Measurement of Evapotranspiration By Chamber Method and Its Application

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The farmland of Japan, generally speaking, is partitioned into small lots and full of variety in the lay of the land and in the nature of the soil. Also various crops are cultivated there.

In such circumstances, it is not easy to know the evapotranspiration in the field. However, this is a vital problem to be clarified for planning irrigation in upland farms.

There are several ways of measuring transpiration from crops and evapotranspiration from the surface of cultivated field, that is, the direct and indirect methods, etc. These methods, however, have both merits and demerits, respectively. For instance, the pot weighing method and the lysimetric method are useful for quick measurement, but in this case the soil is different from the natural conditions. The meteorological method needs a large area of field for measurement and complicated calculations for obtaining results, though it can be applied to measurements in the natural conditions.

The chamber method described in this paper is designed for simple and easy measuring, and applicable to the work in the above-mentioned conditions of upland farms in Japan.

Apparatus for measurement

An outline of the apparatus is shown in Fig. 1.

In case of measurement, the plant to be examined is covered with a transparent chamber and the chamber is aired by a ventilator. The absolute humidity of the air

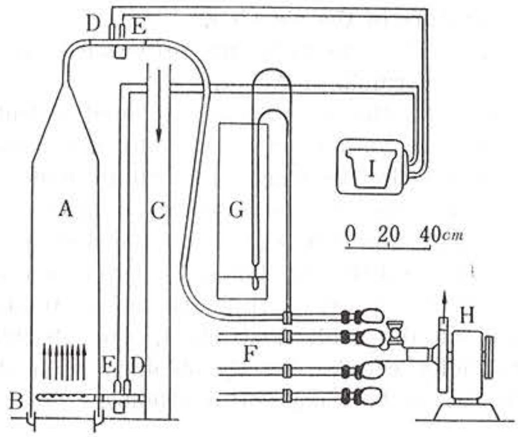

Fig. 1. Apparatus
A: Transpiration chamber. B: Ring for keeping chamber. C: Pipe for inhalation. D: Dry bulb. E: Wet bulb: F: Air-flowmeter with orifice. G: Manometer. H: Blower. I: Electric thermometer. →: Direction of air-flow.

is measured at the entrance and the exit of the chamber by dry and wet bulbs equipped there. The evapotranspiration out of the chamber is obtained by the product of a difference between the absolute humidity measured at the entrance and the exit and the ventilation amount per unit time.

The evapotranspiration is calculated by the formula (1) as follows:

$$\sum^{t} ET = \sum^{t} Q\,(X_2 - X_1) \quad \text{.........................(1)}$$

where, ET: evapotranspiration (gr/min. plant), Q: ventilation (m^3/min), X_1 and X_2: absolute humidity (gr/m^3) measured at the entrance and the exit, respectively,

$\overset{t}{\Sigma}$: total during t min.

The absolute humidity is calculated by the formula (2):

$$X = \frac{e}{760} \times \frac{\sigma\delta}{1+at} \quad \text{.............................(2)}$$
$$= \frac{1.0582\, e}{1+0.00367\, t}$$

where, X: absolute humidity (gr/m^3), e: water vapor pressure (mm Hg), σ: weight of the air gram per cubic meter at 760 mm and 0°C (1.293×10^3 gr/m^3), δ: specific gravity of water vapor (0.622), a: expansion coefficient of the air for 1°C, t: temperature of the air (°C).

The water vapor pressure (e) was calculated by the formula of Angot.

To simplify the above-mentioned calculations, the authors made a table of absolute humidity in the range from 20 to 100% of relative humidity, at intervals of 0.1°C between 0° and 40°C combining the degrees of the dry and the wet bulbs. A psychrometric chart was also made from the table. Making use of the table and chart, the absolute humidity can be directly obtained from the degrees of both dry and wet bulbs.

The apparatus is designed to measure a change of 0.1°C at the minimum in the degrees of both dry and wet bulbs by thermister thermometers and to record it continuously on the electric temperature recorder. The ventilation is regulated by an air-flowmeter with orifice.

Eight kinds of chambers with different shapes were prepared for measurement of different types of crops.

Results of measurements

The measurement of evapotranspiration has been carried out in various kinds of crops which amount to 40 species including ordinary crops, vegetables, fruit trees and pastural plants in each growth period. Cooperative measurements were also made by this method to make clear water consumption characteristics of main upland crops in 11 places throughout the country, that is, in Hokkaido, Honshu, Shikoku and Kyushu.

Some of the results are shown in Figs. 2, 3 and Table 1.

The transpiration is larger in amount in such crops as rice plants, taros and eggplants

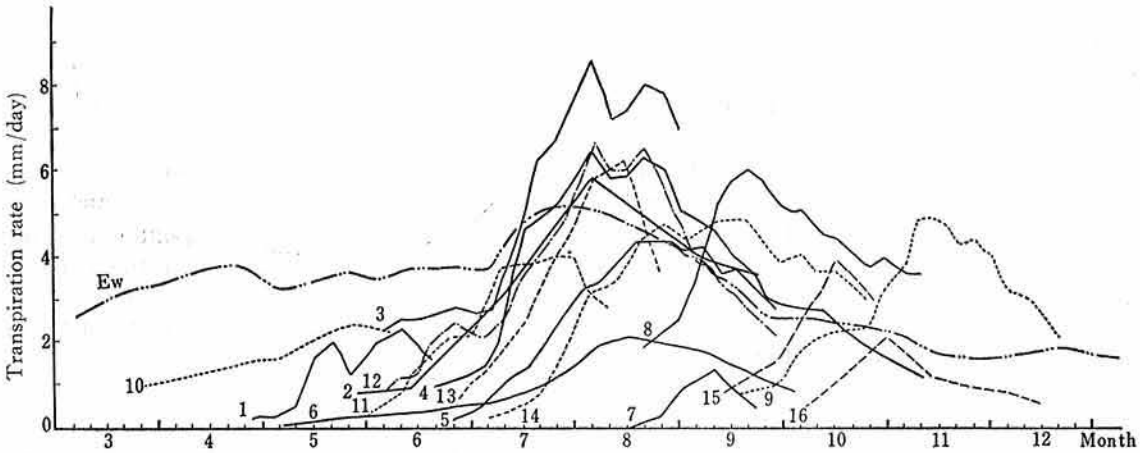

Fig. 2. Seasonal changes of transpiration rate of various crops
1: Lettuce 2: Taro 3: Eggplant 4: Rice plant 5: Soybean 6: Grapevine 7: Ear of rice plant 8: Cauliflower 9: Celery 10: Strawberry 11: Corn plant 12: Green pepper 13: Cucumber 14: Ginger 15: Cabbage 16: Chinese cabbage Ew: Pan evaporation (d, 20 cm)

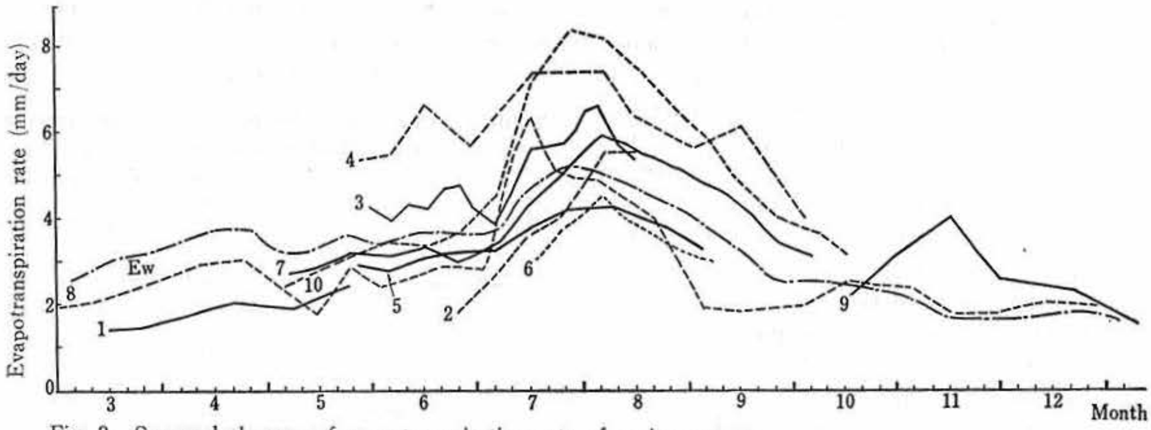

Fig. 3. Seasonal changes of evapotranspiration rate of various crops.
1: Barley. 2: Cabbage (in summer). 3: Corn. 4: Alfalfa. 5: Peach tree. 6: Persimmon tree. 7: Grapevine. 8: Mandarin orange. 9: Cabbage (in autumn). 10: Taro. Ew: Pan evaporation (d, 20 cm).

Table 1. Total transpiration amount and water requirement of crops

Crop	Total transpiration amount kg/plant	Dry matter weight g/plant	Water requirement
Head lettuce	6.6	36	183
Asparagus lettuce	10.1	34	296
Cabbage	34.7	177	196
Kale	41.5	183	227
Chinese cabbage			
Heading type	50.7	154	329
Non-heading type	54.0	114	473
Celery			
Yellow type	55.9	78	716
Green type	55.6	96	580
Taro	156.1	507	308
Ginger	94.8	95	998
Corn plant	39.9	416	96
Rice plant (lowland field)	14.2	48	296
Rice plant (upland field)	17.5	48	364
Soybean	149.0	255	584

which grow vigorously in summer, showing 6-8 mm per day in the period of the maximum transpiration.

On the contrary, it is smaller in strawberries, potatoes and Chinese cabbages which are cultivated in spring or autumn, being 2-4 mm per day. And it is noticed that the transpiration amount and water requirement of heading vegetables, are smaller than that of non-heading vegetables, for example, heading lettuce against asparagus lettuce and cabbage against kale, and that in celery with yellow leaves has more water requirement than that with green leaves, because yellow leaves produced less dry matter per water amount consumed.

It is understood that the characteristics of transpiration thus changes with the seasons and the species of crops.

On the other hand, evapotranspiration which is the sum of the transpiration and the evaporation from the surface of soil looks different from the transpiration as shown in Fig. 3. This is due to the fact that the evaporation from the soil surface is larger during the period when crops are small in size, while it decreases in amount with the growth of crops accompanied with an increase in amount of transpiration.

The seasonal change of evapotranspiration is in good accordance with that of the amount of pan evaporation, and larger in the hot summer season, reaching 7-8 mm per day in the taro and alfalfa. In fruit trees, the evapotranspiration is smaller in general, being about 5 mm at the maximum even in summer. And the ratio of the evaporation from the soil surface to the evapotranspiration is larger than in the other crops. This is a characteristic feature of fruit trees.

The evapotranspiration from the surface of cultivated field is a phenomenon of the evaporation of water and also is a form of the utilization of heat. Accordingly, in case there is a sufficient amount of water in the soil the evapotranspiration is mainly influenced by the insolation.

Correlations between evapotranspiration amount and several meteorological factors are shown in Table 2. It is seen in this table that evapotranspiration is highly correlated with insolation and net radiation, and among those meteorological factors the amount of pan evaporation which is an evaporation phenomenon as same as evapotranspiration is the highest in the correlation.

Table 2. Correlation between evapotranspiration amount and meteorological factors

Meteorological factor	After Kato et al., 1964		After Briggs & Shantz, 1914	
	alfalfa	taro	alfalfa	rye
Insolation	0. 86	0. 71	0. 89	0. 82
Net-radition	0. 89	0. 82	—	—
Temperature	0. 83	0. 16	0. 86	0. 85
Humidity	0. 04	—	0. 84	0. 75
Saturation deficit	0. 59	0. 76	—	—
Wind velocity	—	—	0. 35	0. 38
Pan evaporation	0. 94	0. 91	0. 93	0. 89

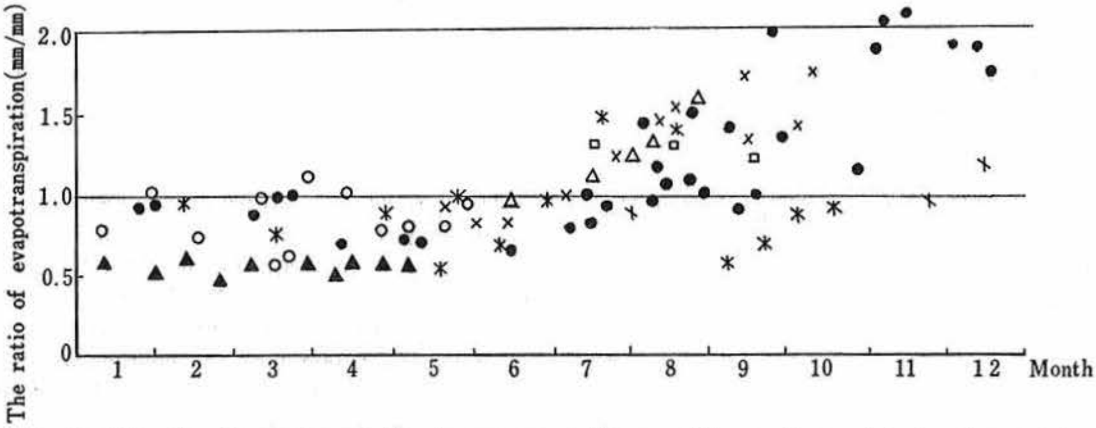

Fig. 4. The ratio of evapotranspiration to pan evaporation over the cropping period of various crops
● Cabbage ○ Barley ⊙ Onion × Taro △ Eggplant ▲ Sugar beet □ Alfalfa
* Orange

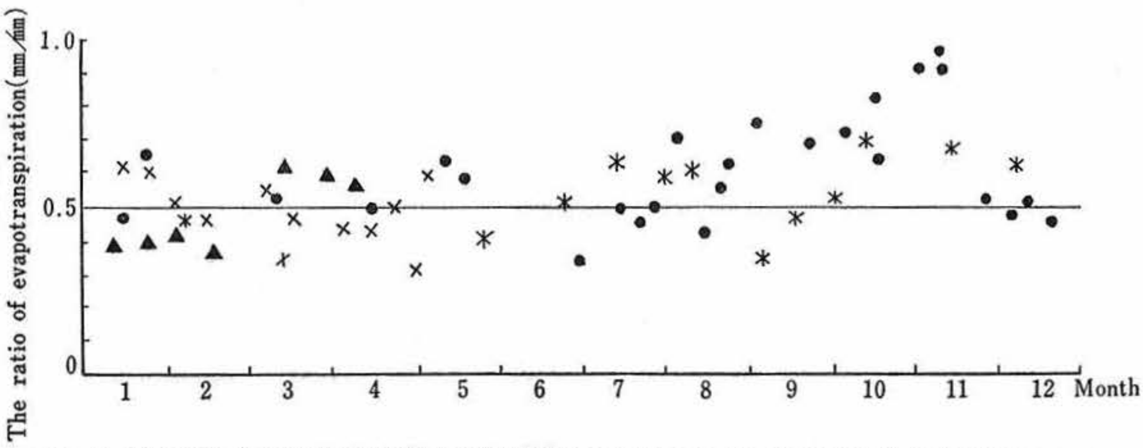

Fig. 5. The ratio of evapotranspiration to insolation amount over the cropping period of various crops
● Cabbage × Onion ▲ Sugar beet * Orange

The ratios of evapotranspiration to the highly correlated factors, pan evaporation and insolation amount, are shown in Figs. 4 and 5.

Both ratios tend to increase in autumn, being about 1.0 in average in the ratio to pan evaporation and about 0.5 in the ratio to insolation amount.

Application of the results of measurements

The measurement of evapotranspiration, as mentioned above, makes water consumption characteristics of crops clear and produces fundamental data for planning of irrigation.

It can also be utilized to know the optimum time of irrigation, being applied to performance of automatic irrigation. The available soil water decreases in amount with the evapotranspiration from crops. Accordingly, the time when the accumulation of daily evapotranspiration amounts to the available soil water is decided to be the time when irrigation is needed.

However, it is not easy to measure evapotranspiration directly, so pan evaporation or insolation amount which is highly correlated with evapotranspiration is measured in place of it, and the time when the accumulation of them reach a certain amount is decided to be the time of irrigation. The principle of this substitution comes from the data shown in Table 2 and Figs. 4 and 5.

The pan evaporation which indicates the time of the beginning of irrigation is calculated by the formula (3) as follows:

$$EW=\frac{1}{R}\times a\times D\times(Fc-CME)\qquad(3)$$

where, EW: pan evaporation indicating the beginning of irrigation (mm), R: ratio of evapotranspiration to pan evaporation (mm/mm), a: absorption rate in the area of root system (%), D: depth of the soil in the area of root system (cm), Fc: field capacity (vol %), CME: centrifugal moisture equivalent (vol %).

The a × D × (Fc–CME) is the water consumed by crops, and corresponds to the evapotranspiration (ET).

For instance, in case the available soil water is 30 mm and the ratio of evapotranspiration to pan evaporation is 0.9 for a crop the time when the sum of evapotranspiration amounts to 30 mm/0.9=33.3 mm is judged as the time when irrigation is needed. Making use of the insolation amount the optimum time for irrigation is also decided in nearly the same way as mentioned above.

There are few examples deciding the optimum time of irrigation by such meteorological factors as evaporation and insolation. The authors place their hope on the application of this method especially in such a place where meteorological conditions are variable and the lay of the land is complicated as in Japan.

An irrigation signal which is making use of the pan evaporation to decide the optimum time of irrigation is shown with an automatic irrigator connected with it in Fig. 6.

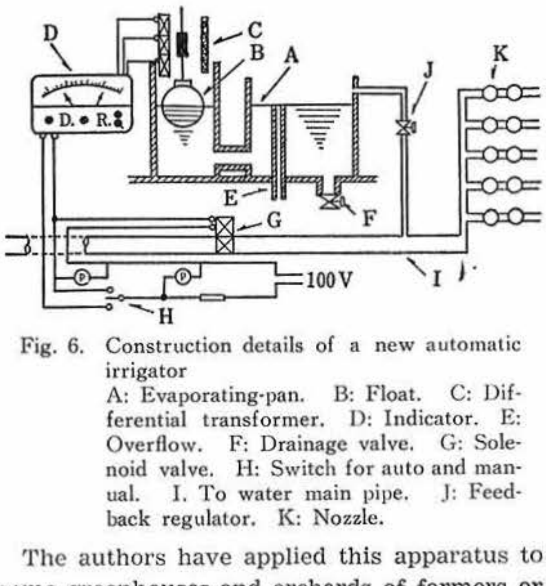

Fig. 6. Construction details of a new automatic irrigator
A: Evaporating-pan. B: Float. C: Differential transformer. D: Indicator. E: Overflow. F: Drainage valve. G: Solenoid valve. H: Switch for auto and manual. I. To water main pipe. J: Feedback regulator. K: Nozzle.

The authors have applied this apparatus to some greenhouses and orchards of farmers or to flower beds of high-storied apartments, succeeding in the practical use of completely automatic irrigation.

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