VIRTUAL WATER VALUE ESTIMATION FOR CROPS AT TAIWAN

EVALUATION DE LA VALEUR DE L'EAU VIRTUELLE DE CULTURE A TAIWAN

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ABSTRACT

Due to the shortage of fresh water at off-island around Taiwan, conflicts arise among the water users in local area development planning. This paper introduces the concept of virtual water and its evaluation from social, economic and water value angles that may be considered at off-island around Taiwan to ease the conflicts.

The Kinmen "Kaoliang liquor" is the focus product in this paper for its fragrance and high selling price. Sorghum and wheat are the raw material for brewing Kinmen Kaoliang liquor. The required irrigation water of these two crops is determined via CROPWAT according to the basic soil and meteorological data at Kinmen, one of the off-island of Taiwan. Water needed for cropping sorghum and wheat is obtained at the second step. It is transferred into water needed per unit production of sorghum and wheat. Virtual value of water for making Kinmen Kaoliang liquor is then estimated at the final stage. In order to investigate the effect of geographical location, the process was repeated using the meteorological data at central Taiwan. The virtual water value for different crops and from different places was then summarized.

The results show that virtual water value for making Kinmen Kaoliang liquor at central Taiwan is higher than that at Kinmen and the virtual water value for cropping wheat is the lowest one. It means the profit or benefit for cropping sorghum at central Taiwan is higher than cropping at Kinmen from the view point of economics. This is an important result for developing the water management policy. Water user organizations can negotiate the water uses through different places to reach the most economical and efficient use of limited water resources.

Key words: *Virtual water value, Taiwan CROPWAT, Sorghum, wheat, Kinmen Kaoliang liquor.*

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RESUME

En raison du manque d'eau douce au large de l'île de Taïwan, les conflits surgissent parmi les utilisateurs de l'eau dans la planification du développement de secteur local. Ce rapport présente le concept d'eau virtuelle et son évaluation du point de vue social, économique et de sa valeur qui peut être considéré pour atténuer ces conflits.

Le « Vin Kaoliang » de Kinmen est le produit principal connu pour son parfum et son prix haut de vente. Le sorgho et le blé sont les matières premières de sa production. Les besoins en eau d'irrigation de ces deux cultures sont déterminés à Kinmen par CROPWAT selon le sol de base et les données météorologiques. A deuxième étape, l'eau est obtenue pour les deux cultures. Ensuite, elle est transférée selon la production par unité de ces deux cultures. A la fin, la valeur de l'eau virtuelle est calculée pour la production du Vin Kaoliang. La valeur de l'eau virtuelle des différentes cultures produites dans différentes régions est présentée en bref.

Les résultats montrent que la valeur de l'eau virtuelle pour la production du « Vin Kaoliang » de Kinmen est plus haute au Centre de Taïwan que celle à Kinmen. La valeur de l'eau virtuelle de la culture du blé est la plus basse. Il signifie les avantages du point de vue économique de produire le sorgho à Taïwan par rapport à Kinmen. Ce résultat est utile pour formuler la politique de la gestion d'eau. Pour réaliser l'utilisation efficiente des ressources en eau limitée, les organisations des usagers de l'eau peuvent négocier les usages de l'eau dans différentes régions.

Mots clés : *Valeur de l'eau virtuelle, Taïwan, CROPWAT, Sorgho, blé, Vin Kaoliang de Kinmen.*

1. INTRODUCTION

Water resource is essential for daily life. However, the allocated amount of water per capita is decreasing due to the increase in population, and the uneven distribution of global precipitation both temporally as well as spatially. Rogers(2009) has pointed out that the demand for fresh water is doubled in every 20 years as the population increases and living standard improves while the supply of fresh water is reducing in the same speed as a result of pollution, climate change and sea water intrusion. In the 5th World Water Forum, President of the Republic of Turkey Abdullah Gül also pointed out in his address that "water is life, water is one of the engines of sustainable development, and without proper use of water resources, we will not be able to fight with poverty and hunger." FAO also warns that by 2025, over 1.8 billion people in the world will be living in the water shortage area, two thirds will be living under water shortage stress, and the situation will be getting worse. In order to alleviate the water shortage, the International Virtual Water Trade has drawn wide attention in recent years. The concept of virtual water emphasises that through the mechanism of economic transactions, the water in a production process is sold to other areas by virtual water trade, and to ease the problems of uneven distribution of water resources. Meanwhile, the virtual water resources become products with quantifiable prices via transactions, and the security management of national water resources is achieved.

Due to global climate change, there are problems in the harvesting of crops in off-islands in Taiwan. Although there are lakes and reservoirs, the available fresh water is not enough to meet the demands of various sectors, and off-islands have become the area of water scarcity. In order to ease the water-insufficiency in the off-islands of Taiwan, hard-wares such as desalination plants, rainwater cisterns and water-saving facilities have been set up. Nonetheless, the effective distribution of water resources for various sectors, in order to meet the demands for domestic purpose and industrial development, is not easy. For the effective utilization of water resources, Kaoliang liquor, which is produced in the famous off-island of Kinmen, is selected as the target for discussion. The computing model of the virtual water values of crops are established by introducing the concepts of irrigation water and virtual water values, and the virtual water values of Kinmen Kaoliang, wheat, and Kinmen Kaoliang Liquor are estimated, and the water cost and benefit of upland crops and their products in Kinmen area, are discussed. Also, the virtual water value of Kaoliang Liquor is compared with that of the same crop planted in Taiwan area, and the possibility for the option of better water utilization is discussed.

2. DEFINITION AND LITERATURE REVIEW OF VIRTUAL WATER

The concept of virtual water was proposed by Allan (1993). The definition for virtual water resources, according to him is the water resources consumed in the cultivation of crops or production process of commodities. In fact, before the idea of Virtual Water was proposed, a concept of Embedded Water has been raised by him to express similar idea. This didn't draw much attention; nonetheless, Virtual Water has now become an extensive concept in economic science.

A few years later, the above concept was followed up and was proposed as a mechanism of economic transactions in that, the virtual water in a production process can be sold to other areas by the way of virtual water transactions. The countries in the middle-east with water scarcity were chosen as the case study area in an attempt to find a long-term solution for the water-shortage problems in the middle-east area. It was suggested that importing high water-consuming food or crops from water resources abundant countries to replace the growing of food crops in the middle-east area could reduce the water resources exhaustion in the area. The more efficient use of water resources should be helpful to resolve the problems of water resources distribution, food, and economic security (Allan, 1997, 1998).

Hoekstra and Hung (2003) first proposed a methodology to quantify the virtual water transaction for crops. Based on the irrigation and drainage references as well as crop yield data from FAO, a quantification model for the virtual water of crops was established, and the flowing of global virtual water of major crops in the transaction balanced areas were compiled from the Department of Statistics. Many research scholars followed-up and found that, even many of the products do not contain water or low water content, the water resources consumed during the production process was surprisingly high. For instance, 32 kg of water is needed to manufacture 2 g of 32 MB computer chips, and 5,500 kg of water for the producing of 1kg of cheese (Williams, 2002, and Chapagain and Hoekstra, 2003).

Ting and Chou (2005) tried to evaluate the value of water usage of the local coastal aquaculture by taking the coastal aquaculture district in Pingtung Plain of southern Taiwan as the case study area. The virtual water value for various fish species were determined from the total amount of water used, water consumption per unit weight of fish species, and market price for each fish species. Jan and Yeh (2009) used the “Kaoliang”, which is the local name for the primary material “sorghum” to produce Kinmen Kaoliang liquor. The FAO-CROPWAT irrigation management model was applied to estimate the water requirement for the whole growing period of the crop Kinmen Kaoliang first, then a computational model for the virtual water value of single upland crops by combining concepts of water economics and virtual water resources.

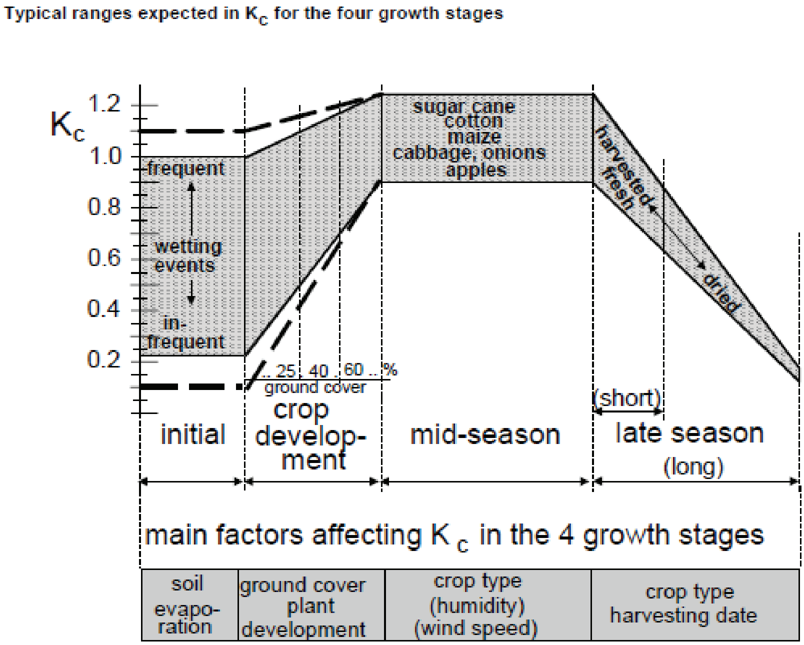
3. MODEL AND THE ANALYSIS OF CROP WATER REQUIREMENT

3.1 Crop Water Requirement

The virtual water for crops is the crop water requirement during the whole growing period, and there are a number of methods to calculate the crop water requirement. In this study, the method suggested by the FAO Irrigation and Drainage Paper #56 “Crop Evapotranspiration (ET)” was adopted to calculate the cumulative ET i.e., ET_C (mm/day) of the whole growing period of crops. The ET_C is the product of reference ET (ET_O) and crop factor K_C, as shown in equation (1):

$$ET_C\ (mm/day) = K_C \times ET_O \tag{1}$$

In equation (1), crop factor is the ratio: (ET/ET_O). There are factors affecting the crop factor, and are illustrated in Figure 1.



Typical ranges expected in K_C for the four growth stages

Fig. 1. Illustration on the Variation of Crop Factor affected by other Parameters (Allen et al., 1998)

For the estimation of ETO, the revised FAO Penman-Monteith equation (Allen, et. al., 1998) was used, as shown in equation (2).

$$ET_O(mm/day) = \frac{0.408\Delta(R_n - G) + \gamma\frac{900}{T+273}U_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34U_2)} \qquad (2)$$

where,

Δ : slope of the saturation vapor pressure temperature relationship [KPa/°C]

T : mean air temperature [°C]

γ : psychrometric constant [KPa/°C)

e_s : mean saturation vapor pressure [KPa]

R_n : net radiation on the crop surface [$MJ/m^2 \times day$]

G : soil heat flux [$MJ/m^2 \times day$]

U_2 : measured wind speed at 2 meter height [m/s]

e_a : actual vapor pressure [KPa]

3.2 Estimation of Water Requirement for Irrigation Schemes - FAO-CROPWAT

CROPWAT is an irrigation planning and management model developed by the Land and Water Development Division of FAO. The most common version now is CROPWAT 8.0 Edition (2009), which was developed under the assistance from the University of Southampton and Institute of Irrigation and Development Studies. This edition can be used under WINDOWS.

Major input parameters of the program are agricultural meteorological data, crop growth data, and soil data, which include (1) meteorological data: highest temperature, lowest temperature, wind speed, sunshine, relative humidity, and rainfall; (2) crop growth data: growing days, crop factor, depth of root system; and (3) soil data: effective moisture, infiltration rate, and starting soil moisture. After the input of basic data, associated 10-day data (commonly used in Taiwan) over the growing period can be calculated. These data include crop factor, index of leaf area, crop evapotranspiration, percolation, water requirement for land preparation, effective rainfall, and irrigation water requirement for crops.

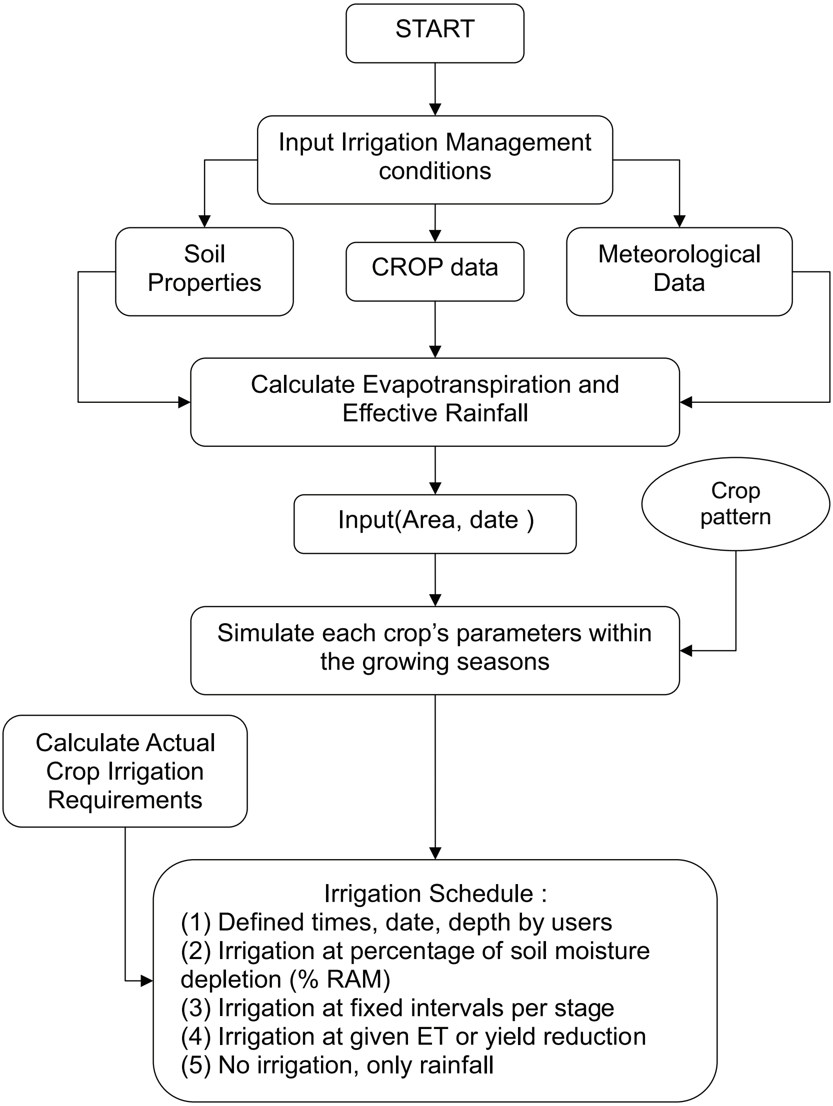
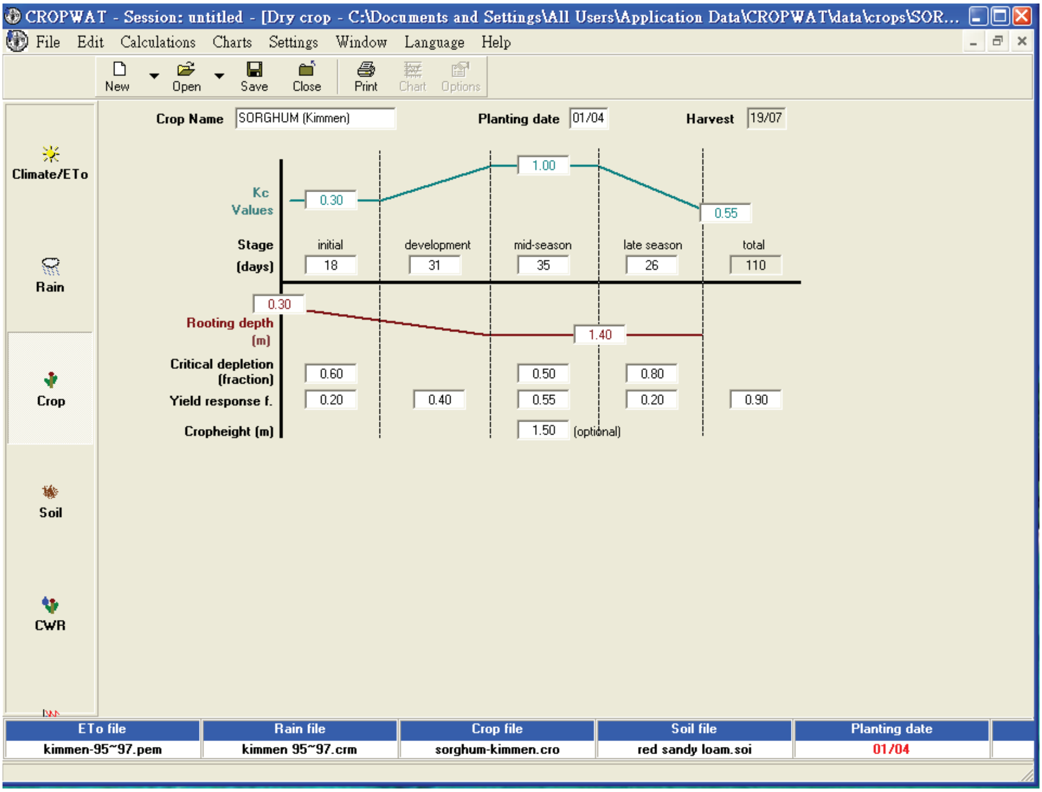


Fig. 2. Flowchart for CROPWAT 8.0 (Molua and Lambi, 2005, redrawn for this study)

In addition, the irrigation period can be determined according to different irrigation methods, including (1) optional numbers of irrigation, time, and depth, (2) optimal irrigation, (3) practical irrigation, (4) irrigation under water-shortage, and (5) no irrigation. When irrigation period is determined, the model starts to calculate the actual field water budget and irrigation water during the growing period of crops, including (1) numbers of irrigation, time, and depth, (2) reducing percentage of soil moisture, (3) percolation, (4) actual ET, (5) irrigation, and (6) crop production, etc. (Kuo, 2001). The flowchart of CROPWAT is depicted in Figure 2, and the screen for the input data of CROPWAT 8.0) is shown in Figure 3.



Crop Name SORGHUM (Kimmen) **Planting date** 01/04 **Harvest** 19/07

Stage	initial	development	mid-season	late season	total
Kc Values	0.30		1.00	0.55	
Stage (days)	18	31	35	26	110
Rooting depth (m)	0.30		1.40		
Critical depletion (fraction)	0.60		0.50	0.80	
Yield response f.	0.20	0.40	0.55	0.20	0.90
Cropheight (m)			1.50 (optional)		

ETo file	Rain file	Crop file	Soil file	Planting date
kimmen-95~97.pem	kimmen 95~97.crm	sorghum-kimmen.cro	red sandy loam.soi	01/04

Fig. 3. Data Input for CROPWAT 8.0

4. CALCULATION OF VIRTUAL WATER FOR CROPS

For crops, the calculation of crop virtual water requires the accumulation of the total water used during the life process from the planting of crops until final harvesting. In order to precisely calculate the virtual water for crops, Hoekstra and Hung firstly proposed an optimal quantification method on the International Experts Meeting of Virtual Water Trade, the Netherlands, in 2003. The method was based on the theory of crop ET, and expanded to establish a quantification model of global virtual water transaction for crops. The first stage of the model was to follow the characteristics of agricultural meteorological data as well as crop growth to simulate actual situation, then to estimate the crop ET for the whole growing period. The second stage was to convert the crop ET into the crop water requirement per unit area by multiplying the accumulated ET with the field area, then divided by the size of the unit area (eq. 3). And the last stage was to calculate the crop virtual water per unit weight. The crop water requirement per unit area (m3/ha) was divided by the crop yield per unit area (ton/ha), and the crop virtual water per unit weight is obtained (eq. 4).

$$\mathrm{CRW(m^3/ha)} = \frac{\mathrm{mean - evapotranspiration(mm/day) \times growth - days(day) \times area(m^2)}}{\mathrm{Total - area(ha)}} \qquad (3)$$

$$\text{Virtual water } (\mathrm{m}^3/\mathrm{ton}) = \frac{\mathrm{CRW}(\mathrm{m}^3/\mathrm{ha})}{\mathrm{total}-\mathrm{yield}(\mathrm{ton}/\mathrm{ha})} \qquad (4)$$

5. CASE STUDY AND DISCUSSION

Kinmen, an off-island to the west of Taiwan, was selected as the case study area along with its upland crops. Situated in the sub-tropical oceanic climate region, the mean temperature of Kinmen is 21^{0}C with highest reaching 33^{0}C in July and August, and lowest reaching 10^{0}C during January to March. Rainfall is scarce throughout the year with annual average below 1,100mm, and is unevenly distributed. In addition, the evaporation reaches 1,400 mm, farm land is poor with low water retaining capability, and is thus not suitable for growing crops with high water requirement (Kinmen Agricultural Research Institute web site, 2009). As a result, upland crops like sorghum and wheat are favored on the island not only due to their ability to endure drought, but also because they could be processed into products with high economic values. Especially, the Kinmen Kaoliang (local name for sorghum) liquor is famous and widely preferred by visitors.

The CROPWAT Model from FAO is adopted in this study to calculate the water requirements for Kinmen Kaoliang and wheat. Following the 2-stage procedure of the model by using the reference ET and growth data for sorghum and wheat, the ET of Kinmen Kaoliang and wheat were calculated first. Then the virtual water transaction of Kinmen Kaoliang liquor is obtained from the water requirements of sorghum and wheat per ton, which are calculated from land area and crop yield. Finally the virtual water values for Kinmen Kaoliang and wheat are obtained by inputting market prices. In order to compare as well as analyze the virtual water values for Kinmen Kaoliang and wheat, the sorghum and wheat from the main island of Taiwan are added in this study. And the computational flowchart is shown in Figure 4.

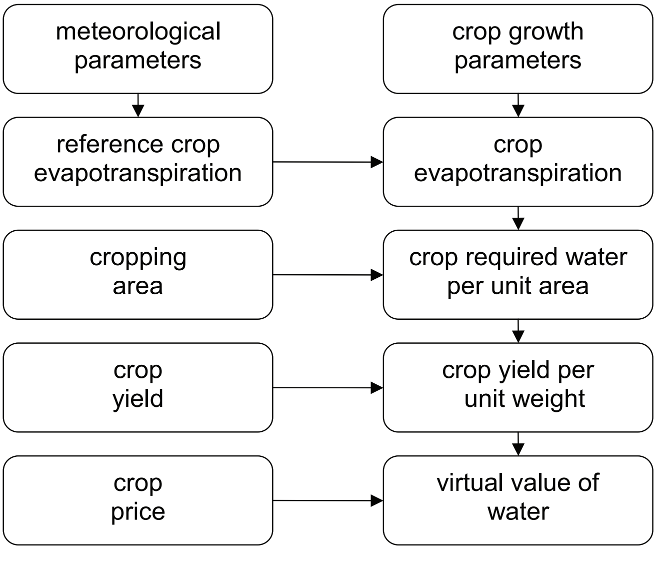


Fig. 4. Computation flowchart for virtual water values for upland crops

5.1 Inputting irrigation data for CROPWAT

1. Climate data

The annual mean monthly meteorological data of Kinmen and Taiwan from 2004 to 2008, including latitude and longitude information of the observation stations, altitude, minimum temperature, maximum temperature, relative humidity, wind speed at 2 meter height, sunshine hours, and rainfall, were input to the model for calculation. Data of Kinmen were provided by the Kinmen Agricultural Research Institute, while the data of Taiwan were quoted from the agricultural meteorological data of Wufong Agricultural Research Institute in Taichung.

2. Growing stage data for sorghum and wheat

Crop growth data include crop factor, growing days, crop height at maturity stage, root depth, critical dissipation rate, and yield factor, and the input parameters are shown in Table 1 and 2. The crop factors for sorghum and wheat were taken from the crop data in the CROPWAT model, the growing days and crop height of Kinmen Kaoliang and wheat are taken from the "Introduction of growing crops" from Kinmen Agricultural Research Institute. Likewise, the data for Taiwan sorghum and wheat are referred to the Guide Book of Taiwan farms.

Table 1. Growing stage data of sorghum from Kinmen and Taiwan

Item	Growing Stage	Initial stage	Developing stage	Middle stage	Final stage	Total
Crop factor		0.30	-	1.00	0.55	-
Kinmen	Growing days for spring crop(day)	18	31	35	26	110
	Growing days for autumn crop (day)	20	35	40	30	125
	Assigned crop height(m)	0.3	-	1.30	-	-
Taiwan	Growing days for spring crop(day)	17	29	34	25	105
	Growing days for autumn crop (day)	17	29	34	25	105
	Assigned crop height(m)	0.3	-	1.37	-	-

Table 2. Growing stage data of wheat from Kinmen and Taiwan

Item	Growing Stage	Initial stage	Developing stage	Middle stage	Final stage	Total
Crop factor		0.30	-	1.15	0.30	-
Kinmen	Growing days (day)	36	36	49	36	157
	Assigned crop height(m)	-	-	0.83	-	-
Taiwan	Growing days (day)	35	35	47	35	152
	Assigned crop height(m)	-	-	0.93	-	-

5.2 Calculation outcome of CROPWAT

As the planting dates for sorghum and wheat may be affected by weather, there are no fixed planting dates. As a result, three dates for sorghum and wheat, respectively, were input to the CROPWAT model to calculate the average ET, effective rainfall, and irrigation requirements for sorghum and wheat during 2004 and 2008, and the impact of different planting dates on the crop water consumption. The spring crop of Kinmen Kaoliang, 2004 is taken as an example here (Table 3), and the ET, effective rainfall, and irrigation water requirement for the unit time of ten days, which is extensively used in Taiwan, are calculated. The irrigation water requirement is obtained by subtracting the ET with the effective rainfall, and the water requirement for growing the spring crop of Kinmen Kaoliang, 2004 is obtained by summing up the ET, effective rainfall, and irrigation requirements of every ten-day period; likewise for other crops of other years, as shown in Table 4.

Table 3. Water use for the growing of spring crop of Kinmen Kaoliang, 2004

Planting date		**Spring crop of Kinmen Kaoliang**								
		2004/03/25			**2004/04/05**			**2004/04/15**		
Month	**Ten-day**	**ETC (mm/dec)**	**Eff rain (mm/dec)**	**Irr. Req. (mm/dec)**	**ETC (mm/dec)**	**Eff rain (mm/dec)**	**Irr. Req. (mm/dec)**	**ETC (mm/dec)**	**Eff rain (mm/dec)**	**Irr. Req. (mm/dec)**
March	3	7.4	3.5	3.9						
April	1	11.2	5.9	5.3	6.7	3.5	3.2			
	2	15.8	6.4	9.3	11.7	6.4	5.3	7.0	3.8	3.2
	3	25.2	13.5	11.6	15.2	13.5	1.7	11.9	13.5	0.0
	subtotal	52.2	25.8	26.2	33.6	23.4	10.2	18.9	17.3	3.2
May	1	34.2	25.2	9.0	24.3	25.2	0.0	15.2	25.2	0.0
	2	40.4	33.5	6.8	33.8	33.5	0.3	24.5	33.5	0.0
	3	49.7	24.3	25.4	49.8	24.3	25.4	42.0	24.3	17.6
	subtotal	124.3	83.0	41.2	107.9	83.0	25.7	81.7	83.0	17.6
June	1	51.0	8.9	42.0	51.3	8.9	42.4	51.1	8.9	42.2
	2	54.7	0.0	54.7	56.1	0.0	56.1	56.0	0.0	56.0
	3	45.8	9.1	36.7	54.6	9.1	45.5	55.1	9.1	46.0
	subtotal	151.5	18.0	133.4	162.0	18.0	144.0	162.2	18.0	144.2
July	1	35.6	21.0	14.6	45.7	21.0	24.7	53.3	21.0	32.3
	2	5.9	5.7	0.2	35.6	28.5	7.1	45.1	28.5	16.6
	3				8.7	9.7	0.0	38.0	35.6	2.4
	subtotal	41.5	26.7	14.8	90.0	59.2	31.8	136.4	85.1	51.3
August	1							5.6	8.4	0.0
Total		376.8	157.1	219.5	393.6	183.8	211.7	404.7	212.0	216.3

ET_C: Crop evapotranspiration; Eff rain: Effective rainfall; Irr. Req: Irrigation water requirement

It can be observed from Table 4 that, only the early planting of the autumn crop of sorghum in Taiwan could reduce the irrigation water requirement, others are not significant. And comparing the water used for growing sorghum and wheat in Kinmen and Taiwan, it is found that growing spring crop as well as autumn crop sorghum in Taiwan consumes less irrigation water requirement, while growing wheat in Kinmen conserves more irrigation water resources.

Table 4. Water use for the growing of spring and autumn crops of sorghum and wheat in Kinmen and Taiwan (average and total of 2004~2008)

area	item / Crop	Spring sorghum				Autumn sorghum				Wheat			
Kinmen	Planting date	3/25	4/05	4/15	average	7/25	8/05	8/15	average	11/15	12/01	12/15	average
	ET_C (mm)	328.3	345.7	359.8	344.6	419.2	406.3	392.2	405.9	377.9	387.3	397.3	387.5
	Eff rain (mm)	362.0	375.6	387.0	374.9	320.2	290.8	248.1	286.4	144.4	180.9	240.8	188.7
	Irr. Req. (mm)	111.5	119.6	127.6	119.6	259.7	252.0	262.1	257.9	261.5	247.5	232.7	247.2
Taiwan	Planting date	3/05	3/25	4/15	average	7/05	8/01	8/25	average	10/15	11/01	11/15	average
	ET_C (mm)	309.1	316.1	335.5	320.2	332.1	311.3	288.5	310.6	371.6	380.3	391.9	381.3
	Eff rain (mm)	464.6	645.2	860.1	656.6	744.5	446.3	294.8	495.2	97.2	116.6	131.8	115.2
	Irr. Req. (mm)	90.3	67.8	60.9	73.0	93.5	139.3	186.1	139.6	303.0	286.2	278.2	289.1

5.3 Crop virtual water value for sorghum and wheat

In order to show the actual water used per unit weight of crops and the economic production values obtained from the planted crops per unit water resources, the planting area, crop yield, and market price were added in this study to calculate the virtual water and virtual water values for sorghum and wheat in Kinmen and Taiwan. The results are shown in Table 5, which could be used to compare the water prices and benefits for growing sorghum and wheat in Kinmen and Taiwan.

The virtual water and virtual water values for sorghum and wheat in Kinmen and Taiwan are compared as follows.

1. Comparison of virtual water for spring and autumn crops of sorghum and wheat in Kinmen and Taiwan

From Table 5, the virtual water for spring crop of Kinmen Kaoliang is 5,030.7(m^3/ton), which is far higher than the autumn kaoliang with 2,598.6(m^3/ton) and wheat with 2,022.4(m^3/ton). The main reason for higher virtual water in the spring crop of Kinmen Kaoliang is due to the low yield per unit area. And when the crops from Taiwan are included for comparison, it can be found that regardless of which crop, the virtual water in Kinmen is always higher. In other words, growing sorghum and wheat in Kinmen where water resources is insufficient, overall speaking from the viewpoint of water resources, is considered high cost.

2. Comparison of virtual water values for spring and autumn crops of sorghum and wheat in Kinmen and Taiwan

From Table 3, it can be seen that although the virtual water has only minor difference, the virtual water value for the autumn crop of Kinmen Kaoliang is much lower than that of Kinmen wheat, and the reason is that the market price for sorghum is much lower than wheat. The same situation is also observed in Taiwan. Therefore, in Kinmen area the water resources depletion could be alleviated while water use efficiency could be raised if the planting area for sorghum is reduced and the planting of wheat is increased. As for Taiwan, for higher efficiency, growing wheat is a better decision.

When the virtual water values for both crops from Kinmen and Taiwan are joined for comparison (Fig. 5), it is observed that the virtual water values for both sorghum and wheat in Kinmen are lower than those in Taiwan. This means that growing either crop in Kinmen, not only the cost is much higher, but also the water resources use efficiency is far lower. It is thus learned that, although the selection of crops with lower water consumption could reduce the consumption of water resources, the optimal use of water resources could be reached if the market prices is included for reevaluation.

Table 5. Virtual Water Values for the spring and autumn crops of sorghum and wheat in Kinmen and Taiwan (average of 2004~2008)

area	item / Crop	Cultivation area (ha)	Total yield (ton)	Yield per unit area (ton/ha)	Crop water requirement (m^3/ha)	Virtual water (m^3/ton)	Price for sorghum ($NT/ton)	Virtual water value ($NT/$m^3$)
Kinmen	Spring Kaoliang	291.6	199.8	0.685	3446.0	5030.7	14000	2.8
	Autumn Kaoliang	1911.4	2985.4	1.562	4059.0	2598.6		5.4
	wheat	1402.3	2686.5	1.916	3875.0	2022.4	22000	10.9
Taiwan	Spring sorghum	1583.6	6662.1	4.207	3202.0	761.1	14000	18.4
	Autumn sorghum	1583.6	6662.1	4.207	3106.0	738.3		19.0
	wheat	67.9	258.6	3.809	3813.0	1001.1	22000	22.0

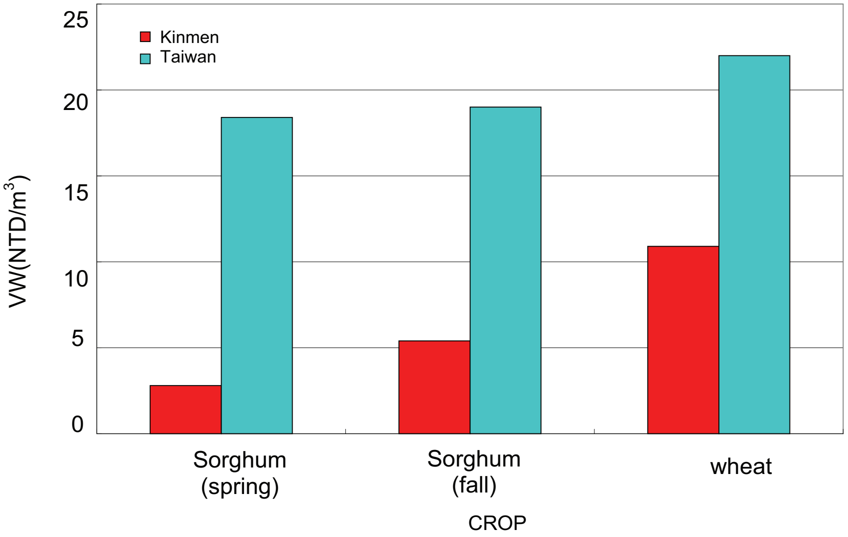


Fig. 5. Comparison of virtual water values for spring and autumn crops of sorghum and wheat in Kinmen and Taiwan

6. CONCLUSIONS

Virtual water resource is the water resource which is consumed in the process of producing crops or industrial products. It reflects the water usage as well as water consumption in the production process, and is regarded as the Water-Consumption Index for evaluating any commodity. It is not limited in the evaluation of water consumption of crops. When the consideration of market price is included, it can even reflect the benefit of water usage for every commodity. If the virtual water quantity and virtual water value of the import and export products are evaluated first, then the products with lower virtual water quantity and higher virtual water value are selected for export, while the commodity with higher virtual water quantity for import, and the cost-benefit of water resources usage will be improved.

Based on the Penman-Monteith Evapotranspiration Method (FAO), the evapotranspiration, effective rainfall, and irrigation requirement in the whole growth period for Kinmen sorghum (Kaoliang) and wheat were estimated with CROPWAT Model. The results show that the water requirement for the spring crop of Kinmen Kaoliang (119.6 mm/day) is lower than those of sorghum (257.9 mm/day) and wheat (247.3 mm/day), thus, growing spring-crop kaoliang in Kinmen is able to reduce the consumption of irrigation water. When the same technique is adopted to Wufong on the main island of Taiwan to estimate the water requirements of sorghum and wheat, and the results show that growing sorghum in the main island of Taiwan saves more water resources, yet growing wheat saves more in Kinmen.

As the variation in the unit area yield and value can affect the benefit of using water resources, the crop yield per unit area and the market price per unit weight were further included in this study to calculate the virtual water value for sorghum and wheat. The results show that the virtual water values of the spring crop of Kinmen Kaoliang (NT$ 2.8 /m^3), autumn crop of Kinmen Kaoliang (NT$ 5.4 /m^3) and wheat (NT$ 10.9 /m3) are lower than those on the main island of Taiwan, namely NT$ 18.4 /m^3 for spring crop sorghum, NT$ 19.0 /m^3 for autumn crop sorghum, and NT$ 22.0 /m3 for wheat. It is concluded that growing sorghum and wheat in Kinmen, where water resource is insufficient, is considered high cost from the viewpoint of water resources. Nonetheless, if the idea of "growing elsewhere but producing in Kinmen" is accepted, then the water shortage problems in Kinmen could be alleviated, and the social cost for Kinmen Kaoliang liquor would be lower as well.

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