Issues of Life Cycle Assessment for Irrigation

Hajime Tanji[*1], Koushi Yoshida[*2] and Hiroaki Soumura[*3]

[*1]*National Institute for Rural Engineering, 2-1-6 Kannon-Dai Tsukuba, Ibaraki, Japan, Zip 305-8609, Phone: +81-29-838-7567, Fax: +81-290838-7609, E-mail: tanji@nkk.affrc.go.jp*
[*2] *Japan Science and Technology Corporation, c/o National Institute for Rural Engineering, 2-1-6 Kannon-Dai Tsukuba, Ibaraki, Japan, Zip 305-8609, Phone: +81-29-838-7568, Fax: +81-29-838-7609,E-mail: koshiy@nkk.affrc.go.jp*
[*3]*National Institute for Rural Engineering, 2-1-6 Kannon-Dai Tsukuba, Ibaraki, Japan, Zip 305-8609, Phone: +81-29-838-7568, Fax: +81-29-838-7609, E-mail: somura@nkk.affrc.go.jp*

ABSTRACT

Sustainability of irrigation is an important theme of water resource management. LCA, which is a common framework for evaluating environmental impacts in factory production, was applied to irrigation canals in this study to evaluate the environmental impacts through environmental load of output, such as energy or CO_2. Therefore LCA of irrigation water can be set as 1) product or 2) input resources. The first approach of CO_2 is discussed here. The application of LCA for irrigation water can help us to estimate the environmental impact of CO_2, which is useful for decreasing the risk of global warming. A simple model for irrigation canals for 30 years showed a canal with gravitational head intake had a 2.2 t-C/ha CO_2 load and a canal with pumping head intake had a 6.0t-C/ha CO_2 load. Thus LCA can be used to evaluate one of multi-functionality of paddy irrigation.

Keywords: LCA, irrigation, multi-functionality, CO2, environmental impact

1. INTRODUCTION

Recently, LCA (Life Cycle Assessment) has widely been used as an environmental assessment method, especially after LCA was given ISO14010 status in 1997. LCA was first used by manufactures, then, by construction companies. Recently, there have been some studies about LCA use in agriculture, which are mainly aimed at the food production system. But these studies ignored irrigation water as an input resource. Therefore, the authors tried to apply LCA to irrigation water supply system to learn about the environmental impact of irrigation.

2. REVIEW OF PAST STUDIES

In the field of civil engineering, LCA was first introduced into architecture by the LCA Guideline Committee (1999). After that, Inoue (1999) and Tsurumaki (2001) studied LCA for public works. The main study methods of LCA are input-output analysis and cumulative estimation. Unit environmental impact load for cumulative estimation is given by input-output analysis, which is based on the economic data of each country. Therefore, references in this paper are mainly based on input-output analysis of Japan.

The LCA Guideline Committee (1999) derived unit load of CO_2 by input-output analysis. Similar unit loads were studied by the LCA committees of the Japan Society of Civil Engineers, Public Works Research Institute, Building Research Institute, National Institute for Environmental Studies, and others. Inoue (1999) collected co-authors in the construction field, for example, architecture, home site development, transportation system, harbor, waste treatment system, drinking water system, waste water system, etc. Tsurumaki (2001) studied LCA of drainage pumping stations.

In agricultural fields, the National Institute for Agro-environmental Studies (2000) and Agro-Information Association (1998) reviewed and studied LCA for rice production and beef production. But LCA study of rice production ignored irrigation as an input resource. Hisamori (2000) compared the LCA of food system between Japanese and Western dishes. Nayayanaswamy (2003) studied LCA of Australian grains and considered drainage water quality but not irrigation water. Martin (2000) studied LCA of food systems but not of irrigation.

3. LCA OF IRRIGATION

In this paper, LCA of irrigation means LCA that features irrigation water as product or service. In its basic form, LCA can treat any environmental load. However, most studies have concentrated on load of energy and CO_2. Unit load data are abundant for CO_2. Therefore the authors started on CO_2 load in their first study of LCA of irrigation.

3.1 LCA by construction cost of irrigation facilities

Input-output analysis of LCA is based on input-output analysis of the economy, which is based on the data of cost of production. The National Institute for Environmental Studies (1995) published unit CO_2 load of construction by input-output analysis. These unit loads were based on the classification of 407 economic sectors. Construction of public works by the Ministry of Agriculture, Forestry and Fishery are divided into a group that contains irrigation, fishery harbors and check dams.

The model area was set to K paddy irrigation project by the local government of T prefecture with a canal length of 18,559m and irrigated area of 1,838ha. Intake discharge at the head barrage was 11.9 m^3/s, which was 56mm/d based on the irrigated area and delivery during a 24hour period. Construction cost of the prefecture irrigation project was 1,764 million yen in 1992 money. Unit construction cost per 1 m canal is 95, 000 yen and unit construction cost by 1m^3/s intake is 148 million yen. In addition to this canal, there was also a 27.1 km-long canal constructed by the central government. Unit load of CO_2 by construction of MAFF's public works is 1.1185 t-C / million yen. Therefore 2,090 t-C was exhausted by K project. This is 175.6 t-C / 1 m^3/s and 1.1 t-C /ha. With consideration of governmental canals, LCA-CO_2 becomes about 4,000 t-C, 336.1 t-C/ 1 m^3/s, 2.2 t-C/ha.

3.2 Estimation by a cumulative method

The next calculation is cumulative estimation by unit load calculated by Japan Society of Civil Engineers. **Figure 1** shows a standard layout of main, secondary and tertiary irrigation and drainage canals. Based on this figure, concrete and rebar volume were estimated. A paddy field is 30 x 100m (0.3ha) rectangle. Tertiary canals are allocated along the short edge of a paddy and their length is 150m. The area irrigated by one tertiary canal is 3ha. While secondary irrigation canals contain 6 tertiary canals in the figure, but secondary drainage canals contain only 5 tertiary drainage canals. By considering this point, each secondary irrigation canal is assumed to contain 5 tertiary canals. Thus the length of a secondary canal is 150m and the irrigated area is 15ha. The main canal is assumed to contain 100 secondary canals and its length is 15,000 m and irrigated area is 1,500ha.

The water requirement rate is assumed to be 20mm/d. The hypothetical velocity of the tertiary and secondary canals is 0.5 m/s and that of the main canal is 1.5 m/s. Water depth can be calculated when the width of channel, discharge and conveyance efficiency are given. When the width of the canal, thickness of the canal and the height (that is, the water depth and free board) are given, the volume concrete and rebar can be derived. Then LC-CO_2 can be calculated based on these volumes of concrete and rebar. The thickness of concrete is assumed to be 5cm for a tertiary canal, 10cm for a secondary canal and 20cm for the main canal. The assumed disposal load of concrete is 10.6t-C/ t-concrete. The layout in **Figure 1** means the length and input resource of the canal are the minimum. The actual canals, especially main ones are much longer because of the distribution of paddy fields. To compensate for the difference between the actual and minimum lengths of the main canal, the retarding ratio was adopted here. A retarding ratio of 2.0 for the main canal and that of 1.1 for the secondary canal were assumed here. With using these retarding ratios, the total sum length of the canal is 48.5 km.

Table 1 shows the structure of canals and conveyance efficiencies of tertiary canal 0.9, secondary canal 0.8 and main canal 0.9. Based on the table, the required intake of the head barrage is 5.4m^3/s for 1,500 ha.

Table 2 shows the calculated results of LCA. CO_2 load is 3,079t-C. This value is 875 t-C/1m^3/s discharge at paddy intake and 570 t-C/1m^3/s intake discharge at the head barrage.

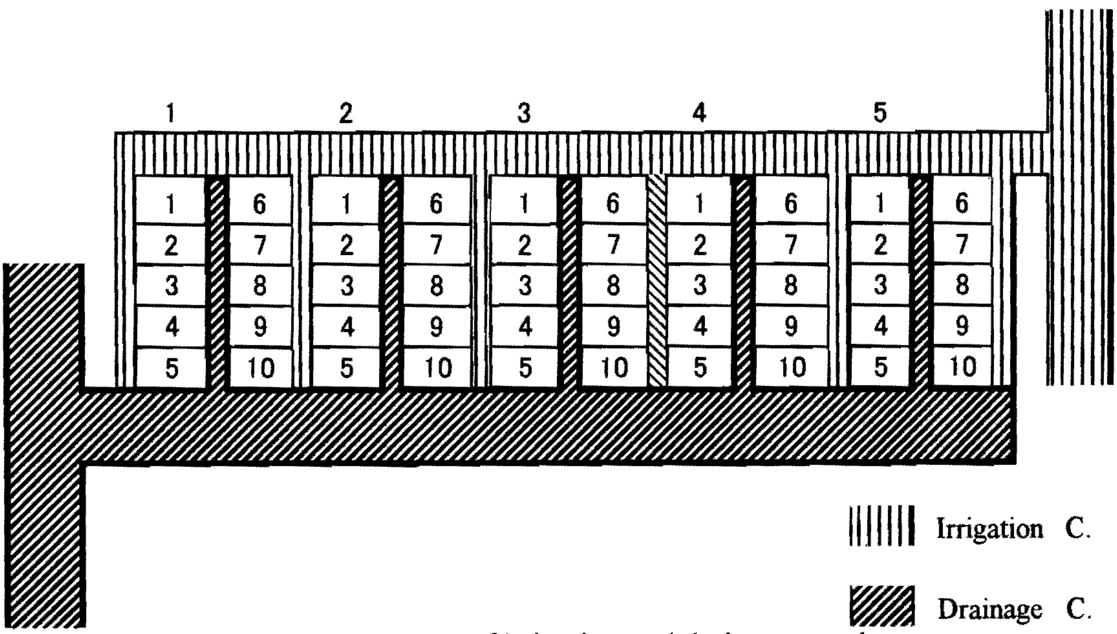

Figure 1 Layout of irrigation and drainage canals

Table 1 Specification of canals

	Total km	Amount m3/s	Conveyance Efficiency	Retarding Ratio of Channel
Tertiary canal	7,500	4.4	0.8	1
Secondary canal	11,000	4.5	0.9	1.1
Main canal	30,000	5.4	0.9	2
Total	48,500			

3.3 Results of comparison

The irrigated area of K project is similar to the 1,500 ha of the cumulative estimation area. But the estimated loads of the two cases differ by a factor of 2. The length of a canal by the cumulative method is 48.5km, while the prefecture canal length is 18.6km. But added to national canals, the total length is 45.7km, which is approximately equal to 48.5km. The water requirement ratio for the cumulative method is 20mm/d or 25mm/d with consideration of loss during delivery. In contrast, the water requirement rate of K project is 56mm/s, which is approximately 2.8 times (or 1.75 times with consideration of conveyance loss) that of the cumulative method. The main cause of this difference is non-used passed-by discharge from irrigation to drainage canals because the variance of the water requirement ratio in a paddy scale is small. Of course, there are other differences, such as discharge velocity, conveyance of input resources, foundation treatment, excavation and conveyance of soil.

3.4 Estimation of LCA of pumping irrigation system

Maintenance cost is not considered in mentioned analysis. There are few data about maintenance load of water management of paddy irrigation. The Japan Agricultural Machinery Society estimated the water management load for paddy fields. The society estimated the water management load of paddy irrigation as 40times mini track transportation of 11km per ha, which means water must managed 2 or 3 times each week during the 100-day rice growing period. CO_2 load from gasoline is 3.1kg-C/ha/y. Here water management load of canals is assumed to be the same level. During a 30-year period for 1,500ha, the load is 139.5t-C.

Next is the case of pumping intake from a river. Unit electricity per 1 m^3/s is 230.6kW/m^3/s for uplift of 20m, efficiency of pumps of 0.85 and gravitational constant of 9.8. Unit load per hour is 29.67kg-C/h because CO_2 load of electricity is 0.129kg-C/kWh. For 30 years management of 100days with 12hours operation, the total load is 1,068t-C.

The load caused by construction and disposal of pumping stations or head intake barrage, is 223t-C when construction cost of 200 million yen and unit load of MAFF-related public works construction of 1.1185t-C/million yen are assumed.

Table 2 CO_2 load by cumulative method

Construction		
Concrete	m^3	t-C
Tertiary canal	412.5	223.0
Secondary canal	1650.0	891.8
Main canal	3360.0	1816.1
Total	5422.5	2930.9
Steel reinforcement	kg	
Tertiary canal	6.4	1.1
Secondary canal	25.7	4.5
Main canal	52.4	9.1
Subtotal	84.6	14.6
Total t	12556.3	2945.5
Disposal		133.6
Total Amount		3079.0

Table 3 · Comparison of Irrigation Methods and LC-CO_2

	Gravity t-C	Pumping t-C	Pumping t-C	Pumping t-C	Pumping t-C	Pumping t-C	Pumping t-C
Uplift m	0	0	4	8	12	16	20
Construction and Disposal	3079.0	3079.0	3079.0	3079.0	3079.0	3079.0	3079.0
Water management	139.5	139.5	139.5	139.5	139.5	139.5	139.5
Pumping Electricity	0.0	0.0	1153.5	2307.1	3460.6	4614.2	5767.7
Headworks and pumping stations	223.0	223.0	223.0	223.0	223.0	223.0	223.0
Total	3441.5	3218.5	4372.0	5525.6	6679.1	7832.7	8986.2
Discharge m^3/s	5.4	5.4	5.4	5.4	5.4	5.4	5.4
t-C /m^3/s discharge	637.3	596.0	809.6	1023.3	1236.9	1450.5	1664.1

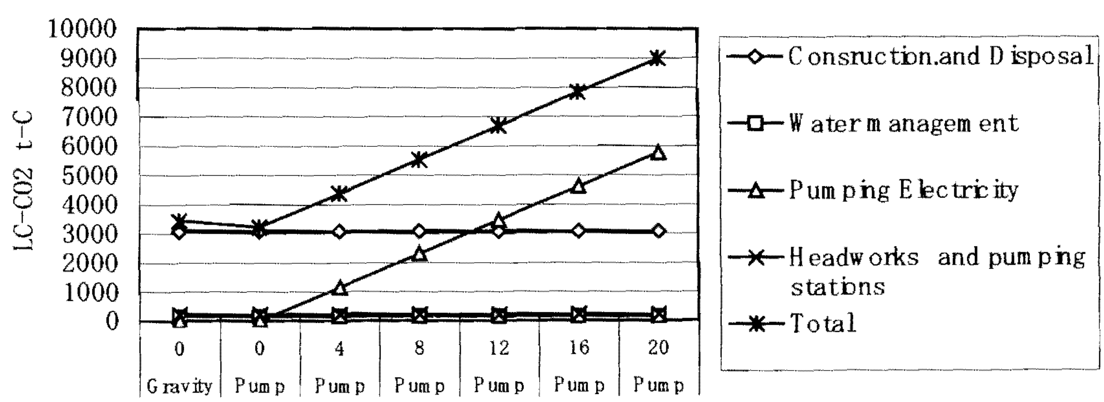

Figure 2 Comparison of gravitational and pumping irrigation

3.5 Comparison of irrigation methods

Table 3 shows the difference in CO_2 load by head intake. The load by the pumping method is 2.6 times that of the gravity method at an uplift of 20m. With the variation of uplift, CO_2 load changes linear to the height of uplift. This relation is shown in **Figure 2**.

In case of uplift of 20m for 30 years, unit load for discharge or area is 637t-C/m^3/s or 2.2t-C/ha for the gravitational method and 1,664t-C/m^3/s or 6.0t-C/ha for the pumping method.

4. CONCLUSION

The application of LCA to Irrigation water can be used to estimate environmental impact of CO_2, which is useful for decreasing the risk of global warming. A simple modeled calculation for irrigation canals for 30 years showed a canal with gravitational head intake had a 2.2 t-C/ha CO_2 load and a canal with pumping head intake of 20m uplift had a 6.0t-C/ha CO_2 load. Thus LCA can be used to evaluate the multi-functionality of paddy irrigation.

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