Influence of soil moisture and stratigraphic structure on actual evaporation

Influence de l'humidité du sol et de la structure stratigraphique sur l'évaporation effective

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ABSTRACT: Mulching is one of the most effective countermeasures against salt accumulation. Mulching consists of overlaying the original ground with a low water retentivity soil material that reduces evaporation. However, the relationship between soil moisture and actual evaporation is still unclear, and thus it is difficult to design the optimum construction of mulching layers. In this study, the evaporation from ground covered with various mulching layers was measured with a weighing lysimeter. First, the relationship between soil moisture and evaporation rate was investigated through free evaporation tests. The mulched ground was equipped with a lysimeter and exposed to natural cycles of evaporation and precipitation. Consequently, it was found that mulching is effective to prevent evaporation.

RÉSUMÉ: Le paillage est l'une des contremesures les plus efficaces contre l'accumulation de sel. Le paillage consiste à recouvrir la surface du sol avec une couche de terre à faible pouvoir de rétention d'eau. Toutefois, le rapport entre l'humidité du sol et l'évaporation effective reste obscur et, par conséquent, déterminer la construction optimum des couches de paillage demeure une tâche difficile. Dans cette étude, nous avons mesuré, à l'aide d'un lysimètre de pesée, l'évaporation depuis des sols recouverts de diverses couches de paillage. Nous avons d'abord évalué la relation entre l'humidité du sol et le taux d'évaporation par des tests libres d'évaporation. Après son paillage, nous avons équipé le sol d'un lysimètre et nous l'avons exposé à divers cycles naturels d'évaporation et de précipitations. Nous avons pu en conclure que le paillage était efficace dans la prévention de l'évaporation.

KEYWORDS: evaporation, soil water retention characteristics, mulching

1 INTRODUCTION

Salt damage is one of the most serious factors for desertification. This is the phenomenon where the salt solution within groundwater concentrates at the ground surface due to more evaporation than precipitation. To prevent salt from rising up to the ground surface, it is important to control the water balance. Penman (1948) and Priestly and Taylor (1972) proposed empirical equations for potential evaporation. However, water loss from the ground is caused not by potential evaporation, but by actual evaporation. Although actual evaporation strongly depends on soil moisture, there are few studies focused on soil moisture. In the field of agriculture, low water retentivity soil material is used as a cover material to reduce actual evaporation. This is called 'mulching'.

In this study, two kinds of free evaporation tests are conducted. One is a mini-scale test for investigating influential factors in actual evaporation. The other one is a soil column test with a lysimeter to investigate the influences of stratigraphic structure on evaporation.

2 EXPERIMENTAL PROCEDURE

The two kinds of free evaporation test procedures are detailed below.

2.1 *Testing material*

Masa soil was used for the free evaporation tests with two kinds of burned sludge provided as mulching materials. The two mulching materials are distinctively called 'Red' and 'White' by their color. Their grain size distribution curves are shown in Figure 1. The mulching materials contain a larger coarser fraction compared to the Masa soil. In particular, the White mulching material contains more gravel. Their soil-water retention curves for the drying process, obtained from the soil column method, are shown in Figure 2. It was found that the water retentivity of the two mulching materials was sufficiently low.

2.2 *Mini-scale test*

Acrylic containers filled with soil samples were exposed to atmosphere and sunlight, and their weight changes were estimated as evaporation. The size of the evaporation surface was 150×180(mm). Various conditions (initial soil moisture, dry density and thickness) were created and influential factors investigated.

2.3 *Soil column test by lysimeter*

A lysimeter is a device that can accurately measure fluctuations in soil column weight. As shown in Figure 3, the lysimeter in

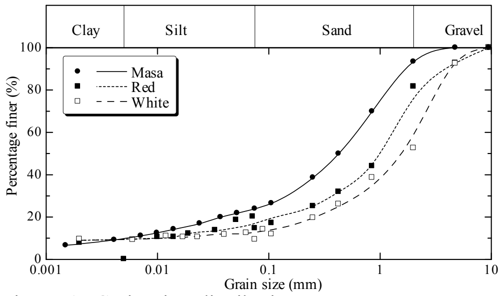


Figure 1. Grain size distribution curves

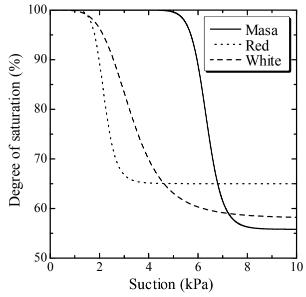
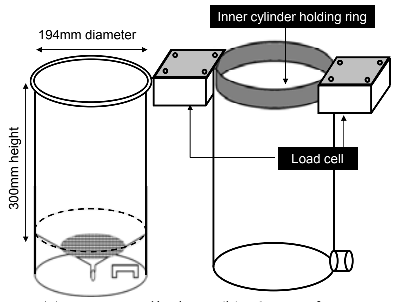


Figure 2 Soil-water retention curves



(a) Inner cylinder (b) Outer frame
Figure 3. Schematic view of lysimeter

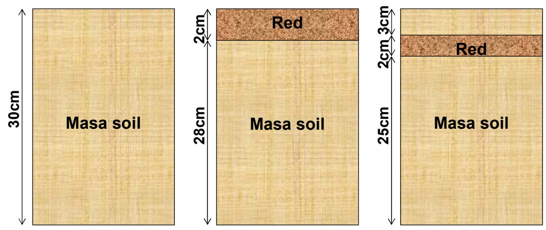
this experiment consists of an inner cylinder, which holds the soil column, and the outer frame, which keeps the inner cylinder in contact with two load cells. The weight changes measured by these load cells can be assumed as evaporation from the soil column. Figures 4 and 5 show the soil column models in this experiment. Three soil columns, each with different stratigraphic structures, were utilized. Evaporation from each column was monitored under the same climatic conditions. The Masa soil layer was compacted until reaching a dry density of 1.6g/cm^3 and a degree of saturation of 60%. Mulching layers were compacted only loosely because of the fear of soil particle breakage and set to a degree of saturation of 60% (the dry densities of Red and White were 0.98g/cm^3 and 1.45g/cm^3, respectively). In experimental Case 1, the effects of mulching (Lysi-2) and improved mulching (Lysi-3) were compared. In Case 2, to investigate the effects of the mulching layer thickness and soil water retentivity, two kinds of mulching materials with thicknesses different from Lysi-2 in Case 1 were provided. Moreover, free evaporation tests were conducted in a temperature-controlled room (atmospheric temperature of 28-30 degree in Celsius and humidity of 20%) on the same soil columns in Case 2 (Case 3). Weather information was measured using the Weather Bucket produced by Agri Weather Co. The Weather Bucket can simultaneously measure humidity, atmospheric temperature, precipitation, solar radiation, atmospheric pressure, and wind speed and direction.

3 EXPERIMENTAL RESULTS OF MINI-SCALE TESTS

The differences in evaporation as dependent on initial water content, dry density and soil layer thickness are discussed below.

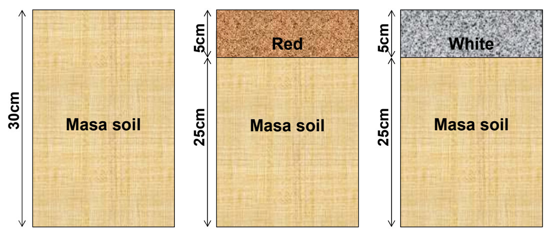
3.1 *Dependency on initial water content*

Evaporation was monitored in the soil column models at the same dry density (1.6g/cm^3) but with various water contents. Initial water content was provided at 6, 9, 12 and 15%. Figure 6 shows changes in the degree of saturation and temperature on three different days. Larger decreases in degree of saturation were determined in soils with larger initial water contents. Though mini-scale model conditions were the same, the amount of evaporation differed across the three days, indicating that evaporation depended on weather conditions. Table 1 summarizes the average atmospheric temperature and integrated solar radiation for all days. Although atmospheric temperature on the second day was the lowest, the degree of saturation, namely evaporation, was the greatest. As humidity was almost the same for these three days, this implies that solar radiation had the strongest effect on evaporation. Solar radiation increased soil temperature in the mini-scale models, thus it appears that soil temperature, and not atmospheric temperature, directly influences actual evaporation.



(a) Lysi-1 (b) Lysi-2 (c) Lysi-3

Figure 4. Stratigraphic structures of column models (Case 1)



(a) Lysi-1 (b) Lysi-2 (c) Lysi-3

Figure 5. Stratigraphic structures of column models (Case 2)

Table 1. Average atmospheric temperature and integrated solar radiation on test days

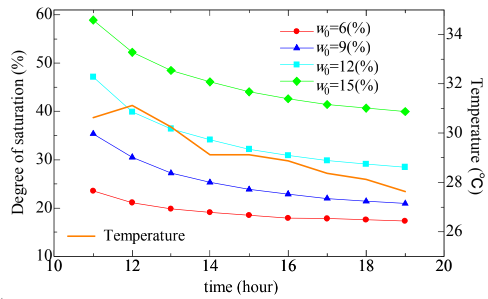
	Test day 1	Test day 2	Test day 3
Average temperature (°C)	29.5	28.4	31.1
Integrated solar radiation (MJ)	8.88	11.95	6.74

3.2 *Dependency on dry density*

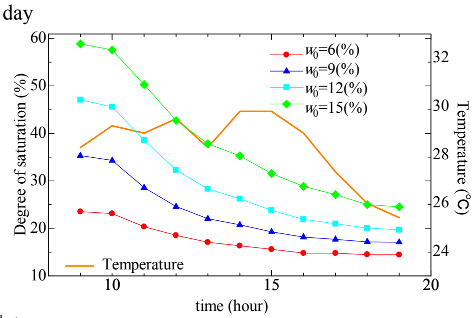
Next, mini-scale models were compacted to different specified dry densities at the same degree of saturation (60%) in order to investigate the effects of soil particles density. Dry densities were set at 1.3, 1.4, 1.5 and 1.6g/cm^3. Figure 7 shows experimental results. It was found that the decrease in the degree of saturation was smaller in models with denser ground. This is because soil water retentivity is higher on denser soil. When degree of saturation decreases due to evaporation, suction increases. On higher water retentivity soil, this suction increase is more obvious, and high suction reduces evaporation.

3.3 *Dependency on model ground thickness*

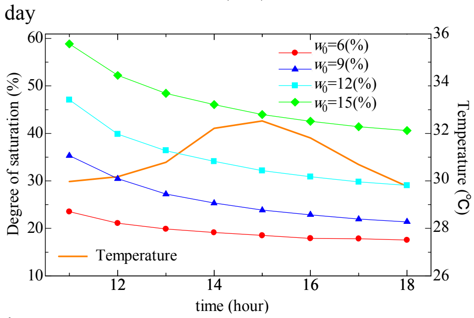
In order to investigate the influence of depth on evaporation, three different thicknesses of the soil layer (20, 30 and 40mm)



(a) 1st day



(b) 2nd day



(c) 3rd day

Figure 6. Soil moisture fluctuations for models with different initial water contents

were provided. Compaction was conducted to maintain a dry density of 1.6g/cm^3 for all soil thicknesses. Figures 8 and 9 show the evaporation amount and changes in degree of saturation, respectively. It can be seen from these figures that evaporation was greater for thicker soil layers. This is because the amount of soil water within the thicker soil layers is larger under the same dry density and degree of saturation. These results mean that the influential depth of evaporation is not less than 40 mm. In this experiment, degree of saturation was calculated as an overall average of all soil layers. If evaporation was independent from soil layer thickness, changes in degree of saturation would be same. However, the decrease in degree of saturation for the thicker soil layers is smaller. This means that the distribution of degree of saturation is not uniform and that degree of saturation close to the soil surface is low.

3.4 *Potential evaporation and actual evaporation*

Evaporation measured in this experiment cannot be quantitatively compared among different days since weather conditions differed. Therefore, the ratio of actual evaporation to potential evaporation was considered. Penman proposed a way to calculate potential evaporation from solar radiation, atmospheric temperature and humidity. Penman's equation is applicable for a large area, and modification is needed for a closed area like the mini-scale test. In this study, model ground was saturated in the mini-scale test first, and potential evaporation was measured. Consequently, a correction coefficient of 1.7 was obtained. Actual evaporation obtained from mini-scale tests was summarized according to degree of saturation using this correction coefficient as shown in Figure 10. It was determined that actual evaporation drastically decreased with decrease of degree of saturation.

4 EXPERIMENTAL RESULTS OF LYSIMETER TESTS

4.1 *Case 1*

The experimental period for Case 1 was two weeks from the middle of October, and it rained two times during this period. Figure 11 shows the weight fluctuation of lysimeters with precipitation, in which decrease in weight can be regarded as evaporation. With time, evaporation between the models was almost the same as at the beginning of monitoring. However, differences started to gradually appear from about 4000 min, when a small rainfall event occurred. During this event, water was supplied to the ground, and evaporation decreased on the mulching model ground in Lysi-2. This resulted from differences in water retentivity between Masa and Red. As seen in Figure 2, Red shows a drastic change in degree of saturation in low suction regions compared to Masa. Permeability strongly depends on degree of saturation. Consequently, a gap in permeability between layers of Masa and Red was generated and an upward flux due to evaporation was inhibited. On the other hand, apparent reduction of evaporation was not seen in the improved mulching model ground, Lysi-3. This is because the gap in permeability was not bigger than Lysi-2. The Red layer was sandwiched by Masa layers, and the decrease of degree of saturation in the Red layer was smaller than Lysi-2. A relatively large rainfall event was monitored around 13000 min. At this point, Lysi-2 showed a remarkable increase in weight compared to the other lysimeters. This is because the surface layer of Lysi-2 was Red, which has larger voids and higher permeability. Therefore, rainfall infiltrated easily, and infiltrated rainwater pooled in voids more than in Masa soil. We can expect two effects, namely reduction of evaporation and acceleration of rainfall infiltration, in the mulching ground. Degree of saturation with depth was measured after evaporation monitoring. Figure 12 shows the depth distribution of degree of

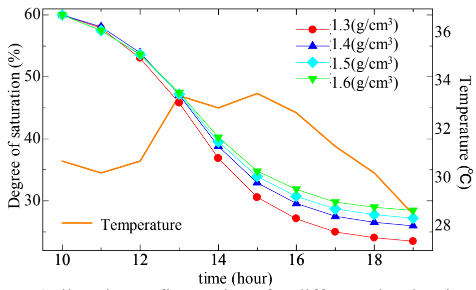


Figure 7. Soil moisture fluctuations for different dry density models

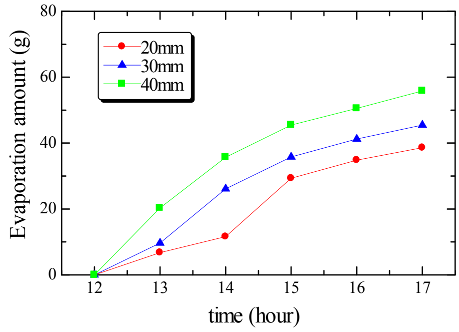


Figure 8. Evaporation from models of different thicknesses

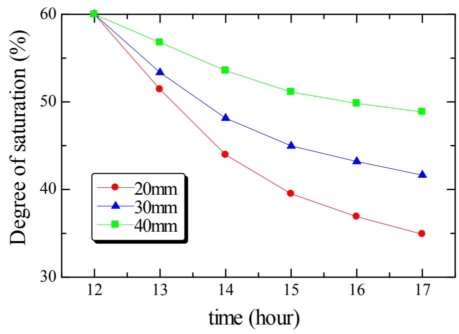


Figure 9. Soil moisture fluctuations for models of different thicknesses

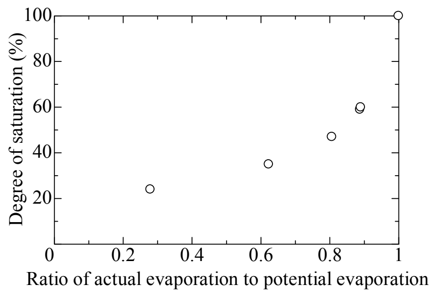


Figure 10. Relationship between the ratio of actual evaporation to potential evaporation and degree of saturation

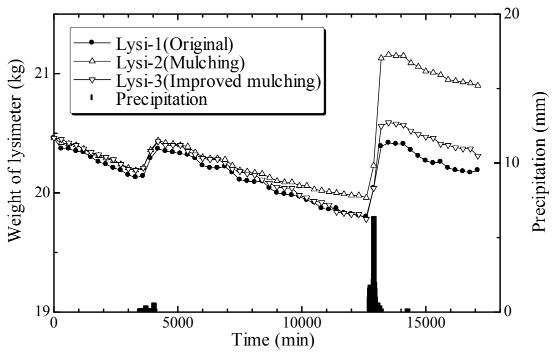


Figure 11. Measured evaporation in lysimeters (Case 1)

saturation. The mulching model ground, Lysi-2, shows a larger degree of saturation at all depths. This result also illustrates the effect of mulching. Moreover, in the improved mulching model ground, Lysi-3, degree of saturation in the surface region was the same as Lysi-1. Nonetheless, larger saturation for Lysi-3 than Lysi-1 appeared in deeper regions and a reduction in evaporation was also observed. This indicates that the decrease in weight shown in Figure 11 was due to water dissipation in the upper Masa layer and that the upward flux in the deeper regions under the improved mulching layer was smaller than in the original model ground. These results also imply that improved mulching can contribute a reduction of salt accumulation.

4.2 *Case 2*

Figure 13 shows measured evaporation from lysimeters in Case 2. This experiment started in the beginning of December (winter in Japan), and the experimental period was about one week. A clear difference in weight change among the three lysimeters was seen. The difference between Lysi-2 and Lysi-3 resulted from the mulching material. White showed a higher effect on reduced evaporation than Red. There was a periodical increase in weight without rainfall in Lysi-1. This phenomenon was observed during the coldest part of the day before sunrise. At this time, if anything, Lysi-2 and 3 actually showed an opposite trend of a decrease in weight. It is difficult to attribute this weight change to evaporation. In Figure 13, the humidity fluctuation is shown. Lysi-1 showed increases in weight after increases in humidity. It was recognized that the increase in humidity induced dew formation around the inner cylinder of the lysimeters, and, consequently, the weight increase by dew formation water was measured. The reason why the effect of dew formation was relatively small in Lysi-2 and 3 depended on the setup conditions of the lysimeters.

4.3 *Case 3*

The effect of dew formation was monitored in Case 2 and the same model ground was used for evaporation tests in a temperature- and humidity-controlled room. Figure 14 shows the experimental results of Case 3. As seen in the beginning of Case 2, evaporation from mulching ground by White was the smallest. The difference in evaporation between the original ground and the mulching ground over ten days amounted to 320 mm. This corresponds to the yearly precipitation in areas of relatively low rainfall.

5 CONCLUSIONS

In this study, evaporation from the ground was investigated in detail by using mini-scale model tests, and the effect of mulching ground was considered using lysimeter tests focusing on the water retentivity of soil materials. Consequently, the following conclusions were obtained.

(1) Actual evaporation strongly depends on the soil moisture of the ground and drastically decreases with a decrease in soil moisture. Therefore, reduction of soil moisture in the surface ground is noteworthy and contributes to inhibiting evaporation from deeper areas.
(2) If low water retentivity material is placed on surface ground, soil moisture at the surface easily decreases, leading to an inhibition of water dissipation. This is the mechanism of mulching.
(3) In improved mulching, upward flux can be reduced in lower layers, even though evaporation from the upper layer is obvious.

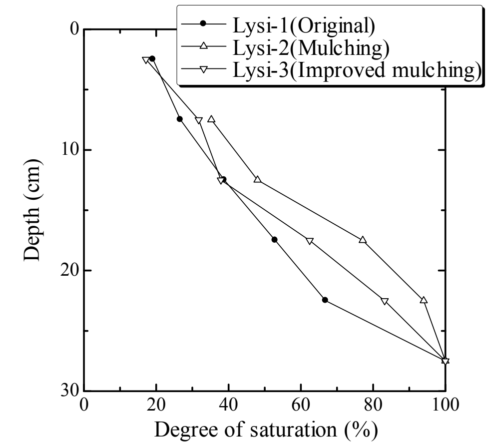


Figure 12. Depth distribution of the degree of saturation after monitoring (Case 1)

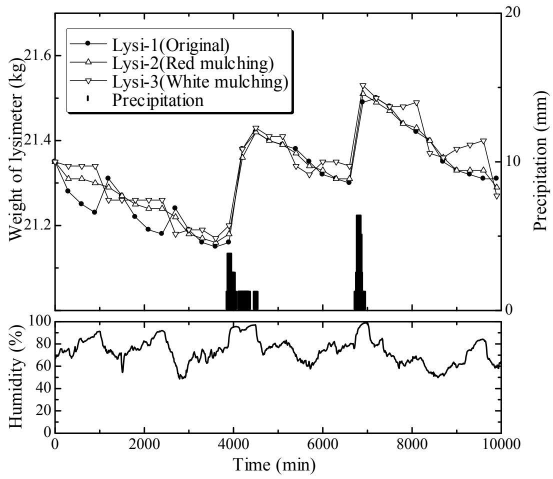


Figure 13. Measured evaporation in lysimeters (Case 2)

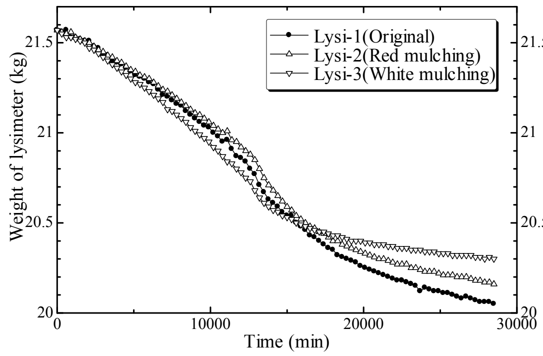


Figure 14. Measured evaporation in lysimeters (Case 3)

(4) Mulching can reduce evaporation and accelerate rainfall infiltration. This effect can be utilized to reduce salt accumulation.

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