

Estimation of Actual Irrigation Requirement by the Water Balance Method

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Actual irrigation situation in a typical upland irrigation district was estimated by the water balance method during the 1993 rainy and the 1994 dry year periods. Soil moisture conditions were analysed for cases where daily district water use was supplied to all the cropped upland farms, and to reduced irrigation area percentages. Consumptive use was obtained through monthly weighted crop coefficients used to reduce Penman's potential evapotranspiration. The moisture budget was examined at three levels of total readily available moisture, TRAM, i.e., 20, 30 and 40 mm; the effect of upward capillary rise was also considered. The results of this study indicated that the actual moisture conditions in upland irrigated farms is influenced by irrigation area, cropping pattern, stage of crop growth and upward capillary rise in the farms. Actual irrigated area was within the range of about 44 to 100% of cropped area while upward capillary rise was between 0.1 and 1 mm day⁻¹; TRAM level of 30 to 40 mm was considered most appropriate for the district. Monthly effective rainfall percentages from the water balance method were fairly close to that determined by the basic irrigation requirement method for some months. Basic irrigation requirement may therefore be considered to incorporate capillary water contribution.

Keywords: Upland irrigation; TRAM; Water balance; Capillary water; Effective rainfall

1. INTRODUCTION

In upland areas of Japan, the procedure of estimating water requirements for supplemental irrigation involve field determination of crop consumptive use through soil moisture depletion in an effective soil layer, the soil moisture characteristic curve, and weather characteristics. Consumptive use for each crop is determined from the daily tensiometric observations of soil moisture during the irrigation period. Since daily consumptive use is affected by meteorological conditions in the measurement period, factors relating to weather such as rainfall, sunshine hours, humidity, and windspeed are also measured. The average soil moisture decrease in a period which can be regarded identical in cultivation management level is regarded as the daily consumptive use of water by the crop (MAFF, 1982).

Actual water use in most upland irrigation districts are widely said to be much less than the designed irrigation depth determined by the moisture depletion method which is crop-based. This situation has been partly clarified by Yomota and Ndegwa (1995) through the analysis of actual water quantity supplied to irrigators on a

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district basis. The highest monthly average actual water use was about 1.4 mm day^{-1} in a period of 6 years while the peak designed water use of the various crops grown was $3 - 5 \text{ mm day}^{-1}$; basic irrigation requirement, i.e. district water use, was about $1 - 2 \text{ mm day}^{-1}$. The low usage of irrigation water may be partially explained by the response of farmers to rainfall events during the crop growing seasons; however, rainfall events alone may not explain the low water use trend. The situation was further clarified through an on-farm questionnaire survey on factors which influence water use in a typical irrigation district (Ndegwa and Yomota, 1995). The aim of the present study was to estimate an actual water use situation from the view-point of water balance in a typical upland irrigation district. Basic meteorological variables and actual water application quantities in the district were used as a basis for the water balance during the 1993 and 1994 early crop growing seasons. Actual areas under the various crops grown in the district were obtained from the water users association.

2. MATERIALS AND METHODS

2.1. Study area

The study area was the Tohaku and Daiei upland irrigated areas of the Tohaku National Irrigation Project. The project is situated in the central part of Tottori Prefecture, Japan, at about 35.3° north, longitude of about 133.5° east and at an elevation of about 10 to 150 metres above sea level. The average annual precipitation is about 2,614 millimetres; however, during extreme weather conditions, successive no-rain days can be as long as 46 days in a period of one in ten years. The main soils of the district are 'Kuroboku', i.e. andosols, which are black soils of volcanic origin. Water melon is the main early season crop and is usually planted in vinyl houses; other crops are mostly grown in the open fields and include lawn grass, vegetables, and fruit trees such as pears.

Water for irrigation was supplied from a dam reservoir (Nishitakao Dam) and is then pumped to 6 farm-ponds located on high grounds; the water is then supplied from the ponds to the upland fields on an on-demand basis. Much of the responsibility for managing water supplies is hence passed on to the farmers; intermittent irrigation is practised in the farms. The quantity of water (m^3) supplied to farmers/irrigators was measured by automatic water stage recorders installed on the farm-ponds while daily rainfall was measured at the reservoir site. Data on temperature, humidity, windspeed, and sunshine hours were obtained from the weather bureau nearest to the irrigation district.

The trend of daily water use is presented in Fig. 1 for the 1993 and 1994 early crop growing season. The year of 1993 was characterized by countrywide heavy rainfall while 1994 was a low rainfall year in which water supply was limited in most places. During the 1993 period, rainfall was relatively low in April and increased in May to mid-June while July and August were rainy. The 1994 period had a long dry period in July to early August.

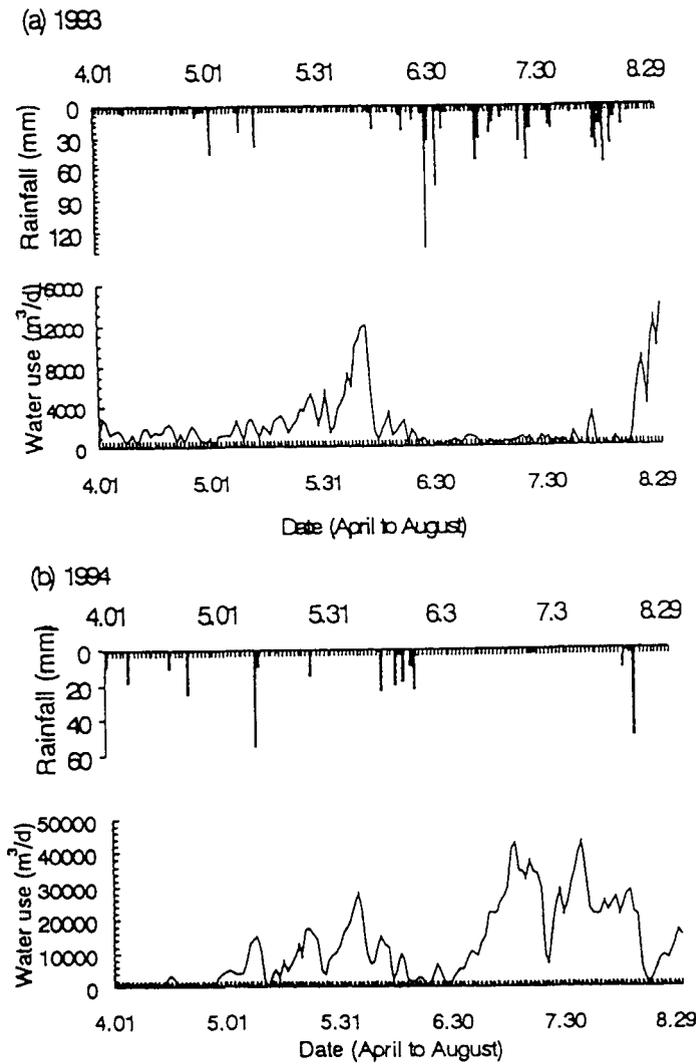


Fig. 1. Daily variation of irrigation quantity and rainfall in (a) 1993 and (b) 1994, Tohaku irrigation district.

2.2. Cropped area and cropping pattern

The area of various crops grown in the irrigation district are presented in Table 1 for the 1994 early season, i.e. spring - summer, crops. The cropped area was about 816.4 ha and was hence less than the total planned area of about 1200 ha; this implied that only about 68% of the planned area had been completed.

Table 1. Cropped area (ha) in the Tohaku irrigation district, 1994.

	Water meon	Lawn grass	Pear	Others	Total (ha)	A/W crops
Total area (ha):	363.1	283.3	59.1	110.9	816.4	295.7
Area percentage (%)	44.5	34.7	7.2	13.6	100.0	(36.2)**

* Data from water users association management office, Tohaku irrigation district.

** Area percentage of autumn-winter (A/W) crops (ha) to total area of early season crops.

The planting date of water melon is spread from the first week of March to about mid-April in order to continuously supply the product to the market and for distribution of farm labour; the harvesting period is mostly between mid-June and end of July. Water melon hence requires most of the irrigation water in the month of May and less in June depending on the planting date. Water requirements of melon were wholly supplied through

irrigation while field crops such as vegetables, lawn grass, and fruit trees mostly depended on rainfall and were supplemented by irrigation during periods of continuous drought days. Tree crops are usually deep rooted and may require less irrigation water except during the fruit formation stage.

2.3. Estimation of consumptive use

Water use of the various crops grown was estimated by reducing potential evapotranspiration by the crop coefficients during the growth period. The estimation of evapotranspiration from a crop, ET_{crop} , is based on the idea that a correlation exists between consumptive use and potential (or reference) evapotranspiration rate, i.e.

$$ET_{crop} = K_c \cdot ET_{pen} \quad (1)$$

where ET_{pen} is Penman's potential evapotranspiration. The ratio of consumptive use to potential evapotranspiration, i.e. crop coefficient, K_c , accounts for the effect of crop characteristics on crop water requirements and depends on the type and stage of crop growth. Daily potential evapotranspiration was determined by Penman method from data on temperature, humidity, windspeed, and sunshine hours obtained from the weather bureau nearest to the irrigation district.

Monthly K_c factors for the various crops in the district were obtained from Doorenbos and Pruitt (1977) and are presented in Table 2. The K_c factors for pear are for an area that is humid, has strong wind, and without a ground cover crop. Since water melon is planted in stages, representative monthly crop coefficients which corresponded to mid-points of a crop coefficient curve were used, i.e. about 0.45, 0.95, and 0.65 for a crop planted in late-March and harvested in late June/early July. High water requirements of earlier planted crops could hence be compensated for by lower requirements of later planted crops. Lawn grass was assumed to transpire at the potential rate throughout the season.

Since July is the major harvesting period of water melon, all water used in July was assumed to have been applied to the field crops especially to lawn grass and pear which are grown throughout the season. Late season crops such as autumn-winter vegetables are usually planted in August after harvesting water melon and may require irrigation water during the planting period. Irrigated areas used in August were for lawn grass, pear and autumn-winter crops presented in Table 1, however, cropped area of water melon and 'other crops', i.e. 474 ha, was higher than that of autumn-winter crops, i.e. 295.7 ha; the difference was assumed to be fallow area and was about 21.8% of total cropped area.

Areal monthly K_c factors were obtained by weighting the various individual crop coefficients by the respective cropped area percentages. The daily consumptive use in the district was obtained by multiplying daily ET_{pen} with the respective areal monthly K_c factor.

Table 2. Monthly crop coefficients, Kc, of the various crops

Crop	Area %	April	May	June	July	August
Melon	44.5	0.45	0.95	0.65	---	
Lawn grass	34.7	1.0	1.0	1.0	1.0	1.0
Pear	7.2	0.45	0.55	0.75	0.80	0.80
Others (veg.)	13.6	0.45	0.95	0.80	---	
A/w crops (veg.) (36.2)						0.35
Kc weighted on area %		0.64	0.94	0.80	0.40	0.53

Kc factors from Doorenbos and Pruitt (1977).

Consumptive use estimates the amount of water the crops use during a given time period and was considered to be potential, i.e. at ET_{crop}, when plant transpiration was not limited by soil water. Actual transpiration rate may fall below the potential rate as soil moisture content decreases when the evaporating demands of the atmosphere are high such as on a clear day though soil moisture supply might be considered adequate (Denmead and Shaw, 1962). To account for the condition where soil water is limiting, a soil moisture stress coefficient was proposed, i.e. K_s, which takes account of the effect of depleting soil moisture in the root zone (Hanks, 1992). The K_s coefficient is the ratio of actual consumptive use of water, ET_a, to crop evapotranspiration, ET_{crop}, or,

$$ET_a = K_s \cdot K_c \cdot ET_{pen} \quad (2)$$

However, since no soil moisture measurements were carried out in the irrigated fields, non-limiting soil moisture conditions were assumed, i.e. K_s = 1.0.

2.4. Irrigated area

Daily water applications on a district basis may be spread on an area that is less than the planned one depending on irrigation water requirements on the individual farms since the supply is on an on-demand basis. Irrigation area in the district can therefore change with cropping pattern and stage of growth of the crops. Two field situations were considered for the soil moisture balance in the district; in the first case, all crops grown in the 816.4 ha were assumed to be irrigated in April, May and June while only lawn grass and pear were irrigated in July, i.e. 342.4 ha or 41.9% of cropped area; crops irrigated in August were lawn grass, pear, and autumn-winter crops, i.e. 638.1 ha or 78.2% of cropped area. In this case, daily irrigation depth (mm) was obtained from the daily district water quantity (m³) divided by the respective monthly cropped area.

The second case assumes that in a particular month, not all crops need irrigation water. Most of the irrigation water used in April, May and June was assumed to have been applied to water melon. This assumption was based on the expectation that water requirements of water melon were mostly supplied through irrigation since the crop is mostly grown in vinyl houses. Daily irrigation depths were hence obtained by dividing the daily district water supply by area under water melon, i.e. 363.1 ha or about 44.5% of the cropped area, for April, May and June. All water used in July and August was similar to the situation in case one.

2.5. Effective range of rainfall

In general, it can be said that rainfall in excess of storage capacity in the soil is not available to meet the consumptive water requirement of a crop since it is lost as runoff, deep percolation or both. The effective range of

daily rainfall was hence taken to have an upper limit corresponding to the TRAM level; three levels of TRAM were used, i.e. 20, 30, and 40 mm. Two cases of the lower limit of daily rainfall were considered; in case one, all throughfall rain within the TRAM level was assumed to infiltrate into the soil, i.e. rainfall between zero (0) mm and TRAM. In the other case, a maximum of about 5 mm of rainfall was assumed to be intercepted by the crop canopy and is hence lost through evaporation; intercepted rainfall does not contribute to consumptive use directly since it does not infiltrate into the soil surface. The actual lower limit of effective range of daily rainfall was hence considered to be between 0 and 5 mm rainfall losses. Rainfall within the effective range is potentially available to recharge soil moisture to TRAM level in a given period.

The amount of rainfall that infiltrates into the soil and replenishes the soil moisture deficit in the rootzone is treated as effective rainfall. Monthly and seasonal effective rainfall percentages were computed from daily values as effective rainfall (mm) divided by rainfall within the respective effective ranges of 0 and 5 mm up to TRAM.

2.6. Water balance computation

At the beginning of the water balance computation, all soil moisture stored in the irrigated farmlands was assumed to be at the TRAM level on 1st April. The water balance was computed for each day of the month by subtracting the daily consumptive use from the sum of the previous day's balance, the day's rainfall within the effective range and irrigation depth. Soil moisture of the i 'th day, SW_i , may be presented as

$$SW_i = SW_{i-1} + P_i + I_i - ET_i + \text{upward capillary rise} \quad (3)$$

where SW_{i-1} is the previous day's balance, P_i is precipitation in the effective range, I_i is irrigation, and ET_i is consumptive use (from eq.1); $\Delta SW (= SW_i - SW_{i-1})$ is the net soil moisture change. The budgeting procedure continues, however, moisture of the day was not allowed to have negative values, it was set to zero when TRAM was depleted. When SW_i was greater than TRAM, then SW_i was set equal to the TRAM level.

In volcanic ash soils, a considerable amount of water is transferred from the wet subsoil to the surface during a dry season (Terasawa, 1962; Kira et al., 1963). During periods of continuous drought days, consumptive use was assumed to be sustained by irrigation applications and supplemented by capillary water from the wet subsoil, otherwise moisture stress conditions would occur. Upward capillary rise was hence computed as the difference between evapotranspiration and irrigation depth of the day during periods of prolonged drought days when TRAM was depleted. Capillary rise was assumed to be negligible when soil moisture was within the TRAM level. Cases were also considered where some upward capillary rise was assumed to occur when TRAM was not depleted such as 0.1, 0.3, 0.5, 0.7, and 1 mm day⁻¹.

2.7. Basic irrigation requirement and effective rainfall

Effective rainfall was also computed from the point of view of areal water use in the district. During periods of continuous drought days, the irrigation quantity that is actually needed, i.e., basic irrigation requirement, Q_o , can be estimated by various methods described by Yomota and Ndegwa, (1995). The difference between the basic irrigation requirement and the actual irrigation application during the month is the quantity of water that rainfall has contributed to the consumptive water use, i.e., effective rainfall

The monthly effective rainfall percentages obtained by the water balance method were compared with those from areal water use where Q_o was obtained by the multiple linear regression method. Daily rainfall used in the determination of Q_o was between 5 mm and TRAM level.

3. RESULTS AND DISCUSSION

3.1. The water balance model

The situation where irrigation water was distributed to all planned area, with consumptive use estimated as Penman's potential evapotranspiration, and no upward capillary rise considered, TRAM was depleted for unreasonably long periods of about 14 and 29 days for early cropping season of 1993 and 1994, respectively. The following field situations were then considered:

3.1.1. Soil moisture variation with cropping pattern in irrigated area (Case 1)

The variation of soil moisture for TRAM levels of 20, 30 and 40 mm is presented in Fig. 2 for 1993 and 1994 early cropping seasons for the case where 816.4 ha was assumed to be irrigated between April and June; zero (0) mm rainfall losses were allowed while upward capillary rise was considered negligible when TRAM was not depleted. During the 1993 season, the planned soil moisture deficit of 20 mm was reached on 4/20 to 4/21 and on 4/25 to 4/27 for a period of 2 and 3 days, respectively; however, moisture was still within the planned range for the 30 and 40 mm cases. The three TRAM levels reached the critical moisture level on 5/31 to 6/12, a period of 13 days. When about 5 mm rainfall losses were allowed, the three TRAM levels reached the critical moisture level on 5/31 to 6/13, a period of 14 days.

In the 1994 season, TRAM levels of 20, 30 and 40 mm were depleted from 5/02, 5/04 and 5/07 upto 5/10, i.e. a period of 9, 7 and 4 days, respectively. All the three moisture levels reached the critical moisture level on 5/30 up to 6/12, i.e. for 14 days. However, TRAM level of 20 mm was depleted again on 7/01 to 7/04 for 4 days.

During the 1994 season, rainfall between 6/30 and 8/18 was about 7 mm spread over 3 days, hence soil moisture was mostly replenished by irrigation during this period. However, excessive water losses were observed from the water balance between 7/13 and 8/04, i.e. for 23 days. This may have been due to various factors such as soil moisture carried over from June, a low monthly K_c factor in July and/or the irrigated area of 41.9% for July was low; some of the water melon crop may have been irrigated in July. The period of excess water losses was reduced to about 7 days for TRAM levels of 20 and 30 mm and to 5 days for 40 mm level when about half of the area under water melon, i.e. 181.5 ha, was assumed to have required irrigation in July; K_c for the crop was taken as 0.65 which increased the weighted K_c for July from 0.40 to 0.54.

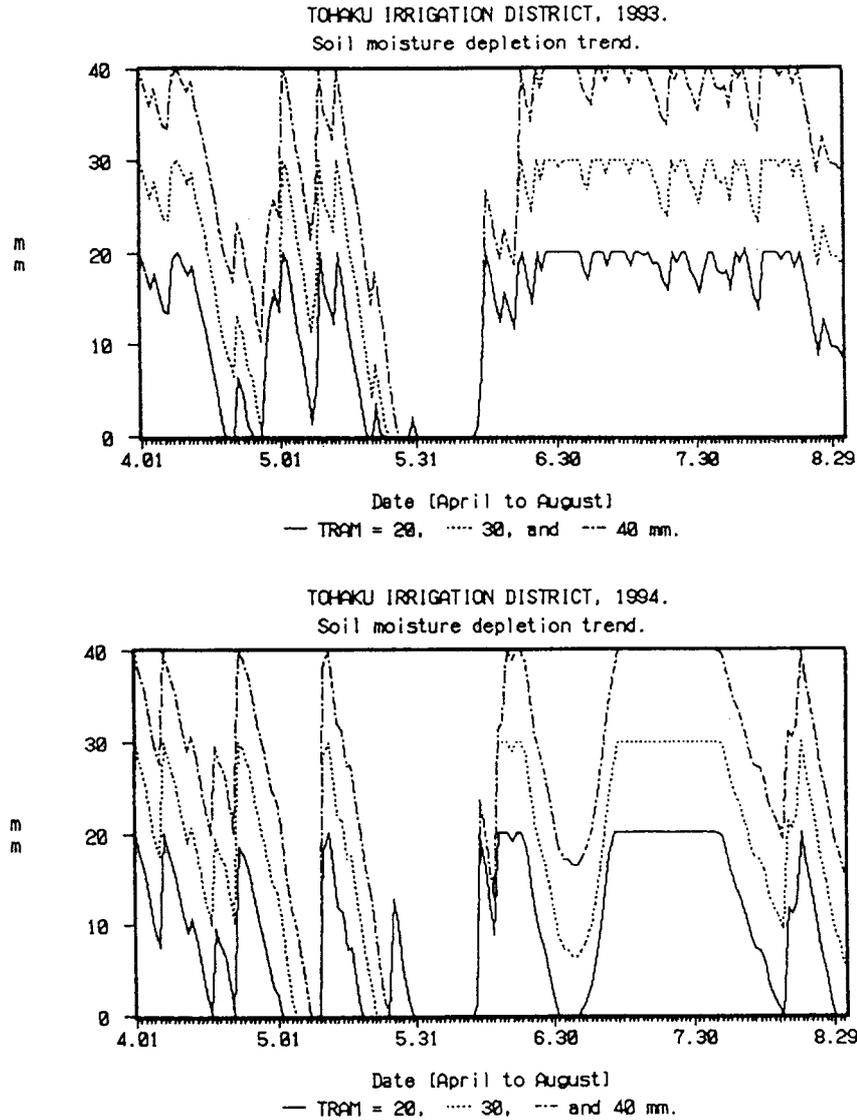


Fig. 2. Daily available soil moisture trend for TRAM 20, 30, and 30 mm for (a) 1993 and (b) 1994 seasons for irrigated area of 816.4 ha between April and June.

3.1.2. Soil moisture in reduced irrigated area percentages (Case 2)

The effect of reducing the irrigated area percentage was to concentrate the district water supply to a smaller area and corresponded to an increase of irrigation depth in the farms. Soil moisture trend for reduced irrigation area percentages is presented in Fig.3 when about 44.5% of the area was assumed to have been irrigated from April to June; zero (0) mm rainfall losses were allowed while upward capillary rise was considered negligible when TRAM was not depleted.

In the 1993 season, the planned moisture deficits of 20, 30 and 40 mm reached critical levels on 5/24, 5/26 and 5/28 upto 5/29, i.e. a period of 6, 4 and 2 days, respectively, when about 5 mm rainfall losses were allowed. However, all the three TRAM levels were depleted from 5/31 to 6/09, i.e. for 10 days; this was the longest period when soil moisture was beyond the planned deficits compared to about 13 to 14 days when the whole cropped area in the district was assumed to have been irrigated during the period.

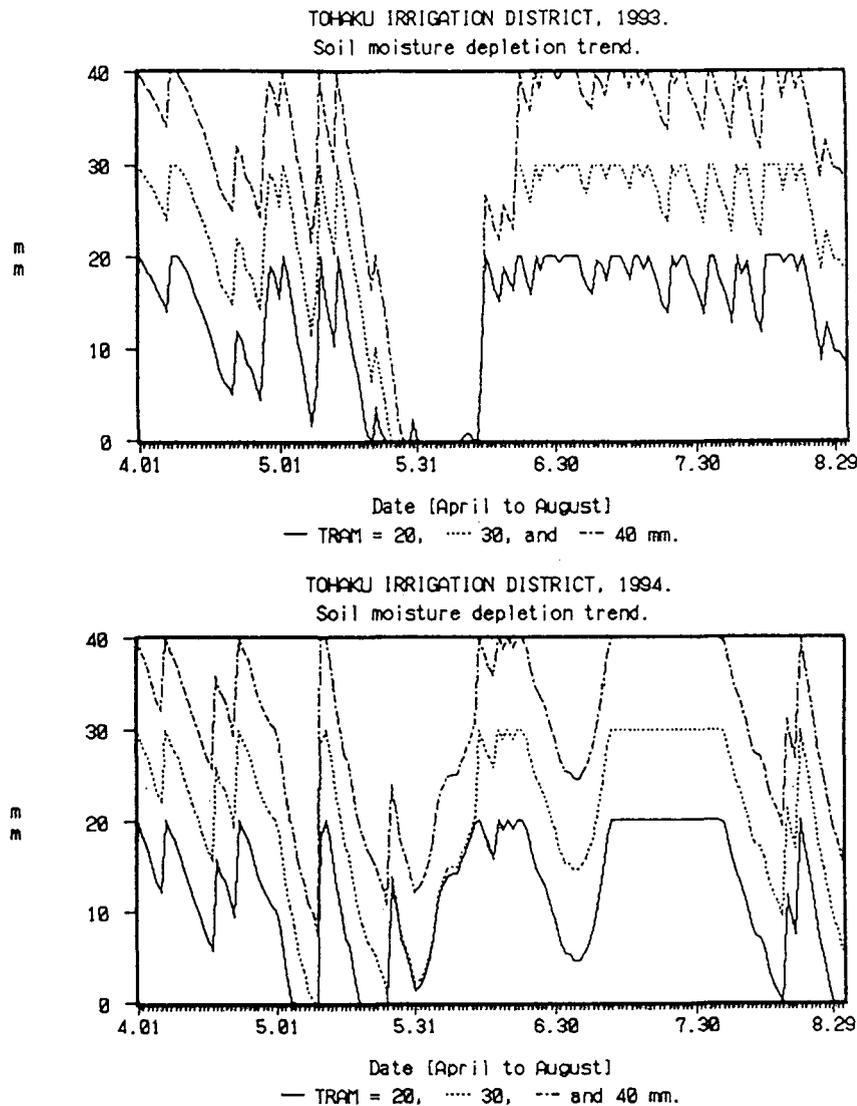


Fig. 3. Daily available soil moisture trend for TRAM 20, 30, and 30 mm for reduced irrigation area percentages in (a) 1993 and (b) 1994 seasons (no capillary water contribution considered).

In the 1993 season, the planned moisture deficits of 20, 30 and 40 mm reached critical levels on 5/24, 5/26 and 5/28 upto 5/29, i.e. a period of 6, 4 and 2 days, respectively, when about 5 mm rainfall losses were allowed. However, all the three TRAM levels were depleted from 5/31 to 6/09, i.e. for 10 days; this was the longest period when soil moisture was beyond the planned deficits compared to about 13 to 14 days when the whole cropped area in the district was assumed to have been irrigated during the period.

In the 1994 season, planned moisture levels of 20 and 30 mm were depleted from 5/05 and 5/09 to 5/10, i.e. for 6 and 2 days, respectively. The moisture level for TRAM of 20 mm was again depleted between 5/19 and 5/25, i.e. for 7 days; the TRAM levels of 30 and 40 mm were not depleted in the period. The 0 mm allowed rainfall losses indicated a similar moisture trend to the 5 mm case. Increased irrigation depth hence reduced the number of days when soil moisture was beyond the critical level from about 15 days in case 1 to 7, 2 and 0 days for TRAM levels of 20, 30 and 40 mm, respectively.

3.1.3. Upward capillary contribution

The maximum number of days when soil moisture was beyond the critical level are presented in Table 3 for upward capillary rise of 0.1 to 1 mm day⁻¹ for the three TRAM levels for reduced irrigated area percentages (case 2) during the 1993 and 1994 seasons; about 5 mm rainfall losses were allowed. Increased upward capillary contribution reduced the number of days within which moisture in TRAM level was depleted, however, TRAM of 20 mm indicated longer days compared to the other two moisture levels. The most reasonable level of TRAM was hence considered to be between the 30 and 40 mm levels since this range indicates the least number of days within which TRAM is depleted. Though upward capillary water contribution can vary during the cropping season depending on climate, TRAM of 30 to 40 mm can have a contribution of about 0.1 to 1 mm day⁻¹ with an allowable moisture depletion period of less than 3 days as indicated by the 1993 and 1994 seasons.

Table 3. Upward capillary rise (mm day⁻¹) and highest number of days of TRAM depletion.

Year	1993				1994
	0.1	0.5	0.7	1.0	0.1
Upward capillary rise (mm day ⁻¹)	0.1	0.5	0.7	1.0	0.1
TRAM level (mm)	20	10	6	5	4
	30	10	5	5	3
	40	10	3	0	0

3.1.3. Effective rainfall from water balance (WB) method

Monthly and seasonal effective rainfall percentages for TRAM of 30 and 40 mm are presented in Table 4 for reduced crop areas (case 2) and upward capillary rise of 1.0 and 0.1 mm day⁻¹ for 1993 and 1994, respectively; 5 mm rainfall losses are allowed. Monthly effective rainfall percentages were relatively low in April and increased in May before decreasing again in June for the respective years. The results suggest that rainfall effectiveness can be increased by changing irrigation area percentage in response to weather conditions and by considering the cropping pattern and stage of growth of the crops. However, seasonal effective rainfall percentages were low may be due to the assumption of a constant upward capillary rise which may actually be low during rainy periods.

Table 4. Monthly and seasonal effective rainfall percentages for reduced cropped area between April and June (5 mm rainfall losses allowed, upward capillary rise of 1.0 and 0.1 mm day⁻¹ for 1993 and 1994, respectively).

Year	TRAM (mm)	April	May	June	July	August	Total (seasonal)
		Effective rainfall percentage (%)					
1993	30	8.6	56.3	33.1	71.1	23.5	31.5
	40	8.6	48.6	36.0	72.3	19.4	30.5
1994	30	42.8	76.5	18.1	0	17.5	36.2
	40	42.8	67.3	18.1	0	14.4	34.2

3.2. Basic irrigation requirement model

3.2.1. Effective rainfall from Q_0 method

The maximum basic irrigation requirements of the district, Q_0 , were obtained for the 1993 and 1994 irrigation seasons and indicate the capacity of irrigation requirements in the respective months. Monthly effective rainfall and effectiveness percentage for TRAM of 30 mm are presented in Table 5 for 5 mm allowed rainfall

losses; Q_o was determined from the multiple linear regression method. TRAM of 30 mm was chosen since the moisture trend within the 30 to 40 mm TRAM level indicate a low depletion number of days as observed in 3.1.3.

Table 5. Effective rainfall from basic irrigation requirements, Q_o (mm day⁻¹), for TRAM of 30 mm during the 1993 and 1994 seasons (816.4 ha irrigated area)

Month	April	May	June	July	August
Year with largest value	1993	1994	1994	1994	1994
Basic irrigation ($N.Q_o$), mm	11.4	39.3	44.7	()	86.4
Actual irrigation applied (Q_i), mm	9.1	32.2	32.5	81.1	72.4
Rainfall amount, mm	52.0	88.0	103.0	7.0	67.0
Effective rainfall range (R_o), mm	52.0	63.0	103.0	7.0	42.0
*Calculated effective rain, mm	2.3	7.1	12.2	()	14.0
Effective rainfall percentage, %	4.4	11.3	11.8	0.0	33.3

() Q_o could not be determined from the multiple linear regression (MLR) method; there was no daily rainfall of 5 mm or more in July, 1994.

*Effective rainfall (mm) = Basic irrigation quantity - Actual irrigation quantity.

Effective rainfall percentage = Effective rainfall (mm) divided by monthly total rainfall (R_o) in the range of 0 to 30 mm.

3.3. Comparison of effective rainfall from WB and Q_o methods

Monthly effective rainfall percentages were computed by the Q_o method for the respective reduced irrigation area percentages (case 2) for TRAM of 30 mm. The monthly effective rainfall percentages from the water balance (WB) and basic irrigation requirement methods are presented in Table 6.

Table 6. Effective rainfall percentage from the water balance (WB) and the basic irrigation requirement (Q_o) methods for TRAM of 30 mm (5 mm rainfall losses allowed)

Month	April	May	June	July	August
Year	1993	1994	1994	1994	1994
Irrigation area (%)	44.5	44.5	44.5	41.9	78.2
WB method	8.6	76.5	18.1	0.0	17.5
Q_o method	9.8	25.3	26.7	0.0	42.5

The WB method indicated higher effective rainfall percentage in May compared to the Q_o method; however, the two methods were fairly close especially in April and June. This indicated that basic irrigation requirement may be considered close to moisture conditions in the farms and is hence influenced by irrigation area, cropping pattern and stage of crop growth in the district. Since the field moisture conditions also included upward capillary rise, then the district water use may be considered to incorporate capillary water contribution.

4. SUMMARY AND CONCLUSIONS

The actual irrigation situation in an upland district was estimated through a simple soil moisture budget during the 1993 and 1994 early crop growing seasons. The following specific conclusions were deduced from the study:

1. For the situation where irrigation water was distributed to all planned area, consumptive use estimated as Penman's potential evapotranspiration, and no upward capillary rise considered, TRAM was depleted for long periods of about 14 and 29 days for early season of 1993 and 1994, respectively.

2. When the daily district water quantity was applied to all the cropped area between April and June, and crop growing stages were considered, the longest period of TRAM depletion was between 13 and 15 days in early June of 1993 and 1994 cropping seasons.
3. When the district water supply was distributed to reduced cropped areas, the period in which TRAM was depleted decreased from about 14 to 10 days for the three TRAM levels in the 1993 season and from 15 to 7, 2 and 0 days for TRAM levels of 20, 30, and 40 mm, respectively, in the 1994 season.
4. Irrigation of reduced crop area, consideration of crop growing stages and upward capillary rise further reduced the period of TRAM depletion to less than 3 days for TRAM of 30 mm while TRAM of 40 mm was not depleted; TRAM of 20 mm still indicated longer periods of TRAM depletion.
5. Monthly effective rainfall percentages from the water balance method were fairly close to that determined by the basic irrigation requirement method for some months especially in April and June.

The results of this study indicated that the actual moisture conditions in upland irrigated farms is influenced by irrigation area, cropping pattern, stage of crop growth and upward capillary rise in the farms. Actual irrigated area can be within the range of about 44 to 100% of cropped area while upward capillary rise can be between 0.1 and 1 mm day⁻¹. However, it would be appropriate to monitor moisture levels in a typical farm throughout an irrigation season to observe actual soil moisture trends especially during periods when TRAM levels are likely to be depleted. Since the field moisture conditions also included upward capillary rise, then the basic irrigation requirements may be considered to incorporate capillary water contribution.

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REFERENCES

- Denmead, O.T., and Shaw, R.H., 1962. Availability of water to plants as affected by soil moisture content and meteorological conditions. *J. of Agronomy*, vol. 54: 385-390.
- Doorenbos, J. and Pruitt, W.O., 1977. Crop water requirements. FAO Irrigation and Drainage paper No. 24, Rome, pp38-46, 61-62.
- Hanks, R.J., 1992. Applied soil physics. Soil water and Temperature applications. 2nd Edition. Springer-Verlag, New York. pp123-124.
- MAFF, 1982. Design Criteria for Upland Irrigation. Bureau of Infrastructure Improvement, Ministry of Agriculture, Forestry and Fisheries, Government of Japan, Tokyo (in Japanese).
- Kira, Y., Soma, K., and Takeda, H., 1963. On the relationships between moisture fluctuation and evapotranspiration in the Kanto-loam volcanic ash soil. *Trans. Agric. Eng. Soc. Jpn.* 7: 81 - 86. (in Japanese with English summary).
- Ndegwa, G.M., and Yomota, A., 1995. Causative factors of low water use in a typical upland irrigation district of Japan. *Journal of Irrigation, Drainage and Reclamation Engineering*. Tokyo, Japan. (Submitted for publication).
- Terasawa, S., 1962. Studies on the movement of moisture in upland soils. *J. Sci. Soil Manure Jpn.* 33: 456-460 (in Japanese).
- Yomota, A. and Ndegwa, G.M., 1995. Water use for upland irrigation in a humid region of Japan. *Journal of Agricultural water management*. Elsevier Science Publishers, Amsterdam, 28 (3): 185-200.