Irrigation Schedules and Conservation Management for a Pilot Farm in the Mu Us Shamo Desert: Control of Desertification and Development of Agriculture in Arid Land Areas in China

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Irrigation Engineering and Rural Planning No. 25, 1993
The Japanese Society of Irrigation, Drainage and Reclamation Engineering

Paper

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Summary As part of the joint research conducted by Japan and China on the agricultural development of the Mu Us Shamo Desert, surveys on soil physical properties, moisture consumption, and the irrigation effect have been carried out on several plants in the fields of the Mu Us Shamo Research Center since 1985. Using these results, schedules were established for the irrigation of a pilot farm which was constructed at the Research Center in 1991.

The irrigation schedules were mainly based on the design guidelines of the Ministry of Agriculture, Forestry and Fisheries of Japan. As a result, the dimensions for the irrigation interval and water quantity per irrigation unit were estimated under the various plants in the pilot farm. From these design dimensions and the daily rainfall measured during the past 27 years, the net water requirement was estimated considering the effective rainfall. Also, the characteristics of the irrigation and rainfall could be explained by discussing the ratio of the total net water requirement to the total evapotranspiration, which subsequently indicates the factors in the pilot farm's future water management.

Finally, in order to prevent the salinization of soils and groundwater and to select suitable irrigation methods, some recommendations are given for better use of technology in conservation management for the pilot farm.

I. Introduction

Irrigation agriculture, which was called "a challenge and a defeat of the environment" in the ancient Mesopotamian plains, miraculously increases the agricultural production of arid land areas. On the other hand, irrigation agriculture can cause soil and water salinization to the extent that nothing can be grown, as well as soil erosion by wind and rainfall in the irrigation field.[1]

In the Mu Us Shamo Desert, there are plentiful groundwater resources which can be economically developed for use as irrigation water, because the depth of the groundwater is 2 to 3 m from the soil surface and the salinity concentration is between 500 and 600 ppm.[2,3] The irrigation agriculture which farmers have

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(Manuscript Received March 11, 1992, Accepted February 12, 1993)

carried out in these areas is mainly dependent upon groundwater, rather than on the rain which falls from June until September.

In this paper, the fundamental dimensions of irrigation schedules and conservation management are discussed for the pilot farm which was constructed in 1991 at the experimental fields of the Mu Us Shamo Research Center situated in the central part of the Mu Us Shamo Desert.[4]

II. Experiment Facility and Method

1. Irrigation Field and Method

The irrigation field was newly reclaimed on the leeward of the wood shelter on the

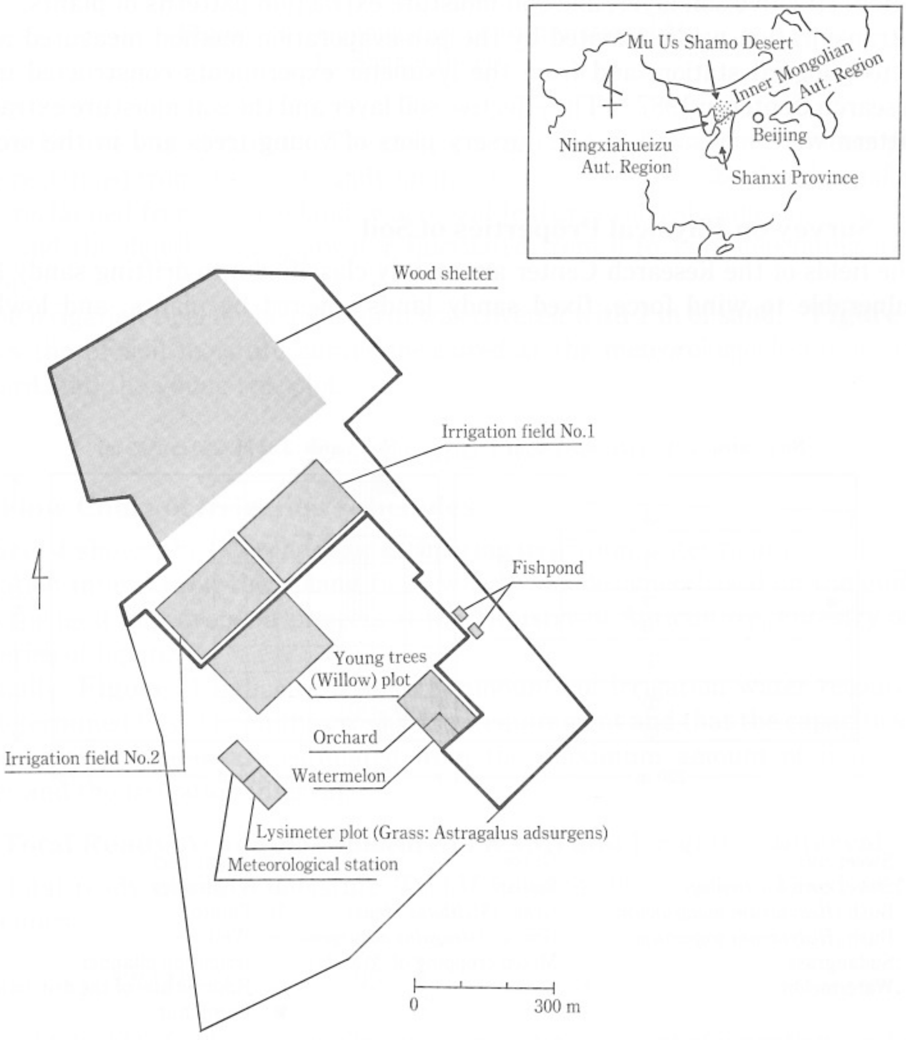


Figure 1 Pilot farm in Mu Us Shamo Desert

pilot farm, as shown in **Figure 1**. Irrigation water was pumped up from underground using wells. Some plants were cultivated in the No. 1 field using the surface and drip irrigation methods, and in the No. 2 field using surface and sprinkler irrigation methods, as shown in **Figure 2**.

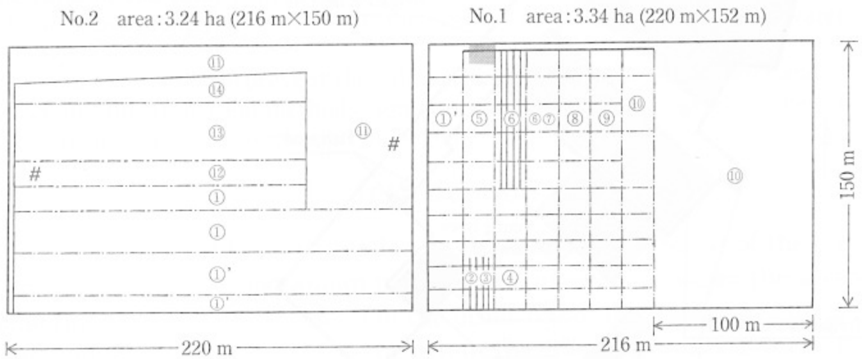
In the surface irrigation plots, where small irrigation channels were built into the blocks and each plot was divided into squares of 18 m by 15 m, in order to prevent deep percolation loss under the root zone in sandy soils. The surface method applied was basin irrigation. The plants cultivated were grass, vegetables, and young trees for revegetation.

2. Survey of Moisture Consumption

The purpose of a survey on moisture consumption is to estimate the evapotranspiration, effective soil layer, and soil moisture extraction patterns of plants. Evapotranspiration was estimated by the pan-evaporation method measured at the meteorological station, and from the lysimeter experiments constructed in the Research Center in 1987. The effective soil layer and the soil moisture extraction pattern were measured in the nursery plots of young trees and in the orchard reclaimed in 1983.

3. Survey on Physical Properties of Soil

The fields of the Research Center are mainly classified into drifting sandy lands vulnerable to wind force, fixed sandy lands covered by plants, and lowlands



① :Sweet corn
①' :Sweet corn for ensilage
② :Bush (*Hedysarum mongolicum*)
③ :Bush (*Hedysarum scoparium*)
④ :Sudangrass
⑤ :Watermelon
⑥ :Grass
⑦ :Radish
⑧ :Grass (*Melitotus albus*)
⑨ :Grass (*Astragalus adsurgens*)
⑩ :Mixed cropping of ⑧ and ⑨
⑪ :Grass
⑫ :Sugar beet
⑬ :Vegetables
⑭ :Potato
:Well
-·-:Irrigation channel
— :Emitter line of the drip irrigation
■ :Pump hut

Figure 2 Irrigation fields No. 1 and No. 2 on the pilot farm

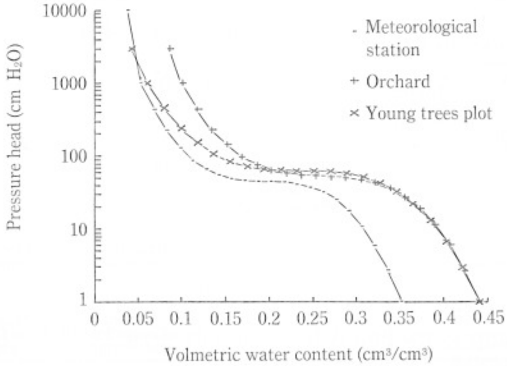


Figure 3 Soil moisture characteristics of Mu Us Shamo Desert

located between sand dunes. The meteorological station and the lysimeter plot were reclaimed from the fixed sandy land. The orchard and the young tree plots were reclaimed from the lowland, where soil textures ranged from sandy to clay loam and the depth of groundwater fluctuated from 0 to 1 m, depending upon season.

The irrigation field of the pilot farm was covered with 1 m of sand. **Figure 3** shows the pF-soil moisture curves measured at the meteorological station, the orchard, and the young tree plot.

III. Results and Discussion

1. Flow Chart of Irrigation Schedules

Figure 4 shows the flow chart for estimating irrigation water requirements and irrigation intervals on the upland field, which was designed based on the guidelines for land improvement projects of the Ministry of Agriculture, Forestry and Fisheries of Japan.[5]

Finally, **Figure 4** indicates that total amounts of irrigation water resources are determined based upon the gross water requirement and that the capacities of the irrigation system are estimated from the maximum amount of irrigation water and the irrigation interval.

2. Total Ready Available Moisture (TRAM) and Irrigation Interval

The total ready available moisture *TRAM* (mm) is shown below, based on the guidelines:

$$TRAM=(FC-Qw)\times D\times\frac{1}{Cp} \quad \cdots\cdots (1)$$

where FC (vol%)=field capacity, Qw (vol%)=moisture content of irrigation starting point, and D (mm) and Cp (%)=thickness and soil moisture extraction pattern of

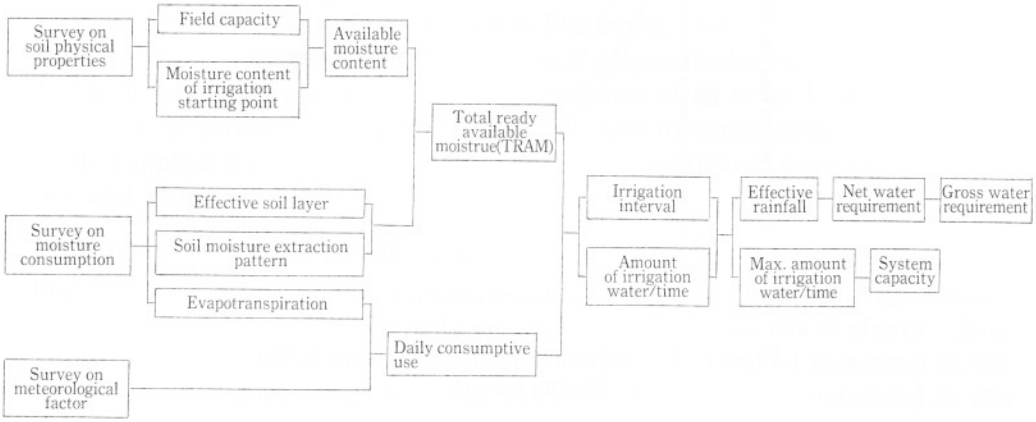


Figure 4 Flow chart for estimating irrigation interval and amount of irrigation water per time

important soil layer for growth of an effective soil layer, respectively. The irrigation interval Ii (day) using Eq. (1) is shown below:

$$Ii = \frac{TRAM}{\text{Max. of daily } ET} \quad \cdots\cdots (2)$$

where daily ET is the averaged value of the total amount of crop evapotranspiration in each month. As a result, the water quantity per irrigation Wq (mm) is arrived at as follows:

$$Wq = Ii \times (\text{daily } ET \text{ in each month}) \quad \cdots\cdots (3)$$

Using the results of the pan-evaporation method in the previous paper,[2] the daily ET was estimated for tomatoes, alfalfa, and grapes, as shown in **Table 1**.

Table 1 Estimation of daily evapo-transpiration of a few crops in the Mu Us Shamo Desert

		Apr.	May	Jun.	Jul.	Aug.	Sep.	TET
Monthly evaporation from a small pan (ϕ 20 cm) (Mean value for 20 years)		268.2	371.7	372.0	309.5	239.5	172.1	1,733.0 mm
Daily ET (mm/day)	Tomato		2.52	4.46	5.99	4.08		524.12 mm
	Grapes		3.24	7.44	5.99	4.64	3.44	756.22 mm
	Alfalfa	4.29	6.12	6.70	5.69	4.40	2.93	919.90 mm

Table 2 Effective soil layer and soil moisture extraction pattern

Plant	Effective soil layer	Soil moisture extraction pattern of important soil layer for growth *Cp*
Watermelon	40 cm	42.5% (Depth of 0 to 10 cm)
Grass, Willow	60 cm	22.5% (Depth of 0 to 10 cm)

Table 3 *TRAM*, irrigation interval *Ii* and water quantity *Wq*

Plant	*TRAM* (mm)	*Ii* (day)	*Wq* (mm)
Vegetables	19	3	18
Grass	35	5	34
Young trees	35	4	29

Available moisture content $(FC-Qw)$=7.9 vol%

It was assumed that the daily ETs for tomatoes, alfalfa, and grapes corresponded to the daily ETs for vegetables, grass and young trees in the irrigation field of the pilot farm.

Also, using the soil moisture depletion method, the effective soil layer and the soil moisture extraction pattern were estimated for watermelon, perennial grass (*Astragalus adsurgens*), and young willow trees, as shown in **Table 2**. It was assumed that D and Cp for watermelon, perennial grass, and willow corresponded to D and Cp for vegetables, grass, and young trees in the irrigation field of the pilot farm.

The *TRAM*, the irrigation interval Ii, and the water quantity per irrigation unit Wq are estimated using Eqs. (1) (2), and (3) and **Tables 1** and **2**, focusing on the irrigation fields of the pilot farm.[4] These results are shown in **Table 3**.

3. Effective rRinfall and Net Water Requirement

Net water requirement Wn (mm/day) is given as follows:

$$Wn = Wq - RO \quad \cdots\cdots (4)$$

where RO (mm) is daily effective rainfall. Using the numerical model in the previous report[6] and employing the data in **Table 3** and the daily rainfall from 1959 until 1985 measured at the Uxin Ju meteorological Station situated 16 km northrwest of the Research Center, the effective rainfall and net water requirement can be estimated.

Here, since Ii and Wq were the maximum values of the irrigation interval and the water quantity per irrigation unit in designing the irrigation schedules of the pilot farm, Wn and RO were also discussed for the cases of smaller than maximum values of Ii and Wq. As a result, the relationships among the effective rainfall,

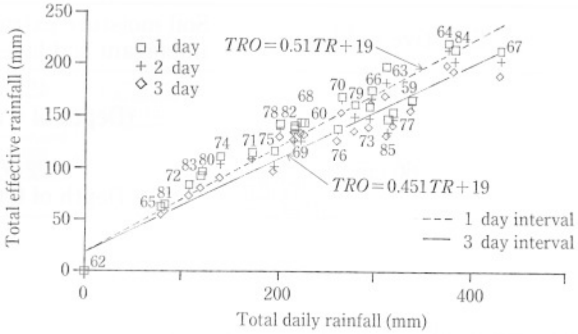


Figure 5 Relationship between the total effective rainfall *TRO* and the total daily rainfall *TR* (The numbers indicate the last two digits of historical years)

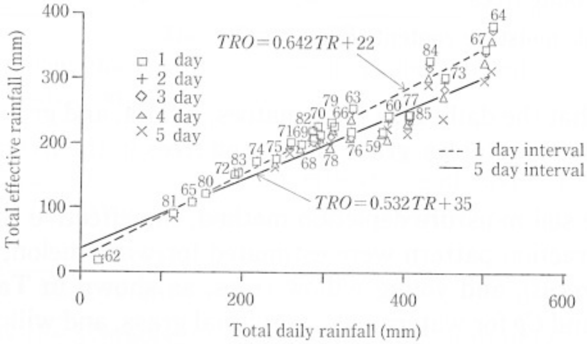


Figure 6 Relationship between the total effective rainfall *TRO* and the total daily rainfall *TR* (The numbers indicate the last two digits of historical years)

the daily rainfall, and the net irrigation water were established under the various cases of *TRAM*, *Ii*, and *Wq*.

Figure 5 indicates the relationship between the total effective rainfall *TRO* (mm) and the total daily rainfall *TR* (mm) during the irrigation period from May to August, under the conditions that vegetables were cultivated in the pilot farm which showed *TRAM*=19 mm and *Ii*=1 to 3 days. **Figure 6** indicates the conditions of *TRAM*=35 mm and *Ii*=1 to 5 days in the grass plot during the period from April to September. Since the relationship between *TRO* (mm) and *TR* (mm) is linear, *TRO* is assumed to have a specified irrigation interval *Ii* as follows:

$$TRO = a \times TR + b \quad \cdots\cdots (5)$$

where a, b are coefficients of the empirical equation: a is the slope of *TRO* to *TR*, and b is an intercept, and assumed to be the soil moisture holding capacity before the irrigation period and to be smaller than *TRAM*. **Tables 4** and **5** show the

Table 4 Irrigation interval and a, b ($TRAM$=19 mm of vegetables)

Irrigation interval	a	b
1 day	0.510	18.5
2 day	0.479	18.5
3 day	0.451	18.5

Table 5 Irrigation interval and a, b ($TRAM$=35 mm of grass)

Irrigation interval	a	b
1 day	0.643	22.0
2 day	0.625	23.8
3 day	0.608	26.5
4 day	0.569	31.4
5 day	0.532	35.0

numbers for a and b where $TRAM$=19 mm in the vegetable plot and $TRAM$=35 mm in the grass plot, respectively.

Next, the water balance equation is given in the effective root zone as follows:

$$TET = TI + TR - TD + (M1 - M2) \quad \cdots\cdots (6)$$

where TET (mm), TI (mm) and TD (mm) are the total amounts of the daily ET, the water quantity per irrigation is Wq, and the percolation loss is D during the irrigation period. $M1$ (mm) and $M2$ (mm) are soil moisture content on the first and the last day of the irrigation period, respectively. Eq. (6) implies that $(M1-M2)=0$ when the irrigation period becomes longer. If there is not deep percolation loss, TI becomes total amount of net water requirement during the irrigation period TWn (mm) indicating $TRO=TR-TD$. As a result, Eq. (6) is given as follows:

$$\left. \begin{aligned} TWn &= TET - a \times TR - b \\ &= TET - TRO \end{aligned} \right\} \quad \cdots\cdots (7)$$

Using the numerical model,[6] the relationship between the TWn and TR are shown in **Figure 7** under $TRAM$=35 mm in the grass plot. Comparing the results of the model and Eq. (7) with the data for a and b of the Ii=1 and 5 days in **Table 5**, it was found, as shown in **Figure 7**, that the calculated results of Eq. (7) agreed relatively well with the results of the model as Ii became smaller (**Figure 7**).

Next, TWn are shown in **Table 6** under the Ii=1 to 5 days based on return periods of 2 years and 10 years with the probability of a non-exceedance of rainfall; these are stated as "1/2 and 1/10 years" in this paper, respectively. The TWn show 703~724 mm and 789~795 mm at 1/2 and 1/10 years, respectively. At 1/2 year, TWn decreased to 2.9% when Ii was reduced from 5 days to 1 day. At 1/10 year, however, the decrease ratio of TWn was lower than that of Ii. These factors indicate that the decrease ratio is smaller than in the upland fields of

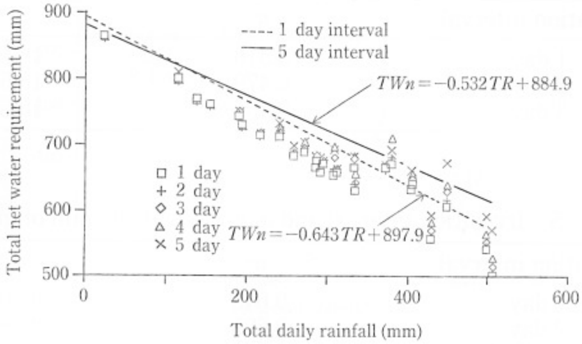


Figure 7 Relationship between the total net water requirement TWn and the total daily rainfall TR (The numbers indicate the last two digits of historical years)

Table 6 Total amount of net water requirment TWn in the return periods of 2 and 10 years with the probability of a non-exceedance of rainfall

Irrigation interval (day)	TWn (mm)	
	2 year	10 year
1	703.3	788.9
2	707.0	790.2
3	709.4	790.3
4	716.3	792.1
5	723.9	794.7

Japan, because there is little rainfall in these areas.

4. Ratios of Effective Rainfall and Net Water Requirement

From Eq. (7), the following relationship is given:

$$\frac{TWn}{TET} = 1 - \frac{TRO}{TET} \qquad \cdots\cdots (8)$$

where TWn/TET, TRO/TET are the ratios of the total net water requirement and the total effective rainfall to the total evapotranspiration, respectively. From the result estimated by Eq. (8) when $TRAM$=35 mm in the grass plot, TWn/TET and TRO/TET showed 0.76~0.79, 0.21~0.24 and 0.86, 0.14 at 1/2 and 1/10 years, respectively. In other words, the amounts of water needed for plant growing are furnished 78% by irrigation and 22% by rainfall during a normal year in these areas; TWn/TET increased from 36% to 54% over the Japan upland field, which had shown 0.22~0.50 in the previous report.[6] At the pilot farm, in other words, water management will become important for irrigation practice, as well as utilization of rainfall.

IV. Conservation Managements

1. Saline Water and Soil Salinization

As described above, although the irrigation water is not so saline, the salinization of drainage water from lysimeter is clearly observed in experiments on grass cultivation,[3,6] the salinization of groundwater is becoming a more serious problem due to the repetitious irrigation.

Soil salinization of the fields in the Research Center is summarized as follows.[7]

(i) In the case of fixed-sand lands like the lysimeter plots, there was little soil salt accumulation in the main root zone during crop cultivation periods over 5 years.

(ii) In the case of lowlands like the nursery plots, where the groundwater levels were kept at depths of 1.5 to 2 m below the soil surface, with an increases in the number of continuous non-rainfall days, the soil moisture contents decreased and salt concentration increased in the main root zone.

(iii) In the case of the stock farm close to the fishponds shown in **Figure 1**, where the groundwater levels were kept at depths of 40 to 50 cm below the soil surface, the soil moisture contents were higher in the total root zone and salt concentration increased in the surface layer regardless of the rainfall conditions.

2. Leaching and Drainage System

Leaching eliminates the salts in the crop root zone and drains the salts from the field to the drainage canals. It is necessary to estimate the requirements both for leaching and for evapotranspiration of crops in the saline fields.

Leaching requirement is dependent upon the irrigation method, the salinity of irrigation water, soil moisture, and crop yield potential. In order to control the soil salinity in the root zone and to increase the crop yield over the designed yield, the FAO recommends leaching.[8]

After irrigation, leaching, or rainfall, the access water below the crop root zone causes an increase in the groundwater level, which leads to serious salt accumulation in the soil surface layer of the fields. As a result, the groundwater must be drained by a drainage system, which may be composed of a tile drain, drainage canal, river, sea, or even a saline lake. The drainage system, as well as the irrigation system, plays an important role in the saline fields of arid lands. There are several saline lakes distributed throughout the Mu Us Shamo Desert. These lakes are considered to be a part of the natural drainage system.

3. Introduction of Irrigation Method

The main irrigation method in the Mu Us Shamo Desert is the surface method, which is subdivided into furrow, border, contour ditch, and basin methods. The furrow irrigation method is suitable for row crops. Farm ditches need to be moderately readjusted according to the bed slope. Crops consume the irrigation water which is infiltrated into the root zone from the farm ditch. In the case of border irrigation, water flows over the field and infiltrates the root zone where the bed slope is moderate and the four sides are surrounded by a low ridge. The border irrigation method is suitable for grass. In contour ditch irrigation, irrigation water flows down at a right angle to the secondary canal which is arranged along the contour line. In basin irrigation, irrigation water flows and is stored in the small plot surrounding the low ridge, as in the case of paddy field irrigation. Basin irrigation is suitable for orchards, where water is usually applied to between one and four trees per plot.

Experiments on the effects of irrigation methods have been carried out on watermelons, vegetables, orchards, and young trees in the fields of the Research Center since 1985. From the irrigation results obtained through 1991, it was found that the ratios of total amounts of irrigation water applied by the surface and sprinkler methods relative to that applied by the drip method were 4 to 6 times and 2 to 3 times, respectively.

The following advantages of the drip method over the sprinkler and surface methods were identified: (i) Evaporation losses were low because the wetted areas were small. (ii) Water application efficiency increased greatly because the water applied was distributed uniformly. (iii) Water losses caused by the strong wind in these areas were minimized.

In the pilot farm, the surface, drip, and sprinkler irrigation methods were used in 1991 for the cultivations of vegetables, grass, and willow trees. Since irrigation methods influenced the scale of irrigation projects which were contained in the total irrigation area, the water resources, and the economic evaluation, it was necessary to select the most suitable irrigation methods by discussing synthetically the following conditions in the object field. (i) Topographic conditions: soil texture, soil salinity, field bed slope, field contour line, water resources, and quality of groundwater resources. (ii) Meteorological conditions: relative humidity, wind velocity, pan evaporation. (iii) Crop condition: crop type, crop spacing. (iv) Economic conditions: irrigation facility cost, maintenance and management costs.

V. Conclusion

Based on surveys in the Research Center of Mu Us Shamo Desert, irrigation schedules were established focusing on the irrigation field of the pilot farm. In accordance with these schedules, total ready available moisture (*TRAM*), irrigation interval, and water quantity per irrigation were estimated for the plots of vegetables, grass, and young trees for revegetation in the pilot farm, based on the previous experiment.

(1) The relationship between total effective rainfall and total rainfall was empirically obtained in the pilot farm during the irrigation period. As a result, the ratios of effective rainfall to rainfall showed 0.45~0.51 and 0.53~0.64 when $TRAM=19$ mm in the vegetable plot and $TRAM=35$ mm in the grass plot, respectively.

(2) The relationship between total net water requirement and total rainfall was derived from the empirical equation. As a result, the net water requirement showed 703~724 mm and 789~795 mm at 1/2 and 1/10 years, respectively.

(3) Based on the ratios of the total net water requirement and the total effective rainfall to evapotranspiration, the water needed for plant growing was seen to be furnished 78% by irrigation and 22% by rainfall. Also, good water management for irrigation practices and rainfall utilization should be strongly stressed.

Finally, conservation management is recommended for the pilot farm in the future, to prevent the salinizations of soils and groundwater and to introduce suitable irrigation methods.

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