Desalination and Water Treatment
www.deswater.com
doi: 10.5004/dwt.2020.26112

200 (2020) 310–322
October

Optimal size estimation of water storage tank for upland crops

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Received 3 January 2020; Accepted 3 March 2020

ABSTRACT

This study estimates the amount of water utilized during the growing season of the cultivated crops and drought frequency analysis is applied to the estimated water requirement. In order to analyze the amount of rainwater flowing into the storage tank to be used by each crop was estimated through the return period of drought frequency analysis and the appropriate capacity of the storage tank was examined. Using the hydrological operation model for the water resources system program, the required quantity of water by crop was calculated using the crop coefficient. In order to analyze the drought frequency according to the growing season of each crop, a suitable distribution is selected between Gumbel, Pearson type 3, generalized extreme value, generalized logistic, generalized Pareto, and generalized normal through the statistical hydrological analysis and the goodness of fitness tests. Based on the selected distribution type, the series of designed water requirement were extracted according to the growing season of each cultivated crop. The shortage of cultivated crops was calculated using the results of the required quantity of water and drought frequency analysis. Estimation of the sufficiency ratio about how much rainwater can be reused using the water demand for the field crops and the height of potential reservoirs, and the optimum rainwater storage capacity of field crops was suggested according to the demand. In this study, it is possible to know the amount of water shortage for cultivated crops. Therefore, if water shortages occur due to extreme drought in the future, it can be provided as basic data necessary for the preparation of drought and it is expected to determine the capacity of rainwater storage tank construction.

Keywords: Drought frequency; Sufficiency ratio; Water demand; Water requirement

1. Introduction

Recently, weather change due to global warming cause the increase in frequency of flood and drought not only in South Korea but also many other countries in world [1]. Especially, in Korea, frequent occurrences of guerrilla rainstorms have caused floods in lowlands and many regions [2]. The annual average rainfall is similar every year but the frequency of heavy rains such as guerrilla storms is increasing, as it is getting longer [3]. In other words, heavy rains are frequently occurring, but the precipitation itself is decreasing. This means that there is an increase in risk of floods and droughts. Therefore, it is essential to improve the efficiency of water use and management in our region, and it is important to improve the efficient management of agricultural water, which accounts for about 50% of the total water use.

The total rural water demand in South Korea is 14.9 billion m^3/y, which is about 50% of the total water use which is 30 billion m^3/y. In particular, during the period from May

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to September, when the water demand increases rapidly, agricultural water supply is inadequate. Therefore, efficient use and management of agricultural water, which accounts more than 50% of water use, is important. In particular, the amount of water required for irrigation is fixed. The minimum amount of water required for the crops is determined according to the growing season of the crops. In addition, crop yield is heavily depending upon demand required the crop demand; the crop yield will be significantly lower for that year.

Climate change leads the changes in the water cycle and ultimately affects the amount of water availability and cause severe flooding and drought conditions in South Korea [4]. For proper management of water resources, there is a growing interest toward storage facilities, capable of efficiently store water to fulfill water requirements for irrigation. Many of the previous studies are more concerning towards optimal sizing of rainwater storage facilities. Some studies are based on the idea of water balance analysis [5–7] and some are based on probabilistic forecasting [8,9]. However, it is concluded that the storage capacity cannot be standardized because of the involvement of site-specific variables such as local rainfall, roof area, and water requirement and population density in the area [10–12]. Therefore, in this study, in order to examine the optimum capacity of the water storage tank, different cases of frequency analysis were considered for the estimated water requirement according to the growing season of the cultivated crops.

Country like South Korea, where cities are highly urbanized and constantly being challenged to achieve a sustainable urban water system. In many developed countries, the storage system is a centralized system and directly connected with the customers [13]. However, large investment and time are required to develop such systems. Therefore, many countries have started focusing on the development of a decentralized system [14], which is cost effective and act as an alternative water resource for non-portable applications, such as toilet flushing, areal climate control, and gardening [15,16].

Literature review showed that for the generalization of results, some researchers such as Fewkes [17], investigated the impact of spatial and temporal fluctuation of rainfall on the behavioral model of rain water harvesting systems. Cheng and Liao [18] investigated regional zoning for rainwater harvesting systems in northern Taiwan using cluster analysis. They judged the rain water harvesting system potential as function of regional rainfall characteristics and system storage size. Moreover, log-linear regressive relationship was derived to estimate the storage capacity for rainwater harvesting system [19].

This paper proposed a dimensionless methodology to determine the optimal size of water storage tank. It is based on the amount of water utilized during the growing season of the cultivated crops, and frequency analysis methodology is applied to estimated water requirement. In order to design the amount of rainwater flowing into the storage tank to be used by each crop, it was estimated through the different cases of return period and catchment area. The optimum size of the storage tank was derived through the comparative analysis of net rainfall and the net demand of cultivated crops.

2. Material and methods

2.1. Study area and data

Sizing of the water storage tank is done to increase the agricultural water supply for the cultivated crop considering the local environmental conditions of the Cheongju city. Therefore, in this study, we used meteorological data of Cheongju meteorological station to estimate the water requirement according to the growing season of the cultivated crops in Cheongju city located in Chungbuk province as shown in Fig. 1 and Table 1.

Meteorological data includes daily precipitation, maximum temperature, minimum temperature, average temperature, average wind speed, humidity, and sunshine hour, as shown in Table 2. The meteorological stations in the Chungbuk area are usually administered by the Korea Meteorological Administration (KMA), Ministry of Environment, and Korea Water Resource Association (K-Water). The daily meteorological data is obtained from Cheongju Meteorological Observatory in Chungbuk province (http://www.weather.go.kr) and meteorological data portal (https://data.kma.go.kr).

2.2. Research methodology

Overall, following steps were adopted for the optimal designing of a rainwater storage tank through greenhouse rainwater harvesting system, (i) estimation of water requirement for each cultivated crop; (ii) drought frequency analysis according to the growing season of each cultivated crop; (iii) simulation of actual rainfall with the changing storage height to decide the optimal capacity of rainwater storage tank.

Estimation of water requirement for each cultivated crop is accomplished through hydrological operation model for water resources system (HOMWRS) program, a reservoir operation model. It is developed by the Korea Rural Community Cooperation (KRC), which has been used in South Korea as a representative program for managing irrigation systems and for establishing the irrigation plan.

The frequency analysis according to the growing time of each crop was accomplished through applying the three parameter probability distribution that can simulate the natural phenomenon well. The linear combination of the probability weighted moment method, L-moment method.

Finally, to examine the optimal capacity of the storage tank, the last 10 y rainfall data was examined, and the annual rainfall use capacity is estimated using the highest, lowest, and average rainfall for 10 y.

2.3. Research methodology

2.3.1. Estimation of water requirement for field crops

The FAO-Penman-Monteith method is recommended by the Allen [20] as the standard method for calculation of ETo. This method is able to incorporated variety of different climatic variables which can be divided into physiological and aerodynamic parameters [21]. Its accuracy and reliability under different climatic variables have been widely accepted in South Korea [22]. Following the methodology

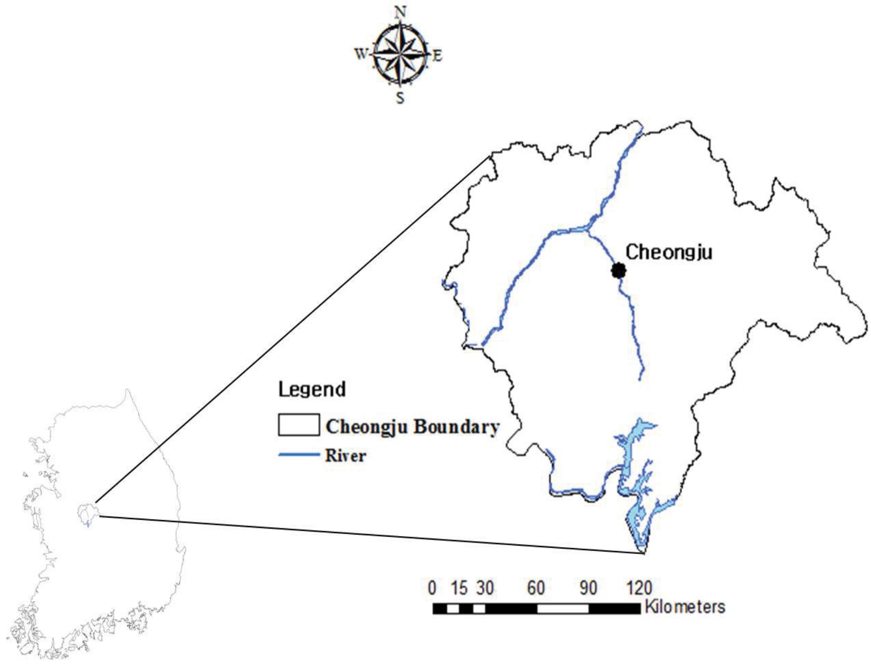

Fig. 1. Location of rainfall station in Chungbuk province.

Table 1
Topographical characteristics of Cheongju rainfall station

Observatory	Cheongju
Code	30111131
River system	Geum River
Starting date of observation	1967–01–01
Longitude	127.441
Latitude	36.639
Altitude	57.16

proposed by Allen [20], method was used to calculate the monthly values of ETo and annual ETo was estimated by accumulating the monthly ETo.

$$\mathrm{ET}_0 = \frac{0.408\Delta\left(R_n - G\right) + \gamma\left(\frac{900}{\left(T+273\right)}\right)U_2\left(e_s - e_a\right)}{\Delta + \gamma\left(1 + 0.34U_2\right)} \quad (1)$$

where R_n indicates the net radiation at the crop surface (MJ/m^2/d), G indicates the soil heat flux density (MJ/m^2 d), T shows the air temperature at 2 m height (°C), calculated on the basis of average of maximum and minimum temperature, U_2 indicate the wind speed at 2 m height (m/s), e_s indicate the vapor pressure of the air at saturation (kPa), e_a indicate the actual vapor pressure (kPa), $e_s - e_a$ showed the saturation vapor pressure deficit, Δ indicate the slope of the vapor pressure curve (kPa/°C^{-1}), and γ indicates the psychrometric constant (0.0677 kPa/°C^{-1}). The details about calculation procedure for each climatic parameter is available in Chapter 3 of the FAO paper 56 [20]. In this study, ET_0 is estimated using the function available in HOMWRS program.

$$\mathrm{ET}_0 = K \cdot \mathrm{ET}_0 \quad (2)$$

Here, ET_c is the crop evapotranspiration, K is the crop coefficient, and ET_0 is potential evapotranspiration.

2.3.2. Estimation of effective rainfall

In the case of irrigation field, the lower limit value is set to 5 mm, and above this value, 80% of the rainfall (R) is set as effective rainfall. The upper limit of the effective rainfall was calculated as total readily available moisture (TRAM) minus the residual water content of the soil just before rainfall. The effective rainfall was calculated by daily soil moisture tracing method using TRAM = (FC–M_L)D1/C_P.

$$\mathrm{TRAM} = \frac{\left(\mathrm{FC} - \mathrm{M\_L}\right)\mathrm{D1}}{\mathrm{C\_P}} \quad (3)$$

Here, TRAM is the total readily available moisture (mm), FC is the 24 h water volume (volume, %), ML is the growth inhibition moisture point (volume, %), D is the limit of soil layer (mm), CP is the value of water consumption rate (0.4 %), FC = 33 kPa water content in soil under atmospheric pressure, ML = 1,500 kPa moisture content in soil moisture under atmospheric pressure (for example 0.6FC > ML, ML = 0.6FC).

2.3.3. Frequency analysis of water requirement according to growing time

In this study, in order to analyze the variation of the water requirement according to the growing time of

Table 2
Hydro-meteorological input data for Cheongju Meteorological station from 1967–2017

Year	Rainfall (mm)	Max. *T* (°C)	Min. *T* (°C)	Mean *T* (°C)	RH (%)	Sunshine (h)	Mean W.S (m/s)
1967	1,078.9	35.4	–24.1	11.5	74.6	2,341.5	2.2
1968	885.1	34.2	–16.2	11.5	75.5	2,205.2	2.1
1969	1,676.2	34.2	–26.4	10.7	76.3	1,990.7	1.9
1970	1,283.7	33.7	–20.0	11.2	76.0	1,956.5	1.6
1971	1,246.4	35.1	–23.2	11.3	75.1	2,218.2	2.1
1972	1,310.7	35.6	–11.0	11.7	73.7	1,980.0	2.3
1973	871.5	35.7	–20.6	11.7	71.6	2,174.3	2.2
1974	1,106.6	34.7	–23.0	10.4	73.5	2,034.5	1.9
1975	1,206.4	33.6	–15.0	12.1	75.3	2,085.4	1.7
1976	1,048.9	34.2	–17.9	11.1	74.5	2,136.5	2.0
1977	1,032.9	35.9	–18.5	11.9	74.1	2,421.7	1.8
1978	1,251.9	35.9	–16.9	12.2	71.9	2,272.0	1.8
1979	1,376.2	34.1	–15.5	12.0	73.4	2,165.3	1.8
1980	1,659.7	32.8	–18.9	10.5	69.6	2,083.0	1.8
1981	1,134.7	36.4	–22.1	10.8	69.3	2,163.9	1.7
1982	850.2	35.2	–16.9	12.1	68.8	2,468.6	1.6
1983	1,238.1	35.6	–15.8	12.0	72.4	2,306.7	1.6
1984	1,103.5	37.8	–19.2	11.4	72.2	2,427.4	1.6
1985	1,372.1	35.8	–18.8	11.8	72.8	2,188.1	1.6
1986	1,157.5	35.0	–18.6	11.2	72.6	2,322.7	1.8
1987	1,656.2	34.0	–16.7	12.0	72.7	2,243.8	1.7
1988	878.9	35.4	–15.3	11.7	71.2	2,422.5	1.9
1989	1,280.3	35.1	–12.6	12.6	74.2	2,403.4	1.9
1990	1,473.7	36.8	–19.3	12.9	78.6	2,105.5	2.0
1991	1,143.6	34.4	–17.2	12.0	69.8	2,418.0	1.9
1992	990.1	34.5	–11.3	12.3	69.4	2,217.8	1.9
1993	1,301.8	32.8	–13.6	11.9	70.3	2,092.1	1.8
1994	1,012.0	37.8	–15.9	13.3	65.2	2,475.7	1.8
1995	1,339.8	35.7	–13.9	12.0	65.3	2,402.9	1.8
1996	928.8	36.2	–13.9	12.1	68.4	2,391.0	2.2
1997	1,456.6	35.0	–15.0	12.7	69.7	2,430.5	2.2
1998	1,640.2	34.4	–12.7	13.6	70.2	2,206.4	2.0
1999	1,326.5	34.9	–12.9	13.1	64.7	2,329.5	1.8
2000	1,357.6	33.6	–13.5	12.3	65.0	2,079.6	1.5
2001	784.1	34.3	–18.1	12.9	63.1	2,201.2	1.3
2002	1,281.8	34.7	–13.1	12.8	64.2	2,029.9	2.5
2003	1,581.8	32.0	–17.5	12.7	66.6	1,806.0	1.8
2004	1,505.9	34.6	–15.5	13.4	61.2	2,206.8	1.7
2005	1,427.2	34.0	–15.0	12.5	60.8	2,157.8	1.7
2006	1,081.1	34.2	–13.3	13.3	62.3	1,965.3	1.6
2007	1,534.5	33.5	–10.1	13.7	64.8	1,900.9	1.6
2008	892.3	35.1	–11.9	13.4	62.3	2,054.7	1.4
2009	1,019.8	33.5	–13.5	13.0	61.3	2,071.0	1.5
2010	1,422.4	35.7	–15.1	13.0	65.3	1,888.1	1.5
2011	1,805.6	35.0	–15.5	12.8	64.6	1,962.7	1.5
2012	1,387.6	36.4	–15.2	12.7	63.7	2,066.9	1.5
2013	1,240.7	35.5	–16.9	13.3	65.1	2,354.6	1.3
2014	913.7	36.0	–9.7	13.9	62.8	2,289.1	1.4
2015	756.9	36.4	–10.8	14.0	59.1	2,411.9	1.4
2016	938.0	36.3	–16.3	13.9	58.9	2,462.0	1.5
2017	1,301.2	36.7	–11.1	13.4	57.7	2,693.5	1.6

Max. *T* = maximum temperature; Min. *T* = minimum temperature; R.H = relative humidity; W.S = wind speed.

cultivated crops, the following distributions were applied; Gumbel (GUM), Pearson type 3 (PT3), generalized extreme value (GEV), generalized logistic (GLO), generalized Pareto (GPA), and generalized normal (GNO). The L-moment based methodology which is a linear combination of the probability-weighted moment method, were used to calculate the parameters of the applied distribution.

2.3.4. Relationship between probability weight moment and L-moment

L-moments are linear combinations of order statistics, and they are relatively robust to outliers and virtually unbiased for small samples. Therefore, it is most suitable for flood and drought frequency analysis, including identification of distribution and parameter estimation [23,24].

2.4. Estimation simulation for determining suitable storage capacity

In this study, we try to make a simulation to supplement the water shortage for cultivated crops in a farm area using a storage tank. In order to evaluate the effect of rainwater storage by reusing the required water for field crops, the simulation was carried out in the following manner as shown in Fig. 2.

The effective rainfall ($R \times f$) is collected in a storage tank indicated by the reception ratio (Sr = V/A), which is collected from the catchment area (A). The stored rainwater can be reused according to the water demand (Wd) and can be supplemented with water from other sources such as tap water, groundwater, or reusable water if the stored rainwater is not sufficient for the daily water demand. The number of days of rainwater available per year and the amount of rainwater available per year is calculated according to the change in the ratio Sr of the storage space V and the collection area A. We estimate the annual rainwater use capacity for the reservoir using three cases of rainfall such as the year of least rainfall in recent 10 y, the year of highest rainfall in the recent 10 y, and the year of average annual rainfall in recent 10 y. Here, the effective rainfall is the daily rainfall (R) × collection ratio (f), the water demand is Wd = Q/A (mm/d), storage height (Sr) = V/A × 1,000 (mm), discarded rainfall = [R × (1 – f)] + overflow, overflow = (R × f) – Wd – storage tank (height).

2.5. Application and specification

2.5.1. Types of cultivated crops

This study is a method of reusing the water stored in the rainwater storage tank by collecting the effective rain generated from the roof of the vinyl house. Seasonal crops were selected for this purpose. The total three selected crops were used as representative crops: spring–summer cultivated corn crop, spring–summer–fall cultivated chili and autumn–winter–spring crops, barley (Tables 3–5).

In order to estimate the water requirement according to the growing time of cultivated crops, the cultivation area for the field of the general farmhouse was set to 0.1 ha, and the storage capacity of the rainwater to the area of the greenhouse In order to estimate the required amount according to the growing time of cultivated crops, the cultivated area of the field was determined as 0.1 ha, In order to compare the storage capacity of the rainwater to the area of 0.1 ha, it is considered as four cases of the vinyl house.

The rainwater collects in rain water, and rainwater falls into the plastic house (Fig. 3). Rainwater falling down from the plastic house collects and flows into the rainwater storage tank through the inflow pipe. In the case of rainfall, which is stored in a storage tank and does not meet the water requirement according to the growing season of the cultivated crop to be proposed in this study, rainwater can be reused. Overall study process is explained in Figs. 4 and 5.

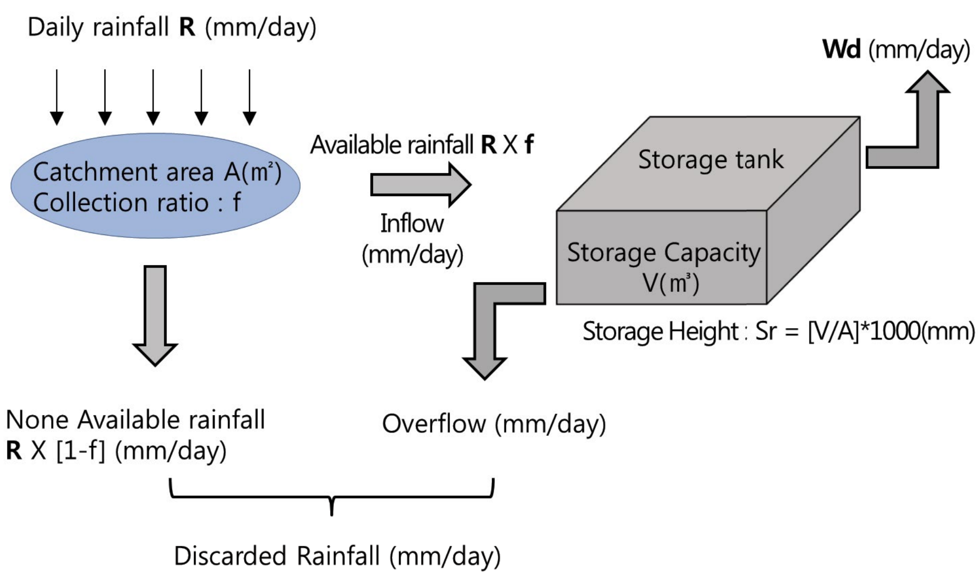

Fig. 2. Simulation process of rainfall for proper storage tank analysis.

3. Results and discussion

3.1. Water requirement per cultivated crop

The water requirement for each crop was calculated according to the growing season of the crop as shown in Figs. 6 and 8. Since the cultivation area of the farmhouse is not that wide, the irrigation area is set at 0.1 ha in general, and the consumption amount of the crops is almost dependent on the rainfall because the rainfall is relatively high at the growing time of the crop.

The effective rainfall required to calculate the water requirement was selected by the daily soil moisture tracing method using TRAM, and the characteristic data of each city and water district is presented in the [National Watershed Survey (Ministry of Land, Water, and Transportation, 2016)] was used in this study. Crop counts for cultivated crops were calculated according to the crop coefficients presented in "technology for the usage of crops by soil, crops, and regions (Rural Development Administration, National Institute of Agricultural Science, 2018)." The mean values of the water requirement calculated using crop coefficients are shown in Tables 6 and 7.

3.2. Goodness of fit test for L-moment ratio diagram

In addition to analyzing basic statistical data using L-moment ratio diagram, the quality of the data is checked through basic statistical tests such as the Wald–Wolfowitz test, the standard normal homogeneity test, and the Grubbs–Beck test. Therefore, the selection of the appropriate probability distribution for the growing time of the cultivated crops was accomplished using L-moment ratio based goodness of fit test statistics (Fig. 7). L-moment ratio diagrams were plotted for the distribution GUM, PT3, GEV, GLO, GPA, and GNO distributions to choose best-fitted probability distribution.

It can be seen from the L-moment ratio diagram that the L-skewness and L-kurtosis points of water requirement are scattered evenly around the curve of the GPA distribution. The mean value of the L-moment ratio is closer to the L-moment curve of the GPA distribution than the L-moment ratio curve of the other probability distributions.

The 10 y frequency value of the water requirement estimated from the GPA distribution is shown in the following figure, and the simulation for determining the appropriate

Table 3
Input values according to growing period by cultivated crop

Crop	Growing period	Irrigation area	Crop
Corn	4/20–8/20		
Chili	5/10–10/15	0.1	25.53
Barley	10/15–5/20		

Table 4
Runoff coefficient according to the land use type of the watershed

Type	Runoff coefficient
Open field	0.10–0.30
Grass, tree lined park	0.05–0.25
Mountain with gentle slope	0.20–0.40
Mountain with STEEP SLOPE	0.40–0.60
Roof	0.85–0.95
Road	0.80–0.90
Impermeable area	0.75–0.85
Surface of the water	1.0

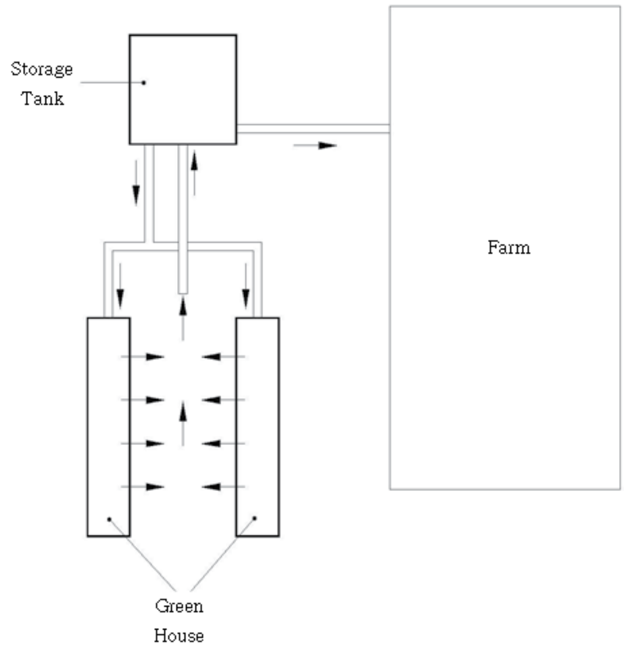

Fig. 3. Schematic diagram of rainwater storage tank.

Table 5
Characteristics and designing criteria for each case

Case	Type	Width (m)	Height (m)	Length (m)	Area (m^2)	Design strength	
						Snow depth (cm)	Wind speed (m/s)
1	07-single-1	5.0	2.6	100	500	50	35
2	07-single-2	6.0	3.3	100	600	50	35
3	07-single-3	7.0	3.3	100	700	50	36
4	07-single-4	8.0	3.6	100	800	48	37

Source: Rural Development Administration (2010), disaster type standard design/specification in horticultural special facility.

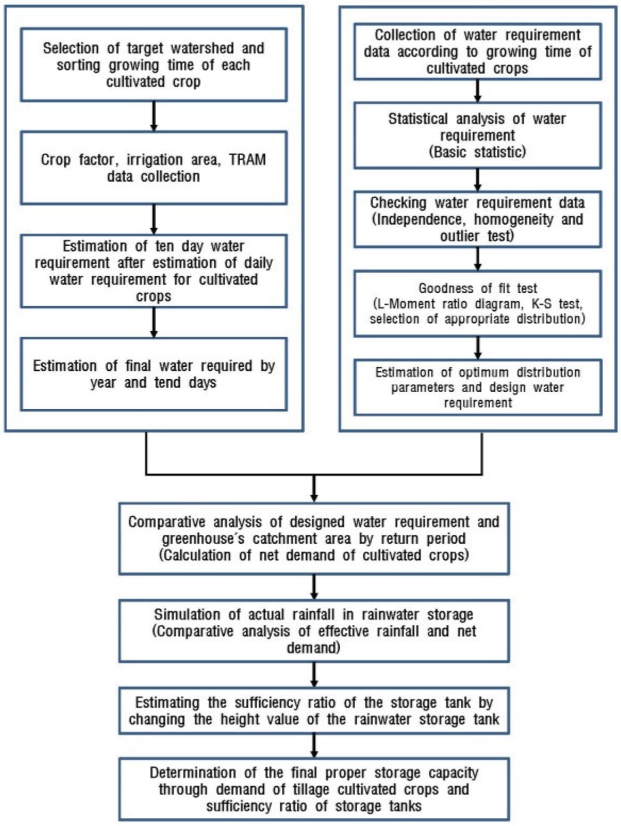

Fig. 4. Flow chart for sizing of optimal water storage tank.

storage capacity for the cultivated crops is determine using the 2, 5, and 10 y frequency.

3.3. Simulation for determining the required storage capacity for the cultivated crops

In this study, the simulations were conducted to determine the optimal storage capacity by changing the ratio of the storage capacity to the catchment area, the rainfall, the roof area of the greenhouse, and the designed water requirement of cultivated crops. The observed annual rainfall at Cheongju branch for 10 y were surveyed, as shown in the following Fig. 8.

In this study, the optimal capacity of stormwater storage was estimated through the simulation process which includes varying the collection area of the greenhouse and the required quantity of design for 2, 5, and 10 y. For example, the process of simulating corn crops for 10 y according to the water requirement is shown in the following Fig. 9.

In the above picture, firstly rainfall is filled in the reservoir according to the required quantity of crops. Rainfall is used first on the day of rainfall. On the day when rainfall is less than the required quantity, rainwater stored in the reservoir is used as shown in Fig. 9.

In the first year of the decade, the space of the storage tank is empty and the rainwater must be filled, so it can be seen that the rainwater is filled for 1 y. In this study, the relationship between the irrigation area (0.1 ha) and the catchment area (case 1–4) is compared with that of the irrigation area (case 1–4) sufficiency ratio (Figs. 11–13). The sufficiency ratio

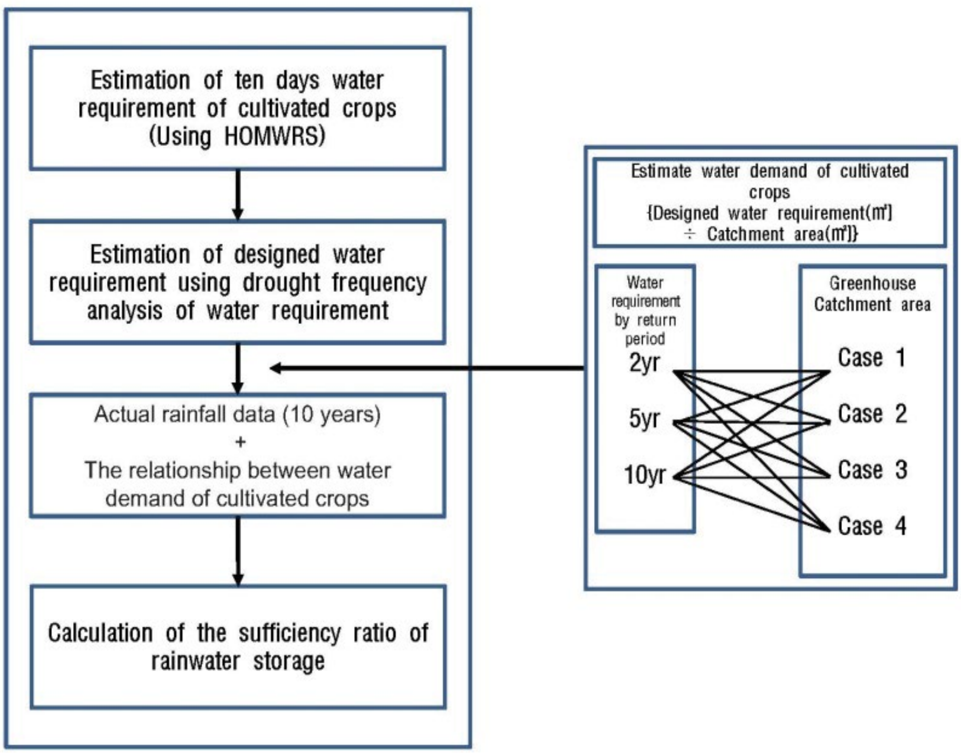

Fig. 5. Estimation process of cultivated crops.

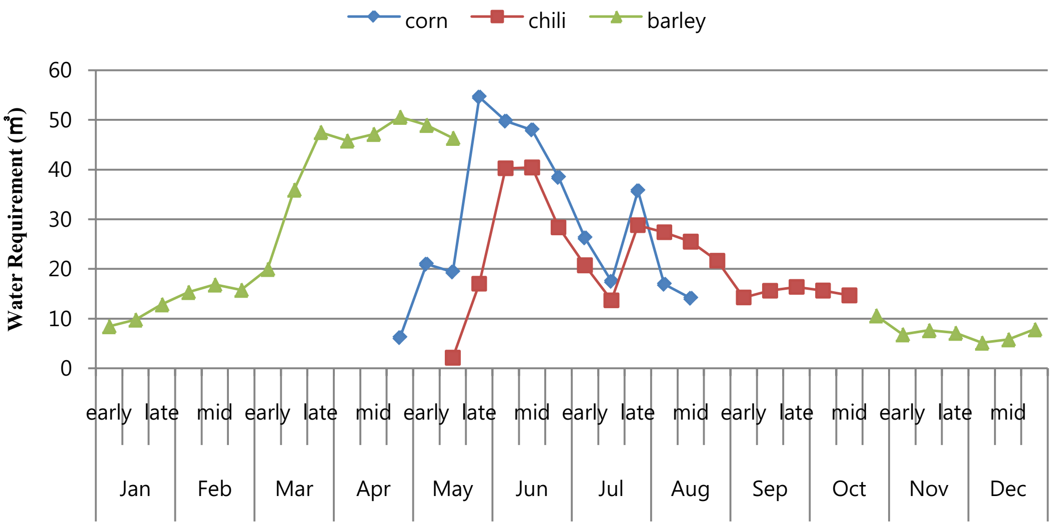

Fig. 6. Water requirement for corn, chili and barley.

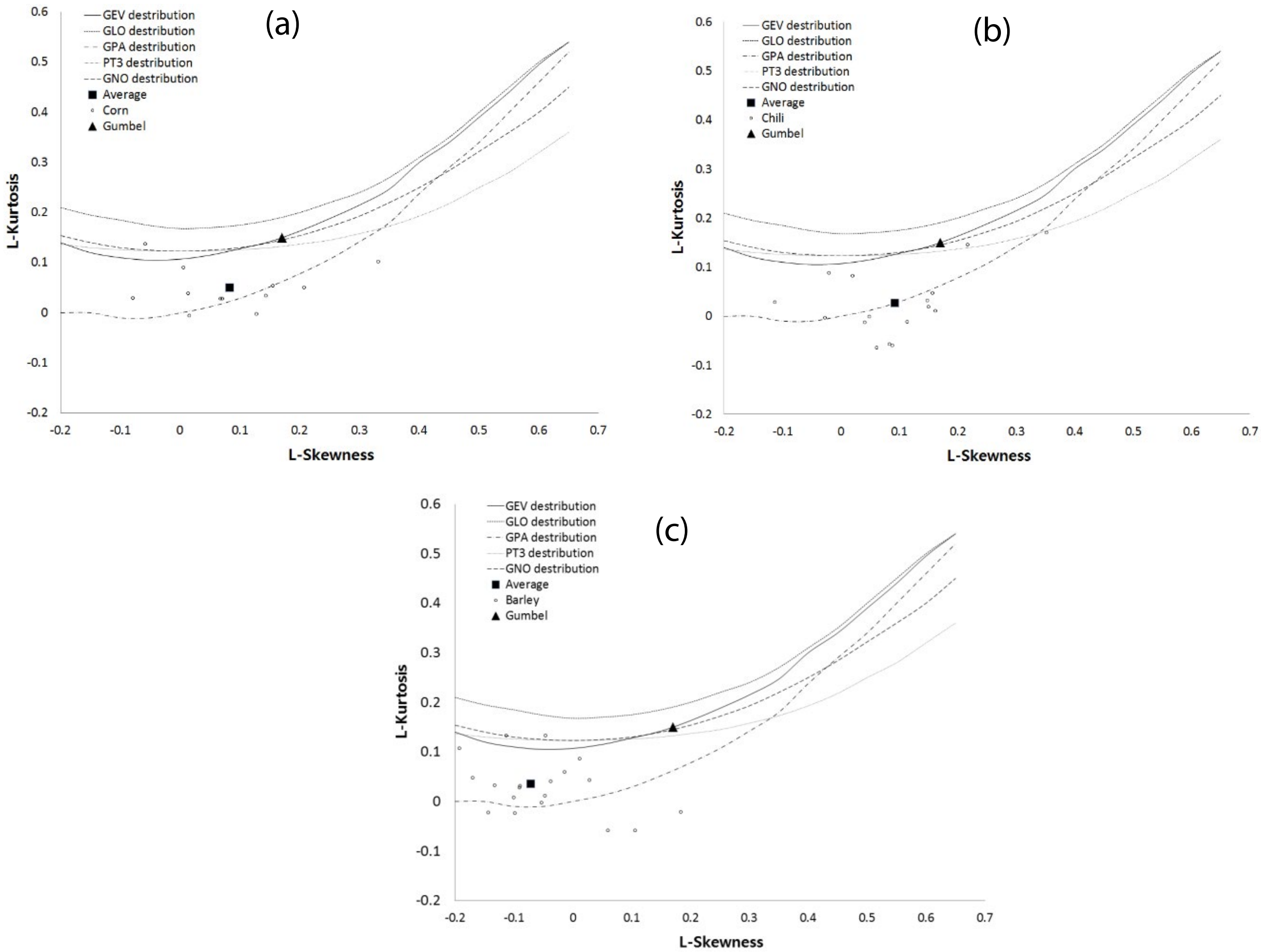

Fig. 7. L-moment ratio diagram for (a) corn, (b) chili, and (c) barley.

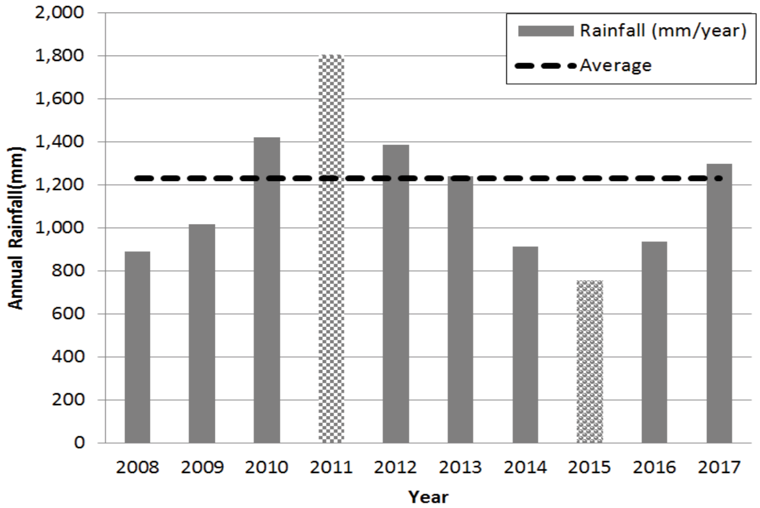

Fig.8. Annual rainfall at Cheongju point.

Table 6
Crop coefficient of corn, chili, and barley

Type	January			February			March			April		
	Early	Mid	Late	Early	Mid	Late	Early	Mid	Late	Early	Mid	Late
Corn	–	–	–	–	–	–	–	–	–	–	0.68	0.68
Chili	–	–	–	–	–	–	–	–	–	–	–	–
Barley	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.30	1.30	1.30	1.30	1.30
Type	May			June			July			August		
	Early	Mid	Late	Early	Mid	Late	Early	Mid	Late	Early	Mid	Late
Corn	0.68	0.68	1.09	1.09	1.09	1.20	1.20	1.20	1.20	0.75	0.75	–
Chili		0.53	0.53	0.96	0.96	0.96	1.06	1.06	1.06	1.06	1.06	1.06
Barley	1.17	1.17	–	–	–	–	–	–	–	–	–	–
Type	September			October			November			December		
	Early	Mid	Late	Early	Mid	Late	Early	Mid	Late	Early	Mid	Late
Corn	–	–	–	–	–	–	–	–	–	–	–	–
Chili	0.82	0.82	0.82	0.82	0.82	–	–	–	–	–	–	–
Barley	–	–	–	–	0.80	0.80	0.80	1.00	1.00	1.00	1.00	1.00

Single crop factor, divided into three types of crops: early, mid, and late. Early: the first 10 d of month, mid: the middle 10 d of month, late: the last 10 d of month. Source: Rural Development Administration (2018), technology of using crops and water according to soil, crop, and region.

can be calculated as the ratio of annual rainwater use and water demand of the cultivated crop; computed as follows.

$$\text{Sufficiency Ratio}(\%) = \frac{\text{Annual Rainwater Use}}{\text{Water Demand}} \quad (4)$$

The sufficiency ratio was calculated by the relationship between the estimated water demand and the annual rainfall usage calculated as the effective rainfall flowing into the reservoir (Figs. 10–12). The sufficiency ratio is the rate at which the stormwater that is stored due to the effective rainfall that can measure the amount of water demand. Therefore, the annual water demand, the annual effective rainfall, and the amount of rainwater in the reservoir were calculated. The recharging period, the catchment area, and the height of the reservoir were changed to estimate the sufficiency ratio of rainwater storage.

The recharging period, the catchment area for cultivated crops, and the height of the reservoir were changed to calculate the sufficiency ratio of the rainwater storage tank. In this study, it was confirmed that rainwater availability is estimated differently according to water demand value and catchment area of cultivated crops. Through the above case study to evaluate the availability of rainwater, it is considered that 100% of the effective rainfall can be used as the recommended capacity of rainwater storage.

Table 7
Water requirement of corn, chili and barley, unit: m^3

Type	January			February			March			April		
	Early	Mid	Late	Early	Mid	Late	Early	Mid	Late	Early	Mid	Late
Corn												6.2
Chili												
Barley	8.5	9.8	12.9	15.4	16.9	15.8	20.0	36.0	47.6	45.8	47.2	46.4
Type	May			June			July			August		
	Early	Mid	Late	Early	Mid	Late	Early	Mid	Late	Early	Mid	Late
Corn	21.0	19.4	54.6	49.7	48.0	38.4	26.3	17.5	35.7	16.9	14.1	
Chili		2.1	17.0	40.3	40.4	28.4	20.7	13.7	28.8	27.4	25.5	21.7
Barley	49.0	46.4										
Type	September			October			November			December		
	Early	Mid	Late	Early	Mid	Late	Early	Mid	Late	Early	Mid	Late
Corn												
Chili	14.3	15.6	16.4	15.7	14.7							
Barley						10.7	6.8	7.7	7.2	5.2	5.8	7.9

Table 8
Sizing optimal water storage tank (unit: m^3)

Storage height (mm)	Cultivated crops by case			
	Case 1	Case 2	Case 3	Case 4
10.0	5	6	7	8
20.0	10	12	14	16
30.0	15	18	21	24
40.0	20	24	28	32
50.0	25	30	35	40
60.0	30	36	42	48
70.0	35	42	49	56
100.0	50	60	70	80
200.0	100	120	140	160
300.0	150	180	210	240
400.0	200	240	280	320
500.0	250	300	350	400
600.0	300	360	420	480
700.0	350	420	490	560
800.0	400	480	560	640
900.0	450	540	630	720
1,000.0	500	600	700	800
1,100.0	550	660	770	880
1,200.0	600	720	840	960
1,300.0	650	780	910	1,040
1,400.0	700	840	980	1,120
1,500.0	750	900	1,050	1,200

3.4. Application of optimal reservoir determination by design quantity

The sufficiency ratio of rainwater use and water demand per year was calculated differently for each return period and for each simulation period. It was judged that the sufficiency ratio was calculated for the irrigation area according to the height of the rainwater storage tank. It was confirmed that the water storage was maintained at a constant value from the height at which the sufficiency ratio of the rainwater storage tank reached at a maximum. This is because the amount of rainwater is limited and the capacity for storage is also limited, so it can be judged as the maximum rate that can be accommodated in the water demand of cultivated crops required. The rainwater storage capacity of the storage tank is multiplied by the height of the potential storage tank that is kept constant at the catchment area or roof area. This can be regarded as a method for determining stormwater storage capacity of field crops to be proposed in this study.

$$\text{Water storage tank}\left(\text{m}^3\right) = \frac{\text{Roof area}\left(\text{m}^2\right)\times \text{Storage height}\left(\text{mm}\right)}{1000} \quad (5)$$

As a result of the above equation, the appropriate capacity of the rainwater storage tank with respect to the catchment area and the height of the storage tank are shown in Table 8. The capacity of the storage tank in case 1 for the 2 y return period with a 100% sufficiency ratio at the storage tank height of 500 mm is estimated as 250 m^3. In the case 1 of pepper, the storage capacity was 100% at the storage tank height of 400 mm, and the calculated capacity of the storage tank is 200 m^3. Finally, in case 1 of barley, the acceptable storage capacity of 550 m^3 was determined because it showed the acceptance rate of 100% at 1,100 mm.

4. Conclusion

In this study, the optimal storage capacity was estimated through the simulation process for estimating the water

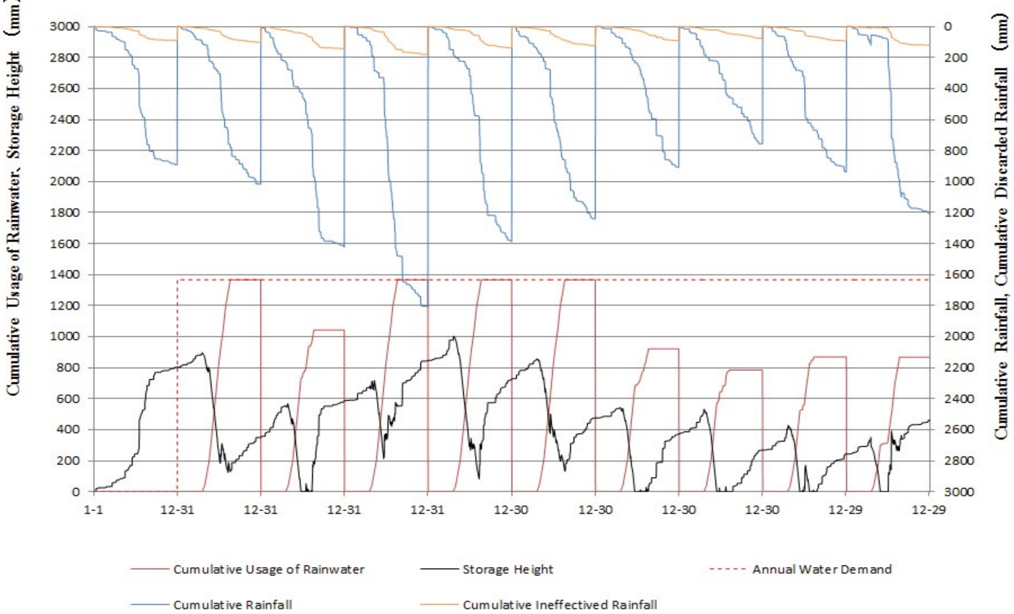

Fig. 9. Simulation for designing optimal storage capacity of storage tank.

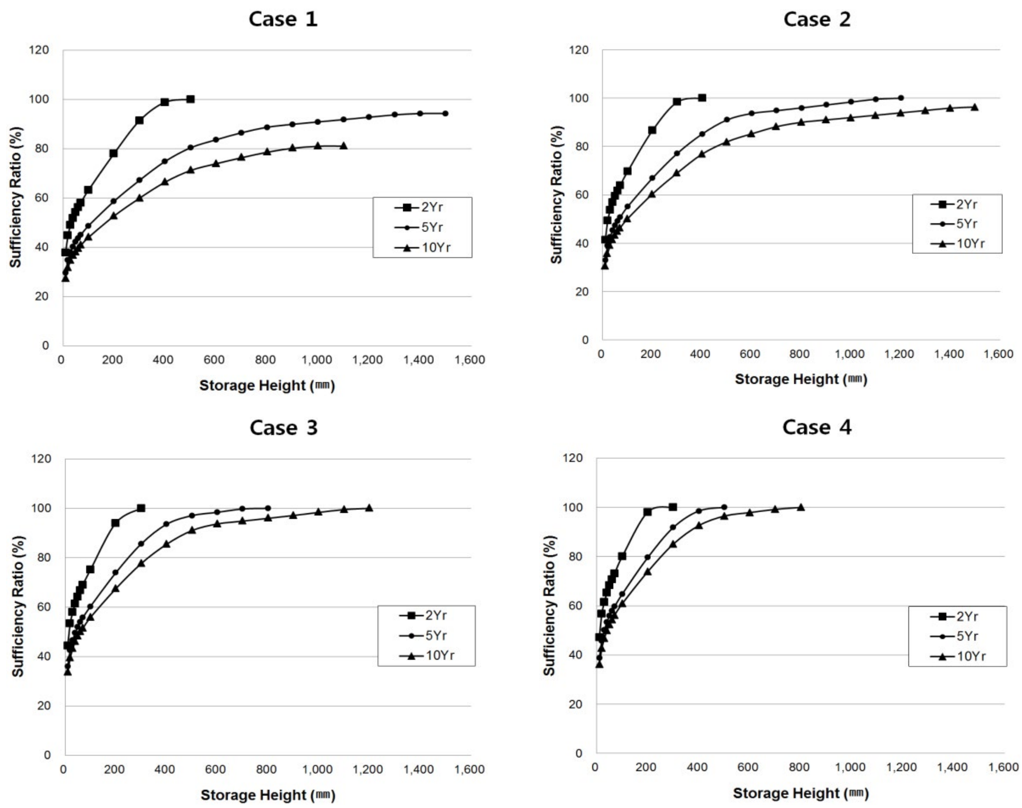

Fig. 10. Sufficiency ratio of cultivated crops by case for corn.

demand of the crops and the capacity of the rainwater storage tank through the frequency analysis of the water requirement and the water requirement during the growing time of corn, red pepper, and barley was estimated. Different ways were suggested to secure rainwater.

The sufficiency ratio calculated for annual rainwater use and the water demand was found different for each case and return period, respectively, and it was judged that the sufficiency ratio for the irrigation area was as acceptable as the area to be irrigated using the stored water depends on the

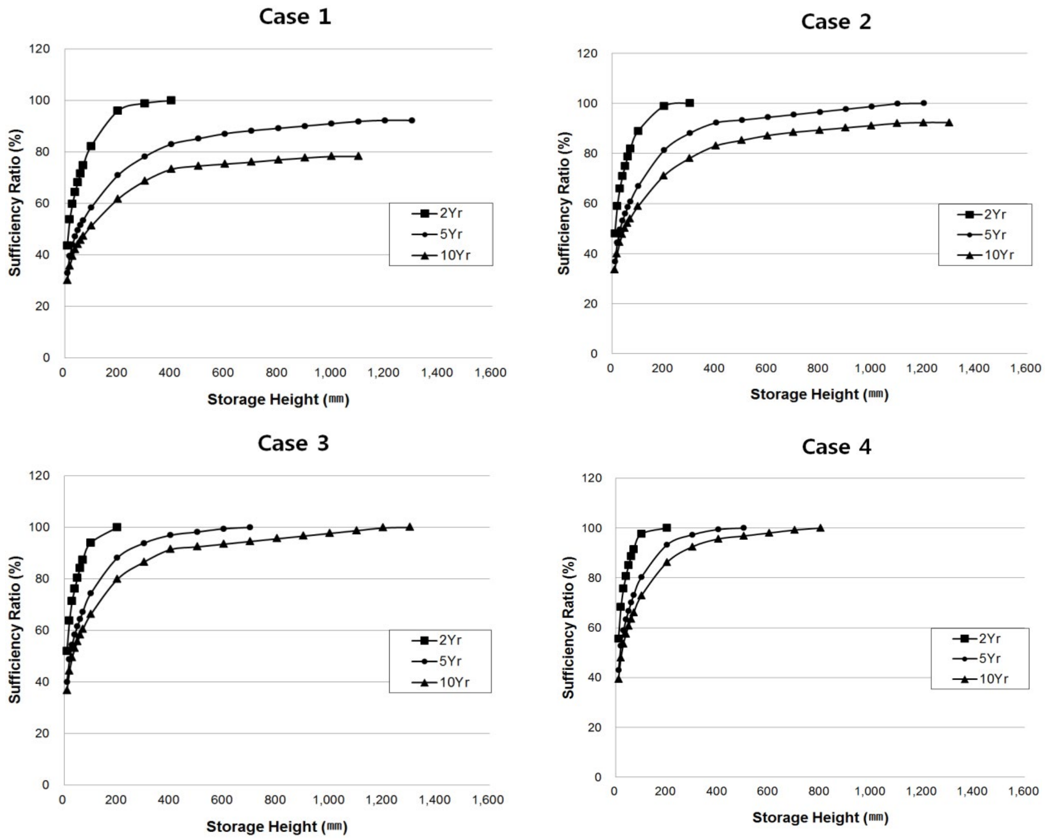

Fig. 11. Sufficiency ratio of cultivated crops by case for chili.

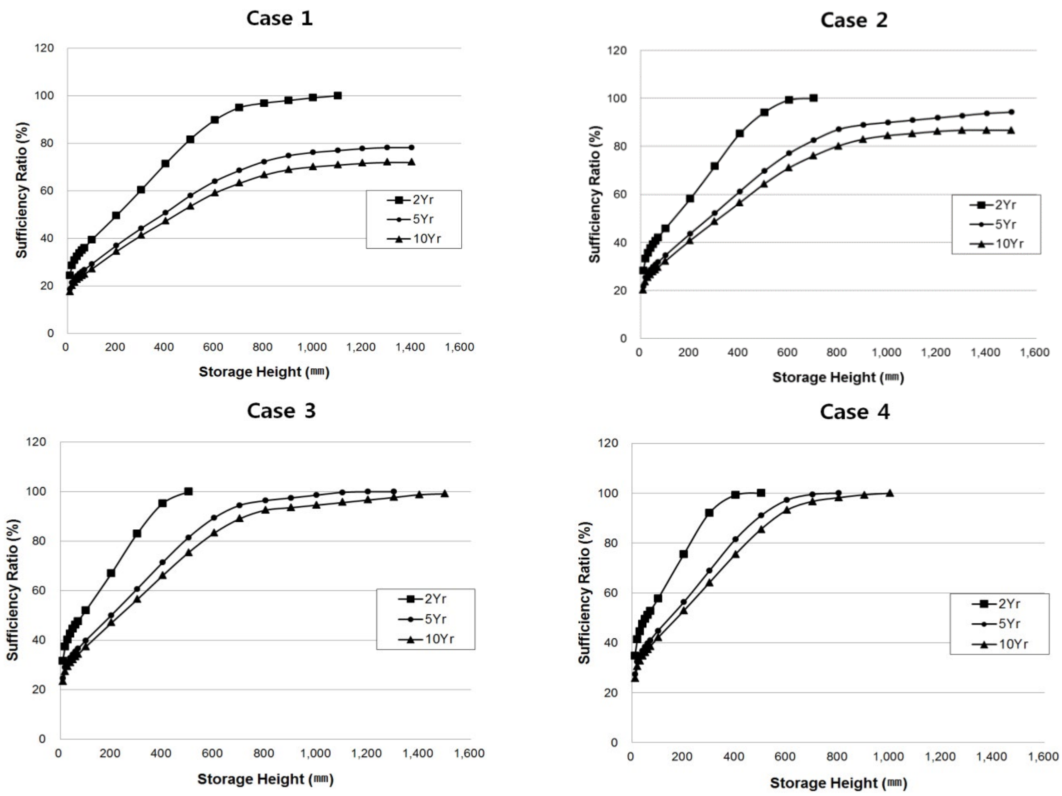

Fig. 12. Sufficiency ratio of cultivated crops by case for barley.

height of the rainwater reservoir. It was confirmed that the storage ratio of the rainwater storage tank is maintained at a constant value from the height at which it is maximized.

Accordingly, if the capacity of the storage tank is determined according to a constant height, the water shortage due to the water demand of the crop will not occur.

The results of this study are expected to contribute as a way to determine the storage capacity in a specific area that can be secured and reused as a means to solve the water shortage of agricultural water. It is expected to operate a rainwater storage tank efficiently in the agricultural water supply and can also be used for the management of groundwater systems.

Acknowledgment

This work was supported by the Chungbuk Research Institute of Korea and this work was also supported by the Ministry of Education of the Republic of Korea and the National Research Foundation of Korea (NRF-2017S1A5B8059946).

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