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# Movement of Water Collected by Vegetables in Plastic–mulching Field

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It is necessary to pay attention to a leaching of nutrient from the viewpoint of the effective utilization of fertilizer and water environmental preservation. Although some literatures describe that plastic mulching system has the benefit to reduce fertilizer loss because the rain that falls in a plastic–mulching field can run into furrows immediately flowing on the impervious plastic film, the facts that the water can infiltrate to the soil through a transplanting hole have been also reported. To analyze in detail the water movement under the mulching condition the procedure to evaluate the water collection function of crop was proposed, and the results of water collection experiment were used to consider the water flow into transplanting holes. The water collection characteristics of leafy vegetables were described relating the geometry of leaves. The results of analysis for the water movement under the mulching condition indicated that the infiltration of rainfall into transplanting holes was quite larger than the quantity of the water that broccoli crop could collect to the center.

## INTRODUCTION

At the Tsukushi plains spreading out over the northern part of Kyushu Island, which is in the western part of Japan, the Chikugo River runs through the plains. The rice cropping has been prosperous there. In recent years, about 50 percent of the paddy field is not used for rice cropping owing to a government's policy (i.e. set aside). In the paddy field used for upland farming, a soybean, wheat and various vegetables have been cultivated. In addition, it is a characteristic of the farming in this area that greenhouse cultivation using a plastic greenhouse has spread rapidly.

There can be a problem of nitrate discharge due to the excess application of fertilizer in the upland field, while it is generally known that paddy field has a function to purify water because of denitrification. There are much fear of this problem for leafy vegetable cultivation such as cabbages or lettuces because these tend to be applied much fertilizer. It can be imaged that soil water dissolving much nutrient spreads rapidly into ground water due to high ground water level and high hydraulic conductivity near the Chikugo River. Therefore, it is necessary to pay attention to leaching of nutrient from the view-

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point of the effective utilization of fertilizer and water environmental preservation when a paddy rice field is used as an upland field.

Plastic film mulch is often used in vegetable cultivation for controlling weed in the area. There are benefits of plastic mulching such as accelerating crop growth, improving quality, preventing soil surface evaporation, reducing fertilizer loss, etc. (Marr, 1993; McCraw and Motes, 1991; Sanders, 1990). In these literatures, it is an evidence for the effect of mulching on reducing fertilizer loss that the less rainfall can pass through the root zone because the rain that falls onto an impervious plastic film covering a bed can run into furrows immediately. This is particularly true in the soil whose hydraulic conductivity is comparatively great such as sandy soils (McCraw and Motes, 1991).

On the other hand, the water of rainfall or irrigation comes into the root zone through a hole on a plastic film for seeding or transplanting (hereafter a transplanting hole), then the soil water content beneath the hole increases (Suzuki, 1998). The apparent increase in the amounts of subsurface discharge and nitrate nitrogen load occurred right after a heavy rainfall even in a full–mulching treatment (Haraguchi *et al.*, 2002). This might indicate that rainfall came into the soil through transplanting holes. Therefore, the knowledge about a movement of water coming into the soil through transplanting holes is important in a study about a subsurface discharge of nutrient in a mulching field.

Water that falls on a canopy due to rainfall or irrigation reaches the ground surface in three ways. Xiao *et al.* (2000) defined them as following:

*Free throughfall*: a portion of the water reaches through the gaps in the canopy without hitting the leaves and branches,

*Canopy drip*: the water drip from canopy surfaces,

*Stemflow*: a portion of the water that reaches the ground by flowing down the stems.

In addition, the sum of free throughfall and canopy drip is defined as *throughfall* by them. Hence, as the water flows into the soil through a transplanting hole, two forms can be conceived. One comes flowing over a plastic film after the water reaches the film as throughfall. The amount of flow in this form will be affected by the size and number of transplanting holes. A quantity of the water should be increased for the effective water use under a water–restricted condition and be reduced for the effective fertilizer use under a much rainfall condition. The other water reaches directly as throughfall and stemflow. The quantity of the water coming along the crop body depends on a variety of crop (van Dijk and Bruijnzeel, 2001).

In this study the characteristic of crop to intercept and collect rainfall depending on a variety of leafy vegetable was evaluated. The redistribution of rainfall under the mulching condition was examined through the lysimeter experiments. The reduction of the effluent load from a plastic mulching farm was discussed relating a quantity of the water that comes through transplanting holes with the soil water movement in the root zone.

## MATERIALS AND METHODS

### Experiment on the water–collection function of leafy vegetables

Four varieties of leafy vegetable, i.e. broccoli, bokchoy, lettuce and cabbage, were selected to examine the function to collect rainfall or irrigation water. A sample for each variety was planted in a pot of a diameter of 0.11 m, and this was fastened in the center of another pot of a diameter of 0.16 m. The larger pot with the smaller pot, in which a sample was planted, was put on a leveled polyvinyl-chloride (PVC) board and was surrounded with 32 plastic beakers of a diameter of 0.07 m. A lattice line was made by interval 0.1 m on the PVC board to keep the position of the sample and the beakers precisely. The sample and beakers were arranged as shown in Fig. 1. The top views of them are shown in

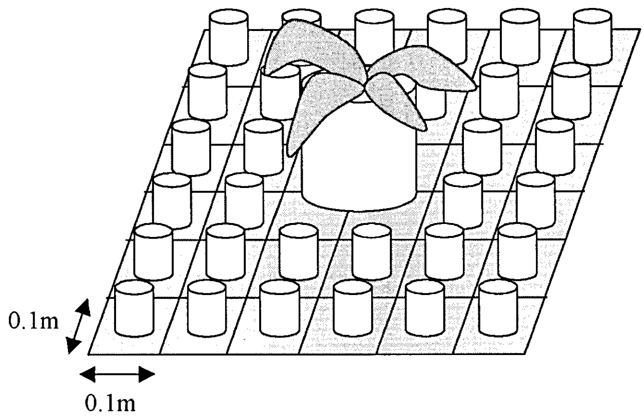


**Fig. 1.** Arrangement of the sample pot and plastic beakers.

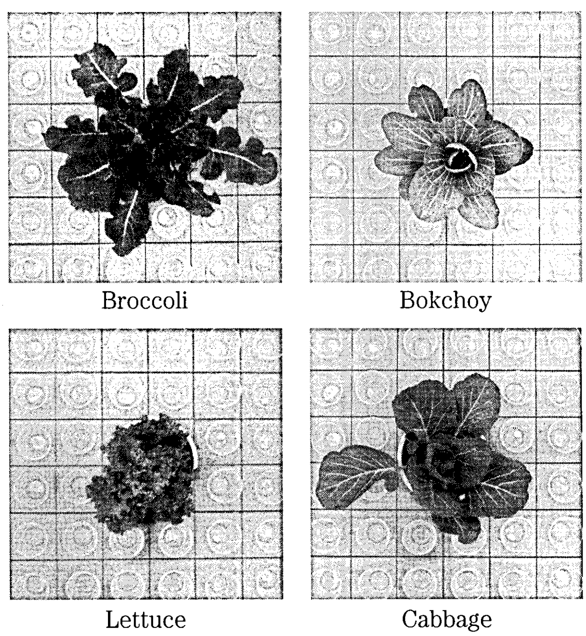


**Fig. 2.** Top views of the sample vegetable and plastic beakers.

Fig. 2. A broccoli and cabbage were such young that an eating part didn't thrive.

Water was uniformly applied for five minutes using a sprayer as a micro–sprinkler irrigation system. The short boom sprayer equipped with four nozzles, which were attached at intervals of 0.33 m, was used. The sprayer was moved constantly at a height of 1.5 m. It was checked that water was applied uniformly at a rate of about 2.6 mm per a minute using this system in a pilot experiment without a sample. The uniformity of watering was made sure again by comparing the quantity of collected water in twenty beakers on the periphery of the area. The quantity of collected water was obtained by weighing. The water collection function of a leafy vegetable was examined comparing the distribution of quantity of collected water in two pots and beakers.

**Experiment on water movement under mulching condition**

The experiments were conducted using a drainage lysimeter, which is 1 $m^2$ in area, during winter season in 2000 and 2001. Soil in the lysimeter was classified as sandy loam with bulk density of about 1.2 g $cm^{-3}$. The experimental site was located in the northern part of Kyushu Island where mean annual precipitation is about 1600 mm.

Chemical fertilizer was plowed equally into the soil layer, which is 0.2 m thick, in the lysimeter at a rate of 30.0 g N $m^{-2}$ before covering with a plastic film. A ridge was made in the middle of the lysimeter immediately after the fertilizer application.

In 2000, soil surface was covered all over with a black plastic–film (polyethylene, 0.02 mm thick), and the surface runoff rate was measured to evaluate how much rainfall comes into furrows. The water coming into both furrows was collected through holes on a wall of the lysimeter, and an amount of the water was measured every day.

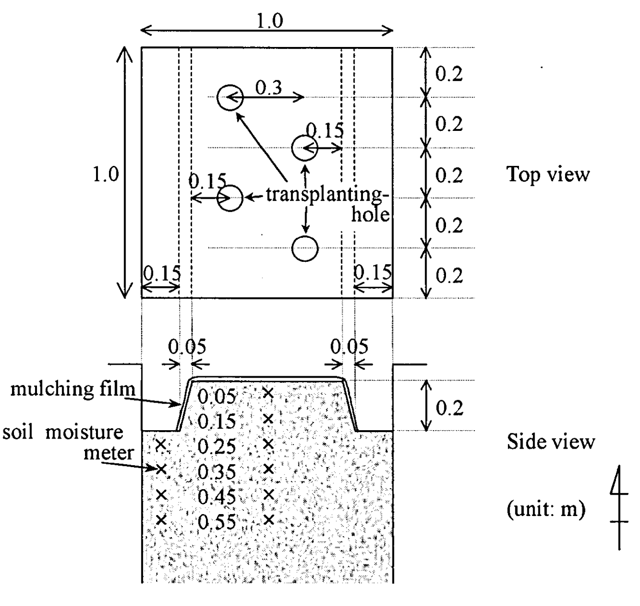


**Fig. 3.** Schematic view of the experimental lysimeter.

In 2001, the soil moisture meters (CS615, Campbell Scientific Inc.) were buried at the same time with the establishment of a ridge. The sensors were buried in the depths of 0.05, 0.15, 0.25, 0.35, 0.45, and 0.55 m from the top at the middle of the ridge, and were buried in the depths of 0.25, 0.35, 0.45 and 0.55 m at a furrow. The direction of a sensor rod agreed with that of the ridge. The data was collected and recorded using a datalogger (CR10X, Campbell Scientific Inc.) every 10 minutes. The only ridge part of soil surface was covered with the black plastic–film.

A total of four broccoli plants were transplanted in both experiments as shown in Fig. 3. A diameter of a transplanting hole was about 0.1 m. The soil water content was comparatively high through the experiment period in both the years, i.e. the matric suction at the depth of 0.15 m was smaller than 20.0 kPa equivalent to pF2.3. Hence, the irrigation was done only at the transplanting period.

Neglecting an amount of the water that was kept on a plastic film and sample body, it can be remarked that all the rain that came into the lysimeter infiltrated into the soil. Actually the rainfall seldom come out of the paddy fields used for upland cropping because they are surrounded by the remaining levee.

## RESULTS AND DISCUSSION

### Water collection function of leafy vegetable

A quantity of water coming through a transplanting hole depends properly on the size of a hole. Hence it is important to clarify the distribution of the quantity of water that reaches the ground surface to control (increase or decrease) the water coming through holes. To evaluate the spatial distribution of the water that falls around a leafy vegetable, three sections were set as shown in Fig. 4. The section 1 is the area of the larger pot, the section 2 is that of the smaller pot, and the section 3 is the remains of the section 1 except for the section 2.

Let an amount of water collected in a beaker, whose area is $A_b$, be $V_b$ and that in the section $i$, whose area is $A_i$, be $V_i$ ($i=1,2,3$). On the periphery of the watered area the water is collected in a beaker without being influenced by a sample. Hence a quantity of water in the beaker, which is expressed in depth, equals to the depth of applied water, $H_{w0}$,

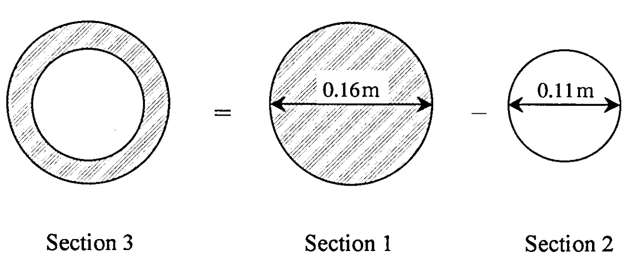


**Fig. 4.** Relation between sections for evaluating water collection function of leafy vegetables.

$$H_{w0}=V_b/A_b. \quad (1)$$

On the other hand, the amount of water expressed in depth for the section $i$ is given as,

$$H_{wi}=V_i/A_i. \quad (2)$$

If there is not a sample in a pot the depth in all sections would equal to $H_{w0}$,

$$H_{w1}=H_{w2}=H_{w3}=H_{w0}. \quad (3)$$

The water depth $H_{wi}$ varies depending on the section because of the presence of a sample. Also the water depth in the section $i$ changes depending on the quantity of applied water. The ratio of $H_{wi}$ to $H_{w0}$, therefore, is used to evaluate the spatial distribution of the water that reaches the ground surface.

The water collection characteristics for broccoli, bokchoy, lettuce, and cabbage varieties are shown in Table 1. The ratio $H_{wi}/H_{w0}$ in the inner part (section 2) is greater than the outer (section 3) for bokchoy and cabbage samples, while the inner is less than the outer for broccoli and lettuce samples. This difference emerged because of the difference in the geometric characteristics of samples. For bokchoy and cabbage the water that fell on leaves could flow to the center of them since a leaf was relatively smooth. For a broccoli sample a leaf was waved and thin near the main stem, the water dripped from leaves before reached the center. For a lettuce sample it is difficult to image the flow of the water on leaves because the geometry was complicate. Synthetically, the values of ratio $H_{wi}/H_{w0}$ for the section 1 indicate that the depth of collected water was 1.2–1.5 times of the applied water depth. This means the leafy vegetables have the ability to collect water into the area near their main stem.

The four samples were different in geometry of leaf, i.e. a size, inclination and shape. Although the inclination and shape of a leaf are inherent in a variety of vegetable, size of a

**Table 1.** Water collection characteristics of leafy crops.

| Variety | $A_s$ (m²) | $H_{w0}$ (mm) | Section $i$ | $V_i$ (cm³) | $H_{wi}/H_{w0}$ | $V_i/V_s$ |
|---|---|---|---|---|---|---|
| Broccoli | 0.120 | 13.3 | 1 | 330 | 1.3 | 0.21 |
| | | | 2 | 122 | 0.9 | 0.08 |
| | | | 3 | 208 | 1.8 | 0.13 |
| Bokchoy | 0.044 | 12.4 | 1 | 359 | 1.5 | 0.43 |
| | | | 2 | 312 | 2.4 | 0.37 |
| | | | 3 | 47 | 0.4 | 0.06 |
| Lettuce | 0.086 | 13.5 | 1 | 286 | 1.2 | 0.52 |
| | | | 2 | 89 | 0.7 | 0.16 |
| | | | 3 | 197 | 1.8 | 0.36 |
| Cabbage | 0.066 | 12.7 | 1 | 371 | 1.4 | 0.32 |
| | | | 2 | 308 | 2.2 | 0.27 |
| | | | 3 | 63 | 0.5 | 0.05 |

Note: $A_s$ is the projected area of a sample body, $H_{w0}$ is the depth of applied water, $V_i$ is the volume of water collected in the section $i$, $H_{wi}$ is the depth of collected water in the section $i$, $V_s$ is the volume of water captured by a sample.

leaf and/or number of leaves vary individually. The values of $H_{wi}/H_{w0}$ cannot express a characteristic of the variety but a characteristic of the sample. To eliminate the influence of sample's size on the amount of the collected water the volume of water collected in the section $i$, $V_i$, is divided by the volume of water captured by a sample, $V_s$. Assuming that the drops of applied water fall vertically to the ground, the volume $V_s$ is obtained:

$$V_s = A_s \times H_{w0} \tag{4}$$

where $A_s$ is the projected area of a sample body.

Since the ratio of $V_i$ to $V_s$ can be regarded to express the water collection function of vegetable due to the inclination and shape of leaf, it can be said that the broccoli variety has less ability to collect water than other vegetables. This might be occurred for the facts that a broccoli's leaf was waved and outer leaves spread horizontally.

The water in the pots was collected as *throughfall* in the experiments. Multiplying the volume of the water estimated using these results by the number of holes on the mulched ridge, the amount of the water that reaches the soil surface on the ridge as *throughfall* would be obtained. Since the water comes into a transplanting hole directly (throughfall) and indirectly (flowing over a plastic film), the amount of the latter should be estimated for investigating the infiltration of the water in the transplanting holes.

**Movement of water under the mulching condition**

The time courses of soil water content under the partial–mulching condition are shown in Fig. 5. It rained 15.0, 8.5 and 4.5 mm at 38, 42 and 45 days after transplanting, respectively. For both the middle of the ridge and the furrow the sharp rises in water content were observed right after rainfall. Since the oscillation was larger and the appearance time of the rising was earlier near the surface at the middle of the ridge, it would be valid that the water content at the depths of 0.05, 0.15 and 0.25 m increased being affected by the infiltration of rainfall from transplanting holes. Although the increases in water content after rainfall at the depths of 0.35–0.55 m in the middle of the ridge was observed, it is not certainty that the increase were caused by the infiltration at the transplanting holes and/or the furrow. If the source of increase were the former, there would be some fear of leaching from the root zone. To reveal this more analysis of the water movement in the soil is necessary.

Figure 6 shows the time courses of precipitation and surface runoff under the full–mulching condition. The total amounts of precipitation and surface runoff for two months after transplanting were 112.5 and 50.3 mm, respectively. The ratio of surface runoff to precipitation was almost constant through the experiment period though the ground cover ratio became larger as the growth of broccoli plant progressed. Neglecting the water that was kept on leaves and film this result suggests that almost a half of the rain that fell into the lysimeter infiltrated into the soil through transplanting halls. If this is relevant about 80 percent of the rainfall that fell on the top part of ridge (0.6 m$^2$) came into the soil through transplanting holes. Considering the results in the experiment for water collection of crop, this value may be quite large though the characteristics of crops to collect the rainfall would different from the case of irrigation. This larger infiltration into holes might occur because the water could flow not toward furrows but in all directions due to the flatted top surface.

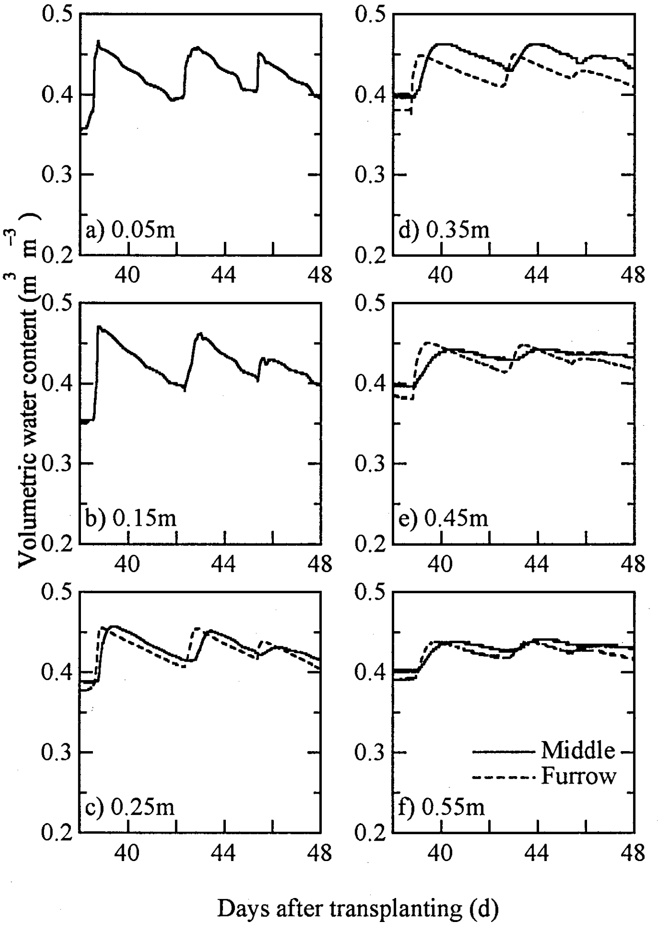


**Fig. 5.** Time courses of soil moisture under the mulching condition.

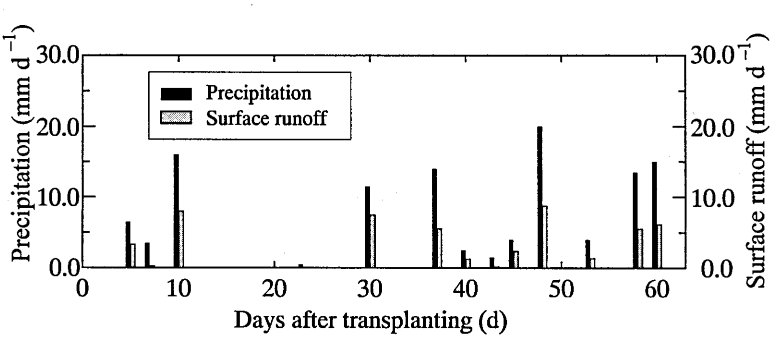


**Fig. 6.** Relationship between precipitation and surface runoff under full–mulching condition.

## CONCLUSIONS

The procedure to evaluate the water collection function of crop was proposed. The characteristics to collect irrigation water for four leafy vegetables evaluated with the procedure were considered relating with their geometric structure. It was suggested that the characteristics of a leafy vegetable strongly depends on the inclination distribution and shape of leaf. The results of water collection experiment were used to consider the movement of rainfall under the mulching condition. The infiltration of rainfall into transplanting holes, which affects the leaching of nutrients from the root zone, was quite larger than the quantity of the water that broccoli crop could collect to the center.

Although the procedure proposed here would be valid to evaluate the water collection function, further experiment to examine the change of the function through the growth stage is necessary. To estimate the effect of the water coming through transplanting holes on the leaching the analysis for the water flow on plastic film should be carried out.

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