Studies on the Transpiration and Evapotranspiration Amount by the Chamber Method.

by Ichiro KATO

It was emergency need to resolve how much water was consumed from cultivated land in order to contribute to prevailing upland irrigation works in Japan.

It is but natural, because water consumption forms fundamental problem in upland irrigation. Such data in Japan are accumulated on paddy field where water is indispensable and is consumed too much. Nevertheless, knowledges in this line was poorly understood in upland field. Because it has much rain in Japan and crops cultivated in upland field were not staple foods and not considered to be important. And there was not found a reliable method to measure evapotranspiration in the other side.

There has been cultivated miscellaneous crops in small patches of field developed on complicated topography and soil in Japan. It has rather different circumstances from foreign countries, where it spells clear dry season and there are cultivated single crop widely in endless plain or monotonous slope land.

Therefore, there exists much doubt in direct application of data obtained in foreign countries. It was principally planed after the war and became recent issue to consume much water in large scale and in multiple ways.

One must be aware of that the chamber method was born in the above circumstances in Japan specially to meet emergency measures.

This method has been applied on various crops over 40 kinds so far and is being used in 11 places throughout the country.

1—1. Apparatus and formula.

A ring made by thin steel plate is inserted into the soil at first where crops are cultivated in the field. A chamber made of transparent vinyl plate covers crops and is kept on its ring. Various sizes of chamber are used according to the kind of crops. The ratio of wall area to basal area is usually over 10. The chamber has a small entrance at the base and an exit at the top, through which ventilation is performed. Namely, the entrance is connected to the pipe for inhalation and the exit is connected to the blower through orifice air flow meter as shown in the Fig. 1. All junctional parts are sealed with plastic tape.

Air enters from the pipe like a chimney into the transpiration chamber (A) and goes out finally to outside by the blower (H). A pair of dry bulb and wet bulb are installed at the entrance and the exit of the chamber.

And dry bulb and wet bulb temperature readings are automatically recorded on the thermograph. An orifice plate is inside tube (F) and (G) is the manometer.

Air flow quantity is adjusted by changing water level of manometer.

Generally, quantity of air-flow is adjusted so as to be 1 or 2 times replacement of the air per minute. Transpiration amount and evapotranspiration amount is computed from the air flow quantity and the difference in absolute humidity between at the entrance and at exit of the chamber.

$ET = (x_2 - x_1)\,Q$ … where x is absolute humidity in gram per cubic meter,

x_2 is absolute humidity at the exit,

x_1 is that at the entrance,

and Q is air flow quantity in litter per minute.

Absolute humidity,

$$x = 0.622 - \frac{1293}{1 + 0.00366\,t} - \frac{e}{P}$$

, where 0.622 is specific gravity of the water vapor, 1293 is the weight of the air gram per cubic meter, 0.00366 is the expansion coefficent of the air, e is water vapor pressure and P is atmospheric pressure.

Absolute humidity is directly found on the table or psychrometric chart from the dry bulb temperature and wet bulb temperature at present instead of complicate computation. The psychrometric chart and table have already been completed and used conveniently, on which 33000 readings of dry bulb and wet bulb temperature combinations are written with the range of 0 to 40 degree in centigrade having the

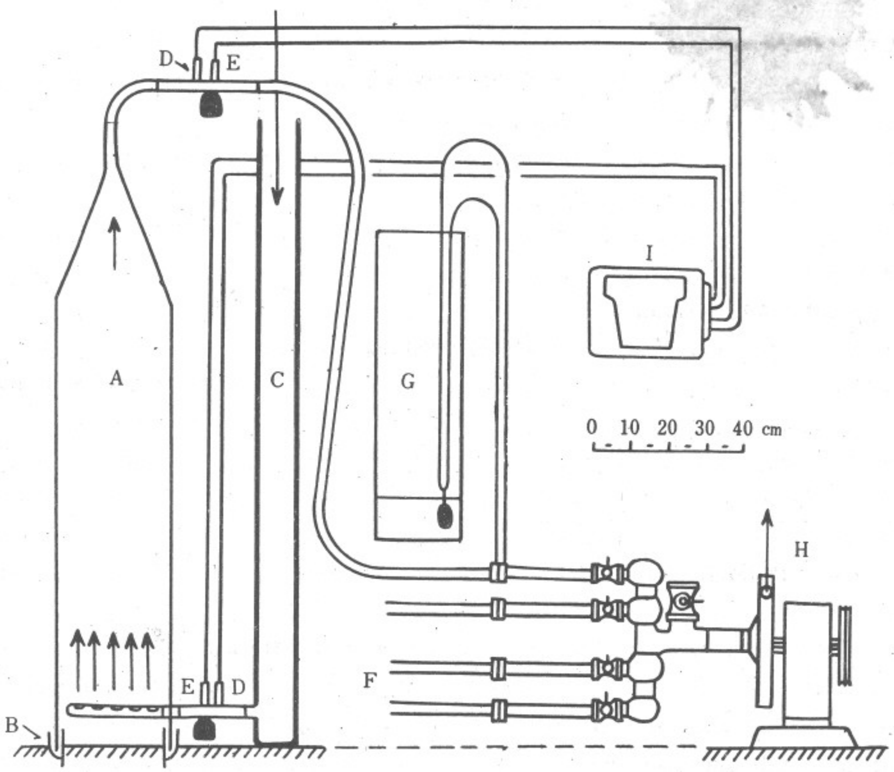


Fig. 1. Apparatus

A – Transpiration chamber B – Ring for keeping chamber

C – Pipe for inhalation D – Drybulb E – Wetbulb

F – Air-flowmeter with orifice and manometer (G). H – Blower

I – Electric thermometer —>- Direction of air-flow accuracy of 0.1 in temperature and in absolute humidity.

When we made the table or psychrometric chart, we used Angot's formula in the calculation of water vapor pressure (e). But there is some space to reconsiderate.

Because tip of thermister used in the chamber method is 2—3mm in width and the air velocity around the tip of thermister is well over 1 meter per second. So it may be better to use Sprung's formula.

1—2. Environmental conditions inside the chamber during measurement.

In the chamber method, first of all, we have to know under what conditions measurement is carried out. Because conditions inside the chamber will be different from that under open air.

Net radiation inside the chamber was smaller in the daytime and was a little larger from late evening to early morning presumably because of green house effect though it was small. Percentage of net radiation inside the chamber to that under open air dropped during the daytime as shown in the Fig. 2. It dropped average 5% from 6 to 18 o'clock. But it was not so much as the insolation.

Temperature inside the chamber was a little higher than outside. Temperature difference between inside and outside of the chamber varied by air-flow quantity and latent heat of evapotranspiration inside the chamber. Usually temperature difference was small and easy to adjust by changing air-flow quantity.

Humidity inside the chamber is apt to rise because of much transpiration and insufficent air flow quantity. So one must be carefull that the too much rise in humidity interfere the transpiration.

As the ventilation rate is usually 1 or 2 times per minute, air velocity inside the chamber is below 1 meter per second. However the air is given through small pores of the ring, so the air velocity reached about 1 meter per second at the 30 centimeter height from the base. There should be problem in that air direction is upward from the base of the chamber. So it might be better to elevate the height of the ring to blew out the air up to plant canopy.

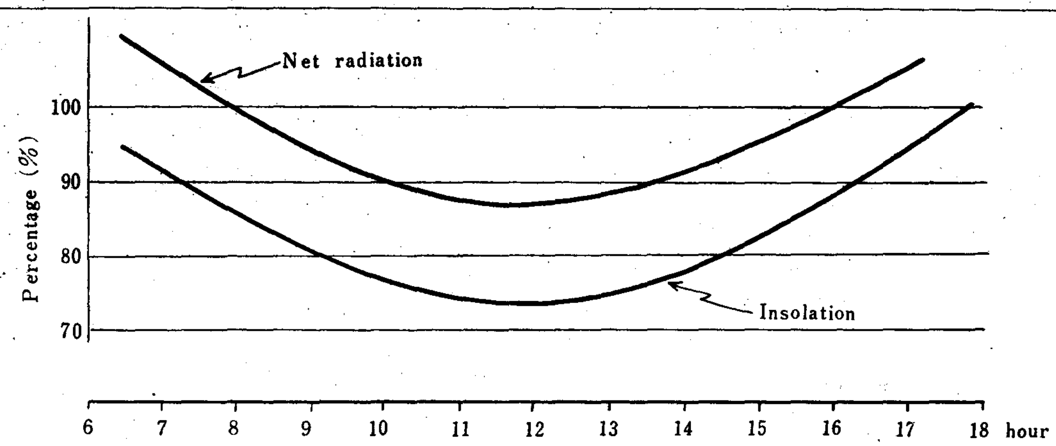
1—3. Comparative measurement by the chamber method and heat balance method.

Measurement of evapotranspiration amount by the chamber method and by heat balance method was simultaneously carried out in the alfalfa field.

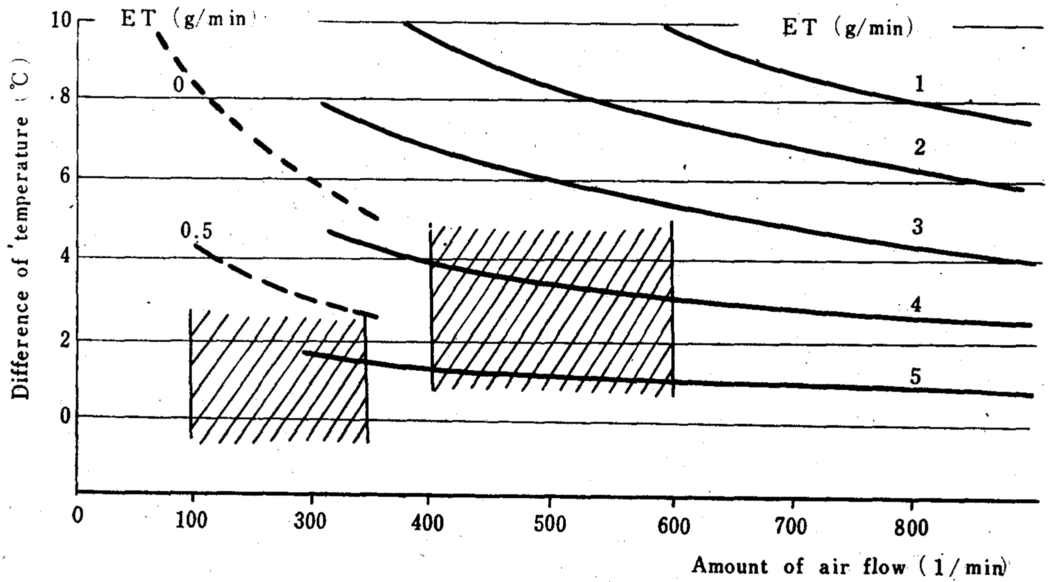
Hourly comparison of the results is shown in the Fig. 3.

The result obtained by the chamber method shows the lower evapotranspiration in the day and higher evapotranspiration in the night, but we hardly found the difference in the daily total amount. This can be chiefly because of the little difference in net radiation as told before. And the other reason may be that the air flow quantity could be a little smaller during the daytime and a little larger during the night, as the air flow quantity had not been changed according to the time of the day. This as well as the direction of air-flow inside the chamber must be improved.

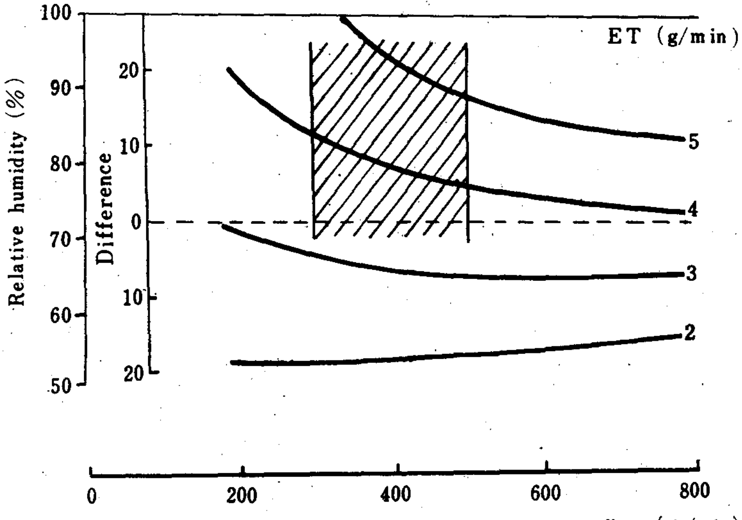
Comparison of results for 12 hours during the daytime is shown in the Fig. 3 too. 5 measurements out of 7 were made on the days when it was high in the relative humidity and soil moisture. So we must be carafull not so as to rise the humidity inside the chamber. Usually this is performed by changing air-flow quantity.



Percentage of net radiation and insolation inside the chamber to those outside chamber.



Difference of temperature between inside and outside the chamber.



Difference of humidity between inside and outside the chamber.

Fig 2. Environmental conditions inside chamder.

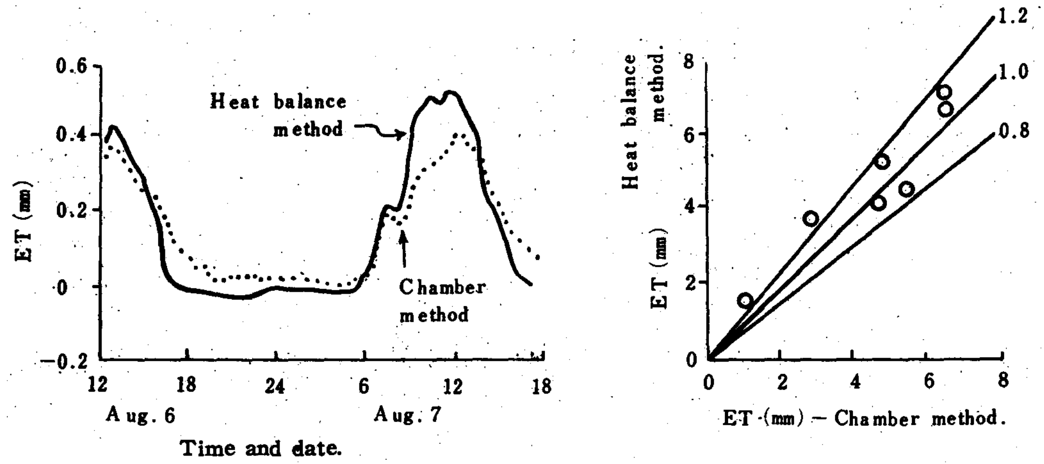


Fig. 3. Comparison of results shown in hourly evapotranspiration and 12 hour's evapotranspiration amount during daytime by chamber method and heat balance method.

1—4. Practical measurement and arrangement of result.

Several preparations and precautions on measurement and arrangement of result are as follows. . Measurement is performed in fields with such size of plot normally found in farmer's fields. Plants are cultivated by customary method to be taken by farmers, in which fields are irrigated by furrow irrigation and sometimes by sprinkler one. A chamber with same basal area equal to the crop spacing should be used, otherwise crop spacing is a little modified.

It is better not to use such chamber with lowered transparency of sun ray.

Measurement is performed 2 or 3 days at every 7 or 10 days interval.

And different indibidual is used at every measurement. This indibidiual is to be selected as one with standard growth according to the growth investigation.

Evaporation from water pan in the measurement field and insolation amount are measured at the same time. Growth investigation is carried out, above all leaf area is must-thing to investigate.

In fruit tree, it is inevitable seperately to measure transpiration and evaporation amount. One chamber contains twig or a part of branch for transpiration measurement and the other is set on the ground for evaporation measurement from soil surface.

Obtained figures are to be revised with 5% correction dividing them by 0.95. Because chamber method computed 5% less amount of pan-evaporation than that by the direct weighing at the same time.

And then the transpiration or evapotranspiration rate (T-rate or ET-rate) is calculated.

Generally the above ET-amount or T-amount and ET-rate or T-rate are used for various consideration, for example on the relation with environmental conditions and plant characters as written in the chapter 2—3 and 2—4.

Average ET-amount or T-amount for 7 or 10 days which contained these days when measurement was not performed is obtained multiplying ET-rate or T-rate by average pan evaporation for 7 or 10 days. Average ET-amount or T-amount is used in the case to know general tendency of ET-amount or T-amount among crops or for long years, which is obtained multiplying ET-rate or T-rate by pan-evaporation averaged for 10 years. In this way various average T-amount and water requirement were obtained as shown in chapter 2—1 and 2—2.

Of course, this cannot be used unless high correlation is found between ET-amount and evaporation amount from water-pan. ET-rate (ET-amount versus insolation amount) is to be used, if it is found higher correlation.

It is usual in Japan either evaporation amount or insolation amount has high correlation with ET-amount. Special concern is to be paid in the case of transpiration amount alone. There were often found high correlation between transpiration amount and leaf area index before the time of green cover formation but not found between t-amount and evaporation amount from water-pan Ew, which will be written in the chapter 2—3.

It is normal after the time of green cover perfection that high correlation between t-amount and Ew-amount is observed.

2—1. Transpiration amount and evapotranspiration amount of various crops at every growth stages.

The Fig. 5, 6 shows seasonal changes of daily transpiration amount of various crops obtained by the chamber method. Avarage pan-evaporation for 10 years in Taketoyo is shown in the same figure. Daily mean of transpiration amount was obtained by the multiplication of relative transpiration amount and average pan-evaporation. Relative transpiration is obtained from the measurement for 1 or 2 days at every 7 or 10 days interval. And the pan-evaporation is the mean for 10 days for 10 years. The applied water-pan was made of coupper plate with 20 cm diameter and 10 cm depth.

Transpiration character varied by crops. These crops, which grew vigorously in summer were of higher transpiration amount. These are, for example, egg-plant, cucumber, rice plant and peaman. But the amount was less than 8 mm per day at largest. Celery was also rather high in transpiration amount though it grew in autumn.

Transpiration amount of spring crops like lettuce, potato and strawberry was less than that of summer and autumnal crops.

Grape vine transpired water very much. But in the case shown in mm there was found less transpiration amount as shown in Fig. 5, which were obtained by dividing transpiration amount of 1 plant indicated by gram by land area occupied by 1 plant. In this indication t-amnunt of those crops which had less leaf area index will naturally become few. It appeared to be that the fruit trees not only grape vine had such difference of transpiration amount caused by the different indication. They had generally less evapotranspiration amount in mm. Because fruit tree is pinched so as to keep suitable spacing and soil surface in their orchards is usually multched by various materials.

Rice plant grown in upland field transpired a little more than in lowland field both in young seedling age and in the latter half of ripening stage. It was due to the larger transpiration per unit leaf area, which would be related to the larger root in the young seedling age. And also it dependeds upon the larger area of green leaves perhaps caused by late decay of root in the later stage in upland field.

Transpiration amount of ear is also shown in the same figure, which was the one third of total transpiration of whole hill.

Percentage of transpiration amount against evapotranspiration amount was naturally less in the begining of crop growth. After that percentage of transpiration gradually increased with plant growth and evaporation rate from soil surface adversely decreased.

The least evaporation rates from soil surface were about 15% in rice field, 20% in corn field, 30% in taro field and 40—50% in orchard. This varied by soil moisture content.

Fig. 4 showed the seasonal changes of evapotranspiration amount of various crops. This curve was leveled but not so steep comparing with transpiration curve caused by that the evaporation from soil surface was rather much when transpiration was not so much in quantity in young stage of plant growth.

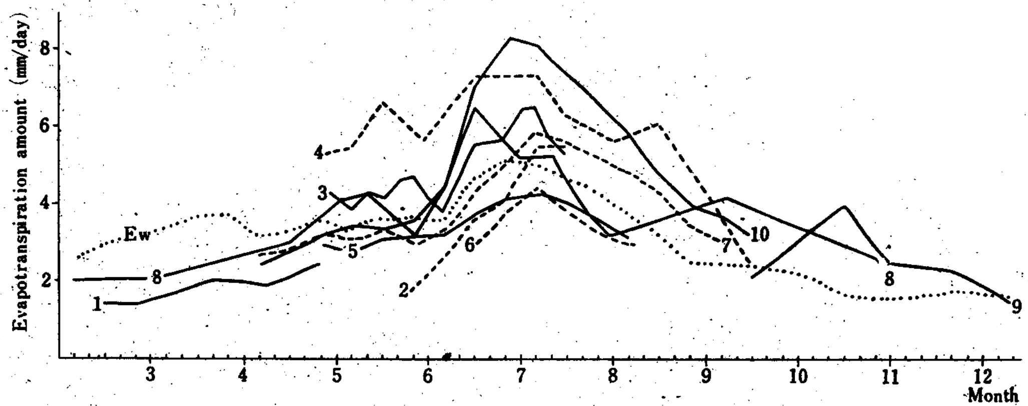


Fig 4. Seasonal changes of evapotranspiration amount of various crops.

1. Barley 2. Cabbage (in summer) 3. Corn 4. Alfalfa 5. Peach tree 6. Persimon tree 7. Grape vine 8. Mandarin orange 9. Cabbage in autumn and summer 10. Taro Ew. Evaporation amount from water-pan

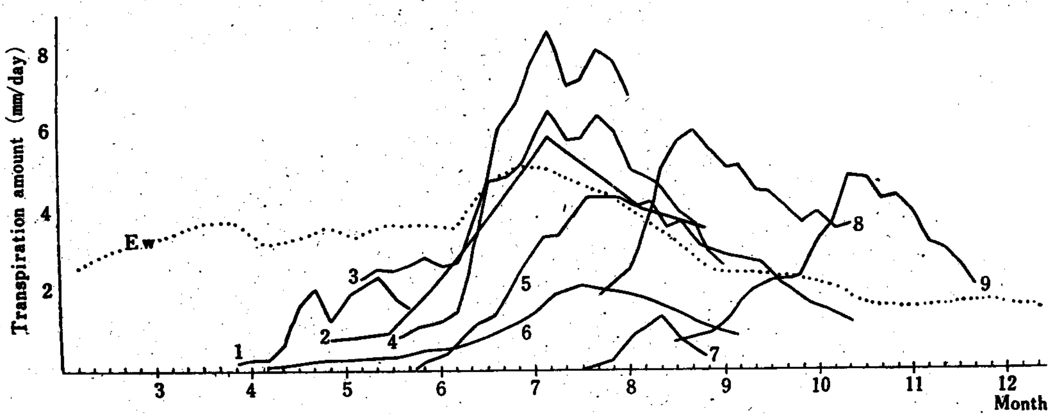


Fig. 5. Seasonal changes of transpiration amount of various orops

1. Lettuce 2. Taro 3. Egg plant 4. Rice plant 5. Soybean plant 6. Grape vine 7. Ear of rice plant 8. Cauliflower 9. Celery Ew. Evaporation amount from water-pan

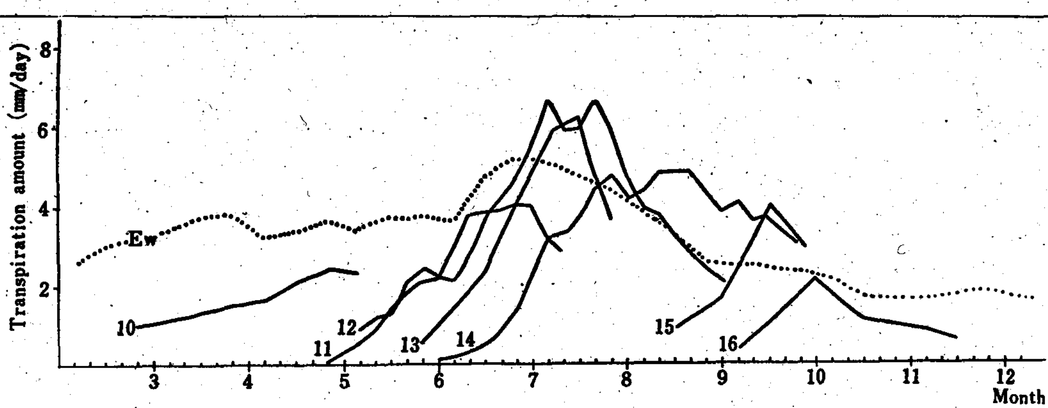


Fig. 6. Seasonal changes of transpiration amount of various crops.

10. Strawberry 11. Corn plant 12. Peaman 13. Cucumber 14. Ginjer 15. Cabbage 16. Chinese cabbage.

Ew. Evaporation amount from water-pan

2—2. Total transpiration amount and water requirement.

The next table shows the total transpiration amount and water requirement of various crops obtained by the chamber method.

Total transpiration amount during growth period varied by crops, growth season and by the length of growth period or by the length of green cover period.

Table 1. Total transpiration amount and water requirement of crops.

Crop	Total transpiration amount (kg)	Dry matter weight (g)	Wate rtequirement
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	145	329
Non-heading type	54.0	114	473
Celery	55.9	76	463
Cauliflower	88.9	153	581
Peaman	96.9	155	625
Egg plant	100.3	237	423
Cucumber	101.7	133	765
Taro	156.1	507	486
Ginger	94.8	95	998
Corn plant	39.9	416	96
Rice plnt (lowland field)	14.1	47	297
Rice plant (upland field)	17.4	48	365
Soybean (rough spacing)	149.0	255	584
Soybean (thick spacing)	42.4	73	581

Taro, cucumber, egg-plant and peaman were more in total transpiration amount.

More water requirement was observed in the crops like ginger, cucumber, peaman, cauliflower and soybean plant, which appeared either to consume more water or to produce less dry matter.

Water requirement of heading vegetables was less than that of non heading vegetables, for example, heading lettuce against asparagus lettuce, cabbage against kale and heading type of chinese cabbage against non-heading one. Because inner leaves of heading part did not contribute much to transpiration. Transpiration depended chiefly upon the old outer leaves.

Celery and morning glory with yellowish leaves had more water requirement than that with green leaves. Because yellowish leaves produced less dry matter per water amount consumed.

Water requirement was less in lowland rice than in upland rice. In the next figure total transpiration amount and dry matter weight during growth period were dotted on 8 treatments respectively as shown in Fig. 7.

Water requirement of lowland rice appeared to be a little less in the case cultivated in lowland field than in upland cultivation. Dry matter weight and transpiration amount were traced and shown at every growth stages in the next Fig. 8.

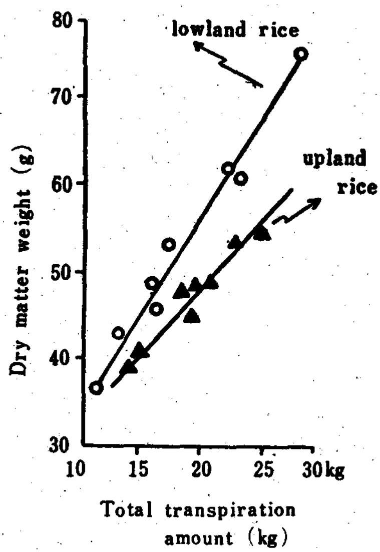


Fig. 7. Total transpiration amount and dry matter weight during growth period.

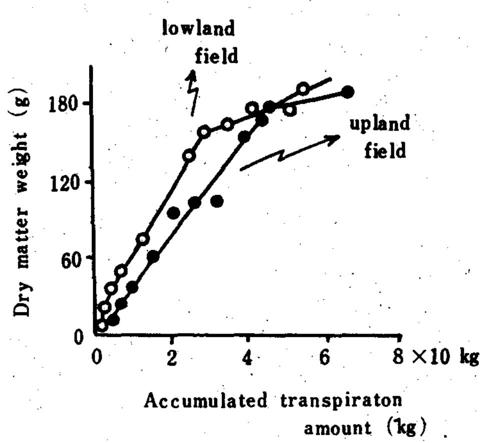


Fig 8. Accumulated transpiration amount and dry matter weight at every growth stages.

Water requirement of soybean plant did not differ with different spacing. But transpiration amount and dry matter weight per unit land-area was more in thick spacing which had longer period of green cover against soil surface.

2—3. Transpiration amount and influential factors upon transpiration.

Relation between transpiration amount and leaf area index is shown on rice plant in Fig. 9 and on soybean plant in Fig. 10. Transpiration amount of rice plant increased with the increase of leaf area index. But it did not increase after the green cover fomation which was in 4—5 leaf area index.

Transpiration amount before the green cover formation was approximately 1.3 times of leaf area index and that after the green cover formation was about 1.2 times of pan-evaporation amount. The time of green cover formation will be practically replaced by heading times as the green cover was usually made in near heading times in rice plant.

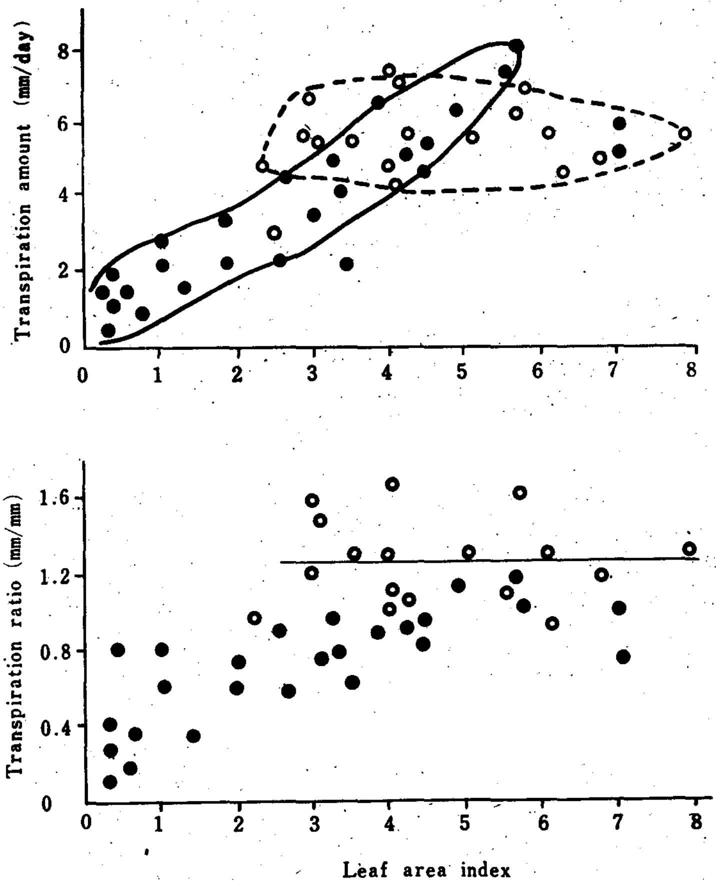


Fig. 9. Leaf area index and transpiration amount in ricé plant.

● transpiration amount before heading.

○ transpiration amount after heading.

(Leaf area in the above case included only green leaves but did not include yellowish dead leaves. This is reason why leaf area index after the heading was indicated small.)

Green cover was formed in 2—3 leaf area index in soybean plant.

Transpiration amount before the green cover formation was by 2 times of leaf area index and that after the green cover formation was 0.93 times of pan-evaporation amount. And it was 73% to total insolation amount, that is, 73% of insolation amount was consumed as latent heat for transpiration.

Therefore, it can be said that transpiration amount was mainly dominated by leaf area among crop factors before the green cover formation and was affected mainly by meteorological factors after the green cover formation.

It will be but natural unless under insufficent soil moisture conditions that transpiration amount is affected by leaf area from which it starts befor green cover formation and transpiration as a kind of latent heat consumption is ruled by the given amount of insolation after green cover formation.

Therefore, it will be easily understood that the transpiration amount per unit leaf area decreased rapidly with the increase of leaf area as the result to share the definite

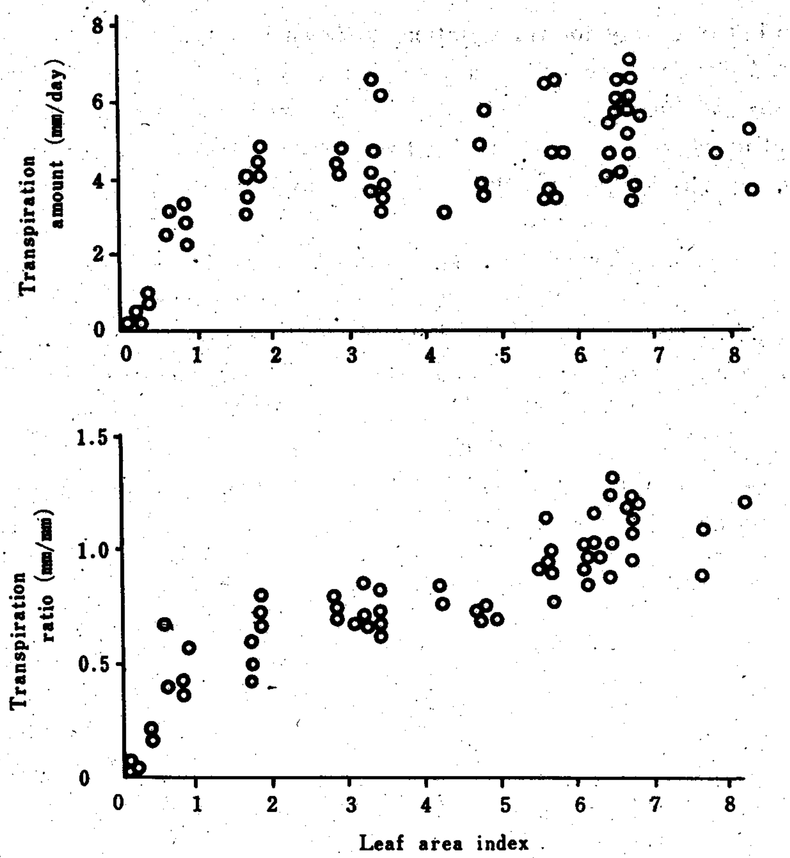


Fig. 10. Leaf area index and transpiration amount in soybean plant.

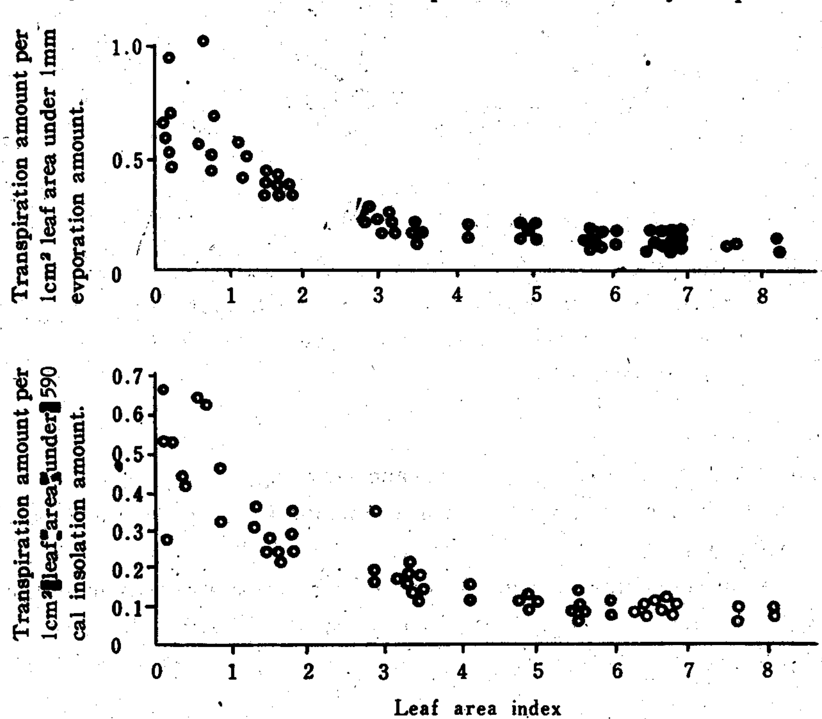


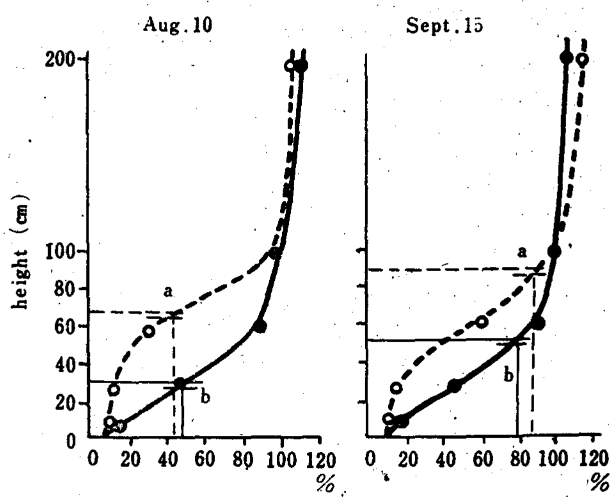
Fig. 11. Leaf area index and relative transpiration amount per unit leaf area index in soybean.

insolation amount of energy for transpiration as shown in Fig. 11.

The increase of leaf area over leaf area index of green cover formation (leaf area index when the soil surface is perfectly covered by green leaves) results to differentiate 2 layers in plant layer, comparatively inactive layer of lower leaves scarecely avairable of sun light and physiologically active layer of upper leaves where was avairable of sun light.

The height of green cover (the height from the ground where leaf area measured from upper leaves reached to the leaf area index of green cover formation) differed by the type of plant canopy caused by different plant spacing. But the evaporation amount at the height of green cover was not so different as in the difference of green-cover-height as shown in the Fig. 12.

It is necessary in knowing characteristics of plant group and community to clarify the time of green cover formation, height, thickness, water content of green cover and utilization of ray and heat of green cover.



Percentage of evaporation amount at respective height to that at 100cm height.

Fig 12 Evaporation power at each height in plant canopy in soybean. (a and b show the height of green cover and evaporation power at the height of green cover in dense spacing and rough spacing.)

2—4. Evapotranspiration rate.

(Instrument to notify the time of watering and autoirrigator)

If it is enough soil moisture, water vapor evaporate from soil surface besides by transpiration from leaves.

In this case evapotranspiration being different from transpiration is mainly affected by meteorological factors. Above all the pan-evaporation amount, insolation amount and net radiation amount had high positive correlation with evapotranspiration amount as below.

Correlation between evapotranspiration amount and meteorological factors.

Meteorolgical factors	Correlation coefficent	
	by Kato etc in alfalfa field	by Briggs and Shantz
Insolation amount	0.86	0.89
Net-radiation amount	0.89	—
Temperature	0.83	0.86
Humidity	—	0.84
Saturation deficitt	0.59	—
Wind velocity	—	0.35
Evaporation amount from water-pan.	0.94	0.93

Therefore the evapotranspiration rate (ET-rate) that are indicated as a ratio of the two is less invariable than evapotranspiration amount or pan evaporation amount alone, so that it distributes in definite narrow range.

This is shown in the next figure.

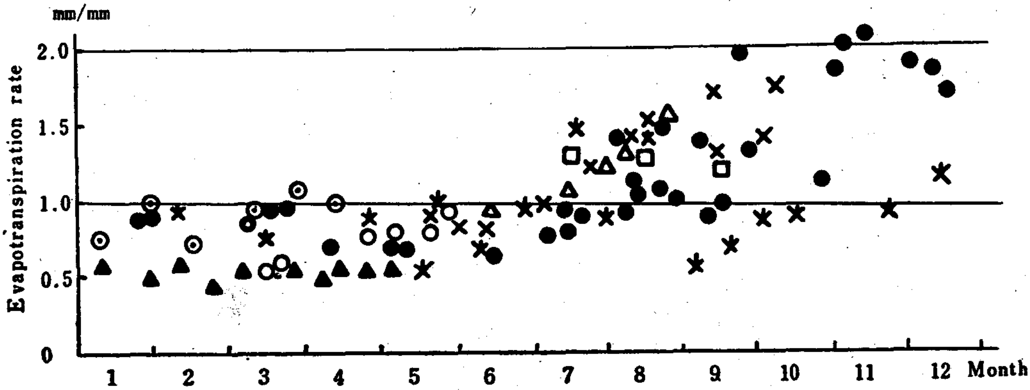


Fig. 13 Monthly evapotranspiration rate to pan-evaporation.

●cabbage ○barley ⊙onion ×taro △egg plant ▲sugar beet □grass ✳orange

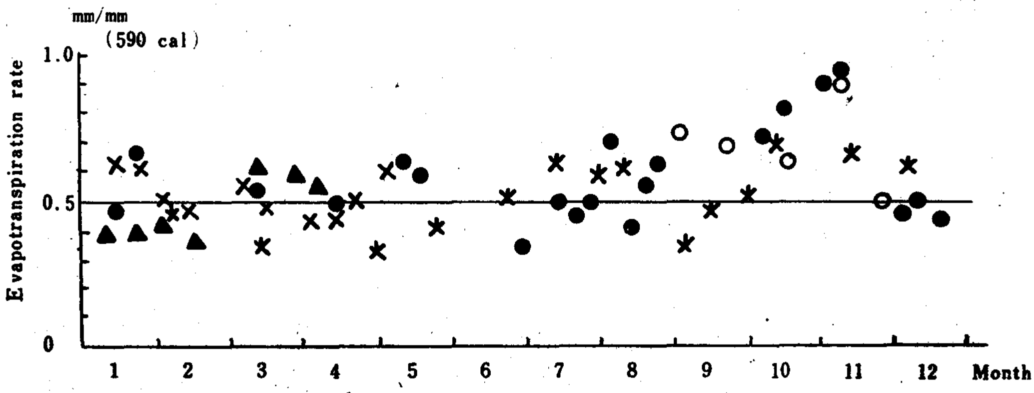


Fig. 14 Monthly evapotranspiration rate to insolation

● cabbage (Tokai-Kinki Agr. Exp. Sta.)............Taketoyo
○ 〃 (Kyoto Agr. Exp. Sta.)......................Kameoka
× onion (Kagoshima Agr. Exp. Sta.)............Kanoya
▲ sugar beet(〃)............Kanoya
✳ orange (Tokai-Kinki Agr. Exp. Sta.)............Taketoyo

ET-rate (against pan-evaporation amount…ET/Ew) showed seasonal changes average value 0.7 in winter and spring, 1.2 in summer and autumn, though it varied by crop. Those crop and trees that declined in autumn did not show higher ET-rate even in autumn.

ET-rate (against insolation amount……ET/Ri) was about 0.5 and 0.7 in autumn. That is, the half of insolation amount was consumed by evapotranspiration as a latent heat.

Water pan to measure evaporation is 20cm in diameter and 10cm in depth. It was placed near to the plant height in the measurement field.

In application of ET-rate it is also possible to know or notify the time to irrigate automatically by accumulating pan evaporation or insolation amount modifyied by ET-rate corresponding to avairable soil water.

If it is connected to the solenoid valve as well in the above case, it is possible to work autoirrigator.

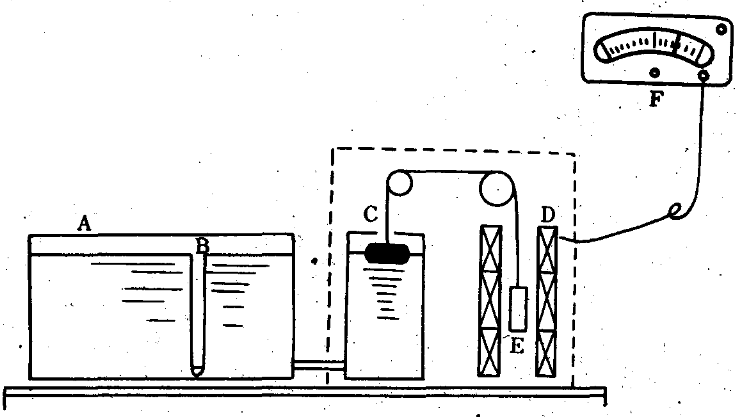


Fig. 15 An instrument to notify the time to irrigate.
A. Evaporation-pan B. Overflow C. Float
D. Differential transformer E. Core F. Indicater

One of instrument to notify the time to irrigate is shown in the above figure.

Depth of subsidence correspond to avairable soil moisture is preset by needle on the indicater. Avairable soil moisture is lost by evapotranspiration, so the depth of subsidience is obtained by next formula.

$Ew = ET/\text{evapotranspiration rate}$

If the avairable soil moisture is 30mm and evapotranspiration rate is 0.8, equivalent depth of subsidence is $30/0.8 = 37.5$mm. This figure is preset beforehand on the indicater. If the accumulated evaporation from water-pan reach to the above figure, the float decends, the core acends, the other needle on the indicater reaches to the preset needle and it notify the time to irrigate by bell or lamp.

The author wishes to express hearty thankness to the great supports by the former Head, Professor Tomizo Imai and the present Head Mr. Tokuzo Tatsuno. I was deeply indebted to my respected friends Dr. Y. Mihara and Dr. Z. Uchijima and the following associates of the first crop laboratory, Mr. Y. Naito, Mr. R. Taniguchi and Mr. F. Kamota.

ERRATA

Page	Line	Erratum	Correction
1	14	planed	planned
2	7	$x = 0.622 - \frac{1293}{1+0.00366t} - \frac{e}{P}$	$x = \frac{0.622\times 1293}{1+0.00366t} \times \frac{e}{P}$
3	21	carefull	careful
	23	veiocity	verocity
	28	blew	blow
	42	carefull not so as to	careful so as not to
5	10	indibidual	individiual
6	25	coupper	copper
	35	t-amnut	t-amount
7	1	dependeds	depended
	6	begining	beginning
	Fig. 5	orops	crops
8	Fig. 6	Ginjer	Ginger
	Table 1	Rice plnt	Rice plant
	〃	Wate rtequirement	Water requirement
7.8	Fig. 4.5.6	5 6 7 8	6 7 8
9	Fig. 8		Dry matter weight and transpiration amount shows per 4 hills respectively.
10	2	formation was by 2 times	formation was 2 times
13	9	Saturation deficitt	Saturation deficit
14	10. 14. 15	avairable	available
	12	work autoirrigator	work as a autoirrigator
	16	subsidience	subsidience
	22	notify	notifies