# Designing Water Requirement of Upland Farms in Humid Regions

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In the present report, methods of determining the rate of consumptive use of water (CU mm/day), which is a basis for designing water requirement on upland farms will be discussed. The CU signifies the amount of water decreased in an effective soil layer (effective root zone), within a favorable soil moisture range permitting normal plant growth, and upland farms refer to farm fields not for flooding irrigation to grow lowland rice. The CU changes with growth stages of crops. When the peak value of CU is used in designing water requirement, the size of irrigation facilities comes to be over-estimated, so that the average of a certain period of time is to be adopted. At the time of peak consumption, necessary amount of water is supplied by extending the irrigation hours per day.

## Difference between CU and evapotranspiration (ET)

CU is originally a synonym of ET. In case when subsoil is dry, as in arid regions, there is no water movement from subsoil to top soil and therefore CU approximates ET in most cases. On the contrary, in humid regions, like Japan, the subsoil contains more water than the top soil layer does, so that the water supply from the subsoil to the top soil takes place, which often causes CU being less than ET. Extent of water supply from the subsoil to top soil varies depending upon the conditions of a given location such as ground water levels and drainage, etc. Examples showing 30% of water supply in loamy soil, and more than 90% in a vinylhouse during an off-season of lowland rice are known.

Methods which are widely known as the methods for determining CU, i.e., calculating methods such as Blaney-Crriddle method, Thornthwaite method, evapotranspiration ratio method, and the measuring methods such as lysimeter method, chamber method, heat balance method, weighing method, etc. are the methods to estimate or measure ET, and hence it is apparently irrational to use these methods in determining CU for the purpose of designing water requirement in the humid regions. For this reason, the soil moisture depletion method has come to be adopted as a method to determine CU in the new "design criteria" in Japan.

In the past, water requirement and size of irrigation facilities have been so far decided based on ET determined by the calculating method or lysimeter method which are applicable to arid regions. As a result, actual irrigation practices are found considerably below the designed ones as shown in Table 1, supporting that the use of ET in designing water requirement results in an over-estimation.

## Problems related to the soil moisture depletion method

The soil moisture depletion method is to measure continuously for a certain period of time the decrease of soil moisture from the field capacity (FC) in each soil layers, and

**Table 1. Irrigation designed and that actually being practiced**

| District | crop | period | AW (mm)[1] | | CU (mm/day) | |
|---|---|---|---|---|---|---|
| | | | designed | practical[2] | designed | practical[2] |
| Arida | mandarin | Jan.~Dec. | 28 | 19.1 | 2.8 | 1.8 |
| | orange | | 28 | 25.4 | 2.8 | 2.1 |
| Kasanohara | Tea | Jan.~Dec. | 30 | 30.0 | 2.5 | 2.2 |
| | pastures | | 30 | 35.0 | 3.3 | 2.6 |
| Toyogawa | cabbage | Sept.~Nov. | 15 | 10.9 | 3.5 | 2.4 |
| | radish | | 15 | 14.0 | 3.5 | 2.3 |
| | cabbage | | 30 | 23.0 | 3.5 | 3.4 |
| Yamagata | fruit trees and vegetables | Apr.~Aug. | 25 | 2.7 | 4.7 | 4.4 |
| | | | 25 | 3.1 | 4.7 | 3.8 |

1) AW: Amount of water supplid by each irrigation
2) AW, CU: Calculated by equation based on data obtained by field survey.

calculate the decrease per day. It can give appropriate basic data for the design of water requirement, reflecting the conditions of the area to be irrigated. However, several problems have come to be pointed out in recent years, as shown below.

Time required for soil moisture to reach the field capacity after rains or irrigations is about 2 days with volcanic ash soils, that is almost similar to the result of Veimeyer et al. (1931), but with soils of poor drainage or fine-textured heavy crayey soils it often takes more than 4 days. Therefore, the decrease of soil moisture soon after rainfalls represents the sum of ET and the downward drainage, giving consequently the over-estimated value for CU. On the other hand, at several days after rainfall the soil moisture in the surface layer has already reached the lower limit of available moisture, so that it becomes impossible to obtain CU within a favorable soil moisture range. In either case it is troublesome to obtain appropriate CU values for the design of water requirement.

For the measurement of CU by the soil moisture depletion method, it is general to install various kinds of soil moisture meter at a given depth of soil, and by reading the meters, the amount of soil moisture decrease is determined indirectly. As to the soil moisture meters, handy tensiometer and electric resistance block are almost exclusively used in Japan. However the former shows some time-lag in response, and is influenced by soil temperature changes. The latter also has a defect that the measurement fluctuates by being influenced sensitively by temperature and salt concentration of soil. In the upland farms of humid regions it is necessary to measure with a high accuracy the soil moisture of the surface layer because large quantity of water is consumed in the surface layer. These two methods are not sufficiently practical for that purpose.

Accordingly, it is necessary to improve further or develop soil moisture meters and also to re-examine the method of measuring CU based on new ideas.

## Determining CU by the use of water balance of farmfields

A new method of measuring CU, proposed here, is an indirect determination of CU, based on an assumption that the sum of effective rainfall stored in an effective soil layer (out of the total rainfall during a certain period of time), and irrigated water (applied if necessary under the dry weather) is equal

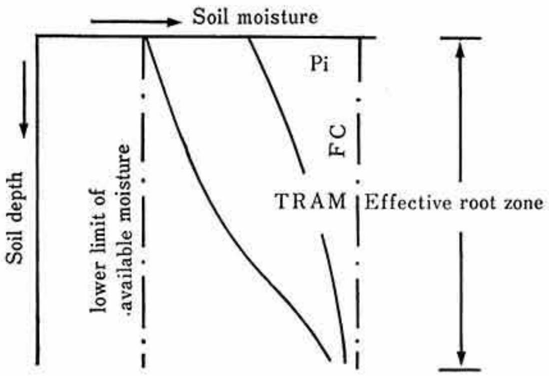


Fig. 1. Moisture decreasing model

to the amount of water decrease during that period.

In Fig. 1, available capacity for moisture storage in an effective soil layer ($P_i$) can be expressed by the following equation, using available capacity in a preceeding day ($P_{i-1}$), effective rainfall of the day ($AR_i$) and the amount of irrigation water applied on the day ($I_i$):

$$P_i = P_{i-1} + CU_i - AR_i - I_i \quad \text{..................(1)}$$

As the maximum value of the available moisture for storage is the total readily available moisture (TRAM), the available capacity for moisture storage in the next day ($P_{i+1}$) can be expressed as follows:

$$\left.\begin{array}{ll} P_i \geq TRAM, & P_{i+1} = TRAM \\ P_i < TRAM, & P_{i+1} = P_i \\ P_i \leq 0 \quad , & P_{i+1} = 0 \end{array}\right\} \quad \text{.........(2)}$$

As to the ratio of effective rainfall ($AR_i$) to the total amount of rainfall ($R_i$), the rate of infiltration of rainwater into soil is taken as 80%, and small amount of rain less than 5 mm each is regarded not to be stored in the effective soil layer due to evaporation loss at the soil surface, then the ratio of effective rainfall is expressed as follows:

$$\left.\begin{array}{ll} P_i \geq 0.8R_i, & AR_i = 0.8R_i \\ P_i < 0.8R_i, & AR_i = P_i \\ R_i > 5 \quad , & AR_i = 0 \end{array}\right\} \quad \text{...............(3)}$$

Water supplied to fields during a certain period of crop growth (T, in days) in the sum of irrigation water ($I_i$) and effective rainfall ($AR_i$), Assuming that the all irrigation water applied is held in the effective soil layer, because the minimum amount of water required for normal plant growth is applied at necessary time, the average of CU ($\overline{CU}$) is expressed as

$$\overline{CU} = (\sum I_i + \sum AR_i)/T \quad \text{..................(4)}$$

The procedure for obtaining $\overline{CU}$ is as follows:

1) Put the first round number of CU (CU′) into the equation (1), and calculate the value of $P_i$.
2) $AR_i$ in this case is obtained by the equation (3).
3) When the daily water balance during the given period (T) is made clear by the equations (1) and (2), $\overline{CU}$ is calculated by the equation (4), and $\overline{CU}$ is compared with CU′.
4) If CU′ is not equal to $\overline{CU}$, the same calculation as above, starting from the equation (1), is repeated by using $\overline{CU}$ as the second approximate value of CU′, until CU′ and $\overline{CU}$ come to be equal.

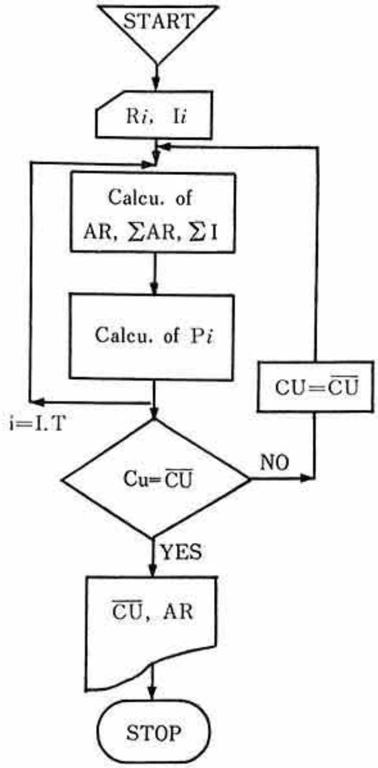


Fig. 2. Calculating flow chart

The calculating flow from the equation (1) to (4) is given in Fig. 2. When T is a short period, seasonal trends of CU can be known, but too short period causes a decrease of accuracy. Assessment of effective rainfall shown in the quation (3) gives only an approximate estimation, and strictly speaking, it varies with field gradient and soil texture. There is a tendency that the less the rainfall, the higher is the accuracy of estimation of CU.

To carry out the measurement by the water balance method, a small experiment field is set up in a proposed irrigation project area, and is planted with crops which are expected to be grown in that area with irrigation. In the experimental field, amount of rainfall and irriagted water is recorded during the growing season of the crops. Cares should be taken not to cause the percolation of irrigated water to lower soil layers, by applying

**Table 2. Applied depth of water** mm (%)

| Districts | Crops | Sowing date | | Supplemental irrigation | | | | insecticide application | washing | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | before cultivation | before seeding | after seeding | growing period | | | |
| Sakata | melon | April | 23 | 6.9( 3) | 10.0( 5) | 10.0( 5) | 172.4(86) | 1.0(1) | — | 200.3(100) |
| | sweet potato | May | 15 | — | — | 1.0( 1) | 146.2(99) | — | — | 147.2(100) |
| | radish | Aug. | 5 | 14.7(21) | 3.8( 5) | 16.3(24) | 29.8(43) | 0.1(0) | 5.2( 7) | 69.9(100) |
| | | | 15 | 14.7(24) | 13.4(22) | 1.1( 2) | 27.7(45) | 0.1(0) | 4.0( 7) | 61.0(100) |
| | | | 20 | — | 10.5(15) | 10.0(15) | 43.2(62) | 0.1(0) | 5.4( 8) | 69.2(100) |
| | | | 30 | — | 9.4(40) | — | 14.1(60) | 0.1(0) | — | 23.6(100) |
| Hamamatsu | radish | July | 16 | 4.0( 7) | 4.0( 7) | 10.9(19) | 30.8(54) | 0.7(1) | 6.9(12) | 57.3(100) |
| | | | 23 | 4.0( 6) | 4.0( 6) | 7.1(11) | 42.8(65) | 0.7(1) | 6.7(11) | 60.8(100) |
| | | | 25 | 4.0( 7) | 4.0( 7) | 7.3(12) | 38.1(62) | 0.7(1) | 7.5(11) | 66.1(100) |
| | | Aug. | 8 | 10.0(12) | 10.0(12) | 10.2(13) | 39.8(49) | 1.3(2) | 10.0(12) | 81.3(100) |
| | cucumber | Aug. | 12 | — | 10.0(16) | 6.8(12) | 42.1(69) | 1.8(3) | — | 60.7(100) |
| | | | 13 | — | — | 19.0(37) | 30.9(61) | 1.0(2) | — | 50.9(100) |
| | chinese cabbage | Sept. | 10 | — | 14.0(36) | 9.5(24) | 15.2(38) | 0.7(2) | — | 39.4(100) |
| | celery | Aug. | 28 | 7.0(19) | 3.5(10) | 4.4(12) | 20.4(55) | 1.6(4) | — | 36.9(100) |

**Table 3. Consumptive use rate (CU) and effective rainfall (ER)**

| Growing Stage | TRAM (mm) | CU (mm) ER (%) | Sakata | | | | Hamamatsu | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Aug. 5 ~ Oct. 14 | Aug. 15 ~ Oct. 15 | Aug. 20 ~ Oct. 20 | Aug. 30 ~ Oct. 30 | July 16 ~ Sept. 10 | Aug. 8 ~ Sept. 20 | Aug. 11 ~ Sept. 25 | Aug. 12 ~ Sept. 20 |
| Total period (Average) | 15 | CU | 2.1 | 1.6 | 2.2 | 1.5 | 1.4 | 1.9 | 2.1 | 1.7 |
| | | ER | 32 | 26 | 29 | 25 | 11 | 9 | 10 | 9 |
| | 10 | CU | 1.8 | 1.3 | 1.9 | 1.1 | 1.3 | 1.7 | 1.8 | 1.6 |
| | | ER | 24 | 19 | 24 | 17 | 8 | 7 | 8 | 8 |
| Peak CU period | 15 | CU | 4.5 | 4.5 | 5.5 | 4.5 | 5.0 | 6.3 | 6.5 | 5.0 |
| | | ER | 64 | 64 | 30 | 69 | 18 | 25 | 26 | 18 |
| | 10 | CU | 3.8 | 3.8 | 4.9 | 3.4 | 3.3 | 5.3 | 5.4 | 3.3 |
| | | ER | 51 | 51 | 19 | 50 | 12 | 20 | 20 | 12 |

water slightly less than TRAM.

## CU determined by the water balance method

Irrigation practices surveyed in Sakata area (sandy soil) and Hamamatsu area (clayey soil) are shown in Table 2. For vegetables, an intensive irrigation at an early stage of growth and water-saving culture in a later stage of growth are practiced in order to achieve scheduled production and marketing.

CU determined by the water balance method is shown in Table 3. An average CU for the whole growing period is about 1.5–2.0 mm/day, with a peak value of about 4–5 mm/day. According to Table 3, the ratio of effective rainfall is expressed to be very small. However, simple comparisons can not be made, because the ratio varys with the amount and distribution of rainfalls during the survey period. In addition, the ratio in an irrigated area tends to be expressed lower than that in an non-irrigated area, because rainfalls immediately after the irrigation become ineffective.

## Closing remarks

Determination of CU by the water balance method, proposed in this paper, is considered as an excellent method and can be used for the practical purpose as a basic datum for designing water requirement. Surveys on irrigation practices of farmers seem to be able to obtain more or less similar results. However, as to the ratio of effective rainfall, it is not supported by sufficient information of experimental results and therefore further studies under the condition of actual crop cultivation are desirable to be done.

## References

1) Kawano, H.: A rationalization of designing water requirement. The 7th plenary meeting for studying upland farm irrigation. 17–28 (1974) [In Japanese].