit quality and growth in grapevines, whereas severe water deficit or saline irrigation decreases the production of assimilates, reduces transpiration, shoot growth, yield and quality of fruit (Shani et al., 1993; Delgado et al., 1995; Pellegrino et al., 2005; Lovisolo and Schubert, 2006; Lovisolo et al., 2008). Water stress could be imposed by withholding water from plants, for example, the soil water content reaches 50% (mild drought stress) and/or 25% (severe drought stress) of

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field capacity (FC) (Ghaderi and Siosemardeh, 2011). Although growing grapevines requires less water per value of crop than most plants, predicted climatic changes (i.e. reduced rainfall and increased evapotranspiration rates) will intensify water stress on vines, particularly in water-limited regions. This will affect the ability of existing varieties to ripen fruit (Jones et al., 2005) and, the quality of the fruit produced, which will have a negative impact on the overall economics of grape production (Santos et al., 2007).

The grape cultivar 'Gros Colman' (*Vitis vinifera*) is a late-maturing variety, with a visually pleasing grape and large round berries (Hogg, 2007), which is mainly cultivated in greenhouses (Okamoto et al., 1999). 'Gros Colman' grape is harvested from the end of October to January, during which the grape can be sold as present in winter holidays. However, water-saving research on this variety is still lacking.

To facilitate adaptation to water scarcity, mulching could provide an alternative means to control grapevine response to irrigation while maximizing *WUE*. Compared with the control, soil moisture was enhanced and the severity of *Botrytis cinerea* (a saprophytic fungus causing botrytis bunch rot in grapes) infection was reduced when shredded paper and grape marc mulches were used (Jacometti et al., 2007a). In a vineyard, a sewage sludge and bark compost mulch improved water retention capacity of the soil and, reduced evaporation and soil temperature fluctuations (Pinamonti, 1998). However, the wavelength-selective polyethylene mulch had no detectable effect on vine development, yield components and fruit quality (Bowen et al., 2004). Rice (or Paddy) straw is normally burnt on mechanized farms, which causes air pollution (Tripathi and Katiyar, 1984). Therefore, using rice straw as mulch can alleviate the air pollution caused by straw burning. So far, the effects of rice-straw mulching on the performance and water use of grapevines are not clear.

Sub-surface irrigation, in which water is applied below the soil surface, can also help conserve water by reducing evaporative water losses (Siyal and Skaggs, 2009), which is similar to the effects of mulching. SS enables the application of small amounts of water to the soil (Std, 1999) while maintaining a relatively dry soil surface (Patel and Rajput, 2008). Application of subsurface drip irrigation caused better condition for grape growth parameters, especially compared to bubbler irrigation and surface drip irrigation (Najafi et al., 2012).

Seeper hose is an absolutely new environmental soil control system which consists of a flexible rubber tubing that contains many micro pores and is laid sub-surface or underground to supply water, air, or fertilizer directly to plants. Water seeps out from small holes very slowly, making water control precise and effective (Zhang, 2009). However, research on using sub-surface seeper hose irrigation for grapevines is scarce.

A combination of mulching and sub-surface seeper hose irrigation has not been tested on grapevines. The primary objective of this study was therefore to evaluate the combined effects of rice-straw mulching (M) and sub-surface seeper hose irrigation (SS) on evapotranspiration (*ET*), soil water content (θ) and soil temperature, growth (shoot length, leaf area, and berry diameter), leaf photosynthesis, yield, berry quality (sugar content) and *WUE* of grapevines.

2. Materials and methods

2.1. Experimental layout, irrigation, plant and soil materials

The experiment began on 5 June 2008 in a greenhouse at the Arid Land Research Center, Tottori University, Japan, using three-year-old 'Gros Colman' grapevines (*Vitis vinifera* L.) grown in large weighing lysimeters (Fig. 1). On 25 February 2008, 'Gros Colman'

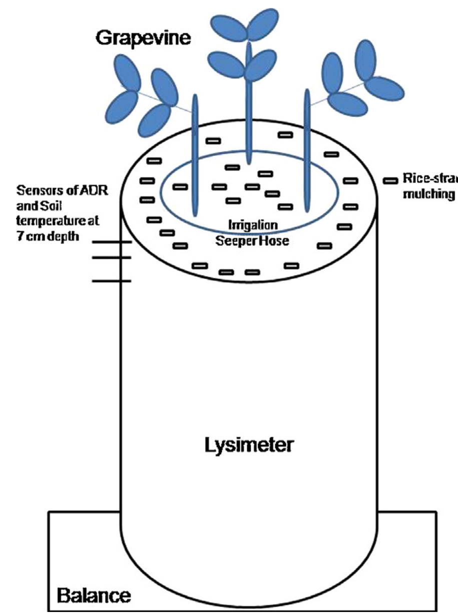

Fig. 1. The layout of experimental setup (including rice-straw mulching, the seeper hose, plants, and the lysimeter).

grapevines were transplanted into four large weighing lysimeters (three vines per lysimeter) in a greenhouse. The amount of water applied was controlled by a time clock-solenoid valve assembly connected to a compression pump. The grapevines were irrigated according to their *ET* measured by lysimeters until the experiment began. The plants were provided liquid fertilizer containing all essential mineral nutrients (see: Wang et al., 2001; Thippayarugs et al., 2002) once a week. There were four treatments: mulching combined with sub-surface Seeper Hose (Fig. 1) seepage irrigation (MSS); no-mulch combined with sub-surface Seeper Hose seepage irrigation (SS); mulching combined with surface Seeper Hose seepage irrigation (MS); no-mulch combined with surface Seeper Hose seepage irrigation (S). Based on the study by Sharma et al. (1985), the thickness of rice-straw-mulch was 3 cm. The length of the rice straw was about 5 cm. Two concentric circles, a large circle (outer ring) and a small circle (inner ring), were made by the Seeper Hose tube and placed in each lysimeter for irrigation. For sub-surface irrigation, the Seeper Hose rings were placed at 15 cm soil depth, since root density was higher in the upper soil layer (0–20 cm) than in the deeper soil layer for grapevines (Morlat and Jacquet, 2003). Water was pumped from a large tank into the Seeper Hose for irrigation daily. The irrigation water amount in *i* day was based on the mean values of actual *ET* in $i-1$ day (last day) (ET_l). For the control treatment: S, vines were irrigated with slightly more water than their ET_l, whereas the irrigation amounts for the other treatments were equal to around 90% of their ET_l. The irrigation water amounts in the experimental period for S, MS, SS and MSS were 1197 mm, 926.8 mm, 909.2 mm and 877.8 mm, respectively.

Each lysimeter was 1.2 m high and had a diameter of 0.798 m (surface area 0.5 m^2). The top 40 cm of the lysimeter column was filled with a mixture of sandy soil (sieved through a 2-mm sieve), peat moss, humic allophone soil and lime in a volumetric ratio of 1200:600:200:1, respectively. The mixture had a pH of 6.2 and the FC of the substrate, measured using the oven drying method, was 0.467 (by volume). A nonwovenes sheet was spread on the bottom of the mixture and around the inner wall of each lysimeter. The rest of the column was filled with a sandy soil.

To encourage uniform vegetative growth, vines were pruned to retain 12 nodes per vine; only two or three shoots per vine were left and were trained horizontally. Eight shoots for each treatment