Comparative Study of Green Water Footprint Estimation Methods for Thailand: A Case Study of Cassava-based Ethanol

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Abstract

Numerous water footprint studies published over the past decade have evaluated consumptive water use for various products and different contexts. Most of them are based on the FAO CROPWAT model using the USDA-SCS method for green water estimation. The proper estimation method of green water use is essential for improving accuracy of the results. In this study, the USDA-SCS, the Fixed percentage and the FAO/AGLW methods for the estimation of the green water use of cassava-based ethanol were compared against the daily soil water balance method in order to test the suitability of these methods for water footprinting studies in Thailand. One ton of cassava-based ethanol product was set as a functional unit. The reference year of the data was 2010. The study has shown that the USDA-SCS, the Fixed percentage and the FAO/AGLW methods underestimate the green water footprint by the average of 54, 56 and 70 percent, respectively. The effect of this will lead to overestimation of the blue water component of the water footprint and increase the opportunity costs of blue water uses. Therefore, it can be concluded that all three methods commonly used for estimating green water use are not appropriate for the conditions in Thailand

Key Words: Green water footprint/ FAO CROPWAT/ Cassava-based ethanol/ Thailand

1. Introduction

Over the last decade, there have been a growing number of studies of water footprint in many countries (Adeoti, 2010; Bulsink, et al., 2010; Chahed et al., 2008; Hoekstra and Chapagain, 2007; Zhao et al., 2009), including Thailand (Pongpinyopap and Mungcharoen, 2011). Hoekstra et al. (2011), recommend to use the CROPWAT (FAO, 2009) software for computation because of its wide application, online availability, good documentation and embedding in FAO practice. The most important step in calculation of the water footprint of crops and derived crop products is to distinguish between green (effective rainfall) and blue (irrigation requirement) water components because any error in the estimation of green water use will be transferred directly to the estimate of blue water use. The CROPWAT model offers several methods to estimate monthly effective rainfall. These methods are the Fixed percentage, the FAO/AGLW and the USDA-SCS. Many water footprint studies have generally used USDA-SCS method for effective rainfall due to its simplicity and being only a function of monthly precipitation (Chapagain and Orr, 2008; Chapagain and Orr, 2009; Chapagain and Hoekstra, 2010). The USDA-SCS method was calibrated on 50 years of rainfall records at 22 locations only throughout the United States. Although it has performed quite well for well-drained soils in the USA– Mohan et al. (1996) found that it under-predicted effective rainfall in India compared to other methods, Hess (2010) also found that it was less accurate in the estimation of effective rainfall in England– Patwardhan (1990) reported that the best estimates of effective rainfall could be obtained by conducting soil water balance computations. Thus, it is quite

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inappropriate for estimating effective rainfall outside the USA.

This paper, aims to compare the estimates of green water use (effective rainfall) based on empirical method from the Fixed percentage, the FAO/AGLW and the USDA-SCS methods, with estimates based on daily soil water balance, in order to test the suitability of each approach for use in water footprinting studies in Thailand. The functional unit in this study was 1 ton of cassava-based ethanol product. The reference year of the data was 2010.

2. Methodology

2.1 Virtual water content of fresh cassava root

According to Chapagain et al. (2006), The Virtual water concept, is the volume of water needed to produce a good or a commodity. In this study, the virtual water content of fresh cassava root (in m^3/ton) was evaluated as the ratio of the volume of water (in m^3/rai) needed during the entire period of cassava crop growth to the corresponding crop yield (in ton/rai). The volume of water needed to grow cassava root in the field will have two components: one, the use of effective rainfall (green water), and two, the use of irrigation water (blue water). The green water use is equal to the minimum effective rainfall and the crop water requirement at that time-step. Total green water use in crop production is calculated by summing-up green water use for each time-step over the entire length of crop period. The blue water use is calculated as the difference between crop water requirement and green water use at that time-step. Total blue water use in crop production is calculated by summing-up blue water use for each time-step over the entire length of crop period. Green water use is independent of irrigation water supply and solely depends on the effective rainfall and crop water requirements, whereas blue water use depends on crop water requirement, green water availability and irrigation water supply. The irrigation requirement is zero if effective rainfall is larger than the crop water requirement (Chapagain and Orr, 2009). The crop water requirement (CWR) is calculated by multiplying the reference crop evapotranspiration (ET_o) by the crop coefficient (K_c). The crop coefficients for the cassava plant were taken from Kwanyuen et al. (2010). The reference crop evapotranspiration (ET_o) is calculated by multiplying the pan evaporation coefficient (K_p) by the pan Evaporation (E_p). The pan evaporation coefficient was taken from Kwanyuen et al. (2010), while data on pan Evaporation were obtained from the Thai Meteorological Department (2010).

2.2 Cassava-based ethanol

In Thailand, Cassava can be planted and harvested at any time of the year. There were 46 provinces with cassava planting in 2010 (Office of Agricultural Economics, 2010). In practice, most crops are typically planted before the rainy period (March/ April/ May) and some are after the rainy period (November/ December/ January) (Phujaroen, 2008). In this study, it is assumed that planting will start in May and roots harvested as from the twelfth month. The climate data in each province are using data from Meteorological station located near the crop field (Thai Meteorological Department, 2010). The data on crop production per unit area of land (ton/rai) were obtained from the Office of Agricultural Economics (Office of Agricultural Economics, 2010). After being harvested, cassava roots are readily converted to dried chips using only a simple chopping machine. After chopping into small pieces, the chips are sun-dried on a cement floor. The conversion ratio of feedstock (ton) to dried chips is approximately about 2.25:1 and water is not required in process. From dried cassava chips to dry (or fuel) ethanol, the processes included in this stage consist of milling, mixing and liquefaction, saccharification, fermentation, distillation, and dehydration. In order to produce 1 ton of anhydrous ethanol, approximately 3.06 ton of dried cassava chips (65% starch content) are required. About 3.78 m^3 of water is required in this process (Sriroth, 2010).

2.3 Effective rainfall methods

Numerous methods for estimating effective rainfall have been proposed in the past, including: direct measurement techniques, empirical methods, and soil water balance methods. As mentioned above, there are several options to estimate monthly effective rainfall based on empirical method in CROPWAT software. Details of each option are described in the following sections.

2.3.1 Fixed percentage

Effective rainfall is a fixed percentage of actual rainfall, being calculated according to:

$$P_{eff} = \text{Fixed percentage} * P \quad (1)$$

Where P is the gross monthly rainfall. The fixed percentage is to be given by the user to account for the losses due to runoff and deep percolation. Normally losses are around 10 to 30%, thus the fixed percentage equal to 0.7-0.9. The fixed percentage value of Thailand was 0.8 (Dastane, 1974).

2.3.2 FAO/AGLW

Based on an analysis carried out for different arid and sub-humid climates, an empirical formula was developed in the Water Service of FAO to estimate dependable rainfall, the combined effect of dependable rainfall (80% probability of exceedance) and estimated losses due to Runoff and Deep Percolation. This formula may be used for design purposes where 80% probability of exceedance is required. Calculation according to:

$$P_{eff} = 0.6 * P - 10 \quad (2)$$

for P <= 70 mm

$$P_{eff} = 0.8 * P - 24 \quad (3)$$

for P > 70 mm

where P is the gross monthly rainfall.

2.3.3 USDA Soil Conservation Service

The United States Department of Agriculture's Soil Conservation Service has developed a technique to predict effective rainfall by processing long climatic and soil moisture data. The USDA SCS method estimates monthly effective rainfall from gross rainfall, soil water holding capacity and ET_c. It was calibrated on 50 years of rainfall records at 22 locations throughout the United States. The effective rainfall is calculated according to the formula developed by USDA Soil Conservation Service which is as follows:

$$P_{eff} = P * (125 - 0.2 * P) / 125 \quad (4)$$

for P <= 250 mm

$$P_{eff} = 125 + 0.1 * P \quad (5)$$

for P > 250 mm

where P is the gross monthly rainfall.

2.3.4 Daily Soil Water Balance Method

A daily soil water balance is rather like a bank account. Rainfall and irrigation are on the credit side, while soil moisture depletion is on the debit side. Precise data on the maximum water holding capacity (field capacity) is necessary for this method. Any amount in excess of this capacity is a surplus and will be a deep percolation loss or runoff. When the balance reaches nil, no more withdrawal is possible and hence further depletion is treated as water deficiency.

Rainfall and irrigation are directly measured while the evapotranspiration is computed from any of several available formulae (Dastane, 1974). Hence, the daily soil water balance equation in form of expression is:

$$\Delta SW = (P + I + C) - (ET + D + RO) \quad (6)$$

where:
ΔSW = the change in soil moisture storage in the crop root zone (mm)
P = rainfall (mm)
I = irrigation (mm)
C = contribution from the groundwater table (mm)
ET = evapotranspiration (mm)
D = deep drainage (mm)
RO = surface run-off (mm)

In this study, the data of maximum water holding capacity (field capacity), permanent wilting point and average available water capacity in each provinces for the cassava plantation were taken from Office of Science for Land Development (Office of Science for Land Development, 2011). It is assumed that the soil water content is never allowed to fall below a permanent wilting point. When soil water content is depleted to the lower limit of available water capacity, irrigation is applied.

3. Results and Discussion

Figure 1 shows the effective rainfall (green water) for cassava at each province estimated by different methods. It shows that the FAO/AGLW method produced lowest estimates of the green water use at all provinces followed by the Fixed percentage, the USDA-SCS methods and the soil water balance method, respectively. The underestimation of green water use are about 54, 56 and 70 percent, compared to the soil water balance method, were derived from the USDA-SCS, the Fixed percentage and the FAO/AGLW methods, respectively. These results are consistent with Mohan et al. (1996) which reported that the effective rainfall estimates by the soil moisture water balance method were generally higher than those by the USDA-SCS method. This difference is ascribed to the fact that the latter considers only evapotranspiration and the period of estimation is a month whereas the former does a continuous accounting of different components on a daily basis. The provision of additional storage space makes the soil moisture water balance method result in effective rainfall higher estimates. Surprisingly, the USDA-SCS method which popular used to estimate effective rainfall in previous water footprint studies underestimated effective rainfall by 54 percent with the soil water balance method, perhaps reflecting the differing rainfall characteristics of Thailand compared to the USA. The effective rainfall value obtained from the soil water balance method indicated that cassava can grow without irrigation which corresponds to Phujaroen (2008) and Damen (2010). This suggests that the estimate of green water use of cassava derived from the soil water balance method is more appropriate for conditions in Thailand than the other methods based on empirical method. These methods are implemented in the CROPWAT software.

The weighted average water footprint of cassava-based ethanol production in Thailand estimated by different methods is shown in Figure 2. The total weighted average water footprint of cassava-based ethanol production is 2405 m^3/ton. The value obtained is similar to Damen (2010). This amount does not include the water footprint relating to pollution control via field level and wastewater flows from processing sites. Green water is found to contribute 99, 46, 44 and 30 percent of the total water footprint of cassava-based ethanol, were obtained from the soil water balance, the USDA-SCS, the Fixed percentage and the FAO/AGLW methods, respectively. The error in the estimation of green water use will result in the estimate of blue water use. The overestimation of blue water use are about 1287, 1340 and 1670 m^3/ton of the total water footprint of cassava-based ethanol, were derived from the USDA-SCS, the Fixed percentage and the FAO/AGLW methods, respectively. These results indicated that the effect of underestimation of green water will be to overestimate the blue water component of the water footprint, which lead to increasing opportunity costs of blue water uses.

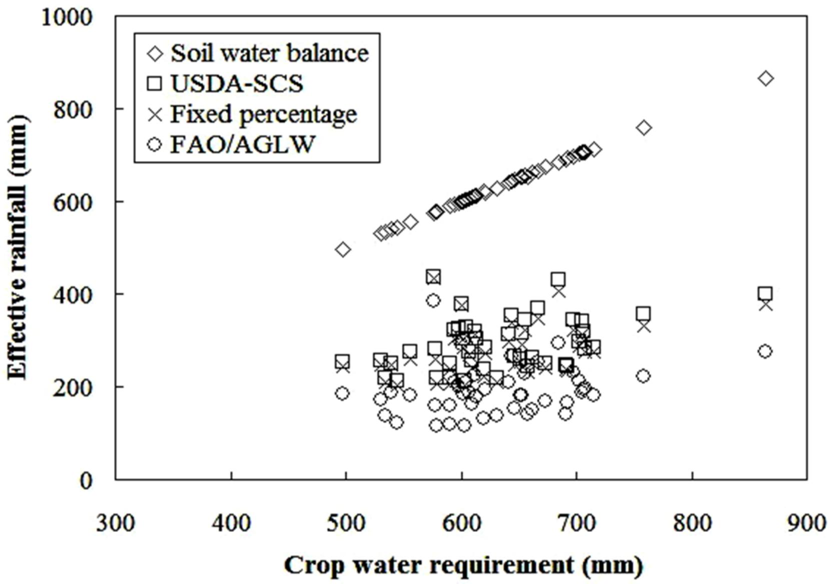

Figure 1 Comparison of effective rainfall (green water) estimated by different methods for cassava.

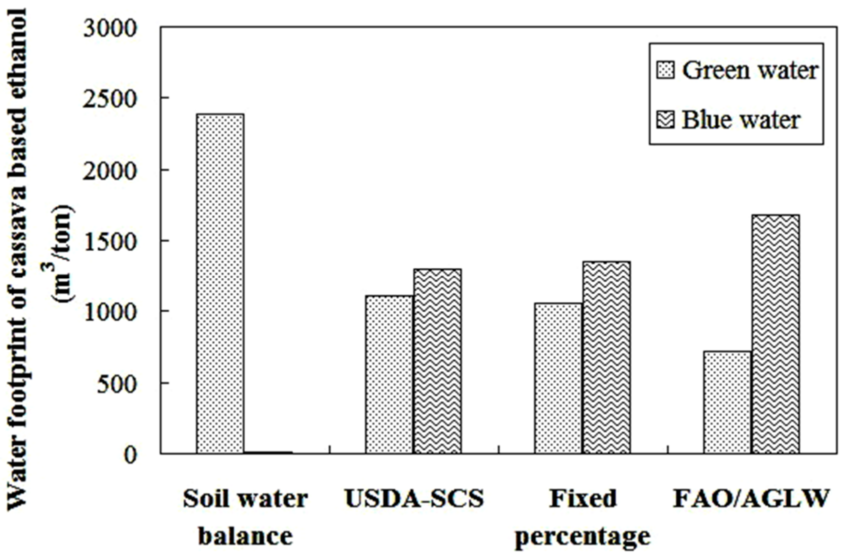

Figure 2 Comparison of weighted average water footprint estimated by different methods for cassava-based ethanol production in the Thailand.

4. Conclusion

The soil water balance model for estimating green water use is applied in evaluating the accuracy of three established green water use estimation methods in order to test the suitability of these methods for water footprinting studies in Thailand. The three methods evaluated are the Fixed percentage, the FAO/AGLW and the USDA-SCS methods. One ton of cassava-based ethanol product was set as a functional unit. The reference year of the data was 2010. The study has shown that the USDA-SCS, the Fixed percentage and the FAO/AGLW methods underestimate the green water footprint by an average of 54, 56 and 70 percent, respectively. The effect of this will lead to overestimation of the blue water component of the water footprint and increase the opportunity costs of blue water uses. Therefore, it can be concluded that all three methods commonly used for estimating green water use are not appropriate for the conditions in Thailand . Since, using the soil water balance method for estimate of green water is more complex than the empirical method. Thus, we suggest that the development of effective rainfall model based on an empirical method which is appropriate for the conditions in Thailand should be done.

5. Acknowledgement

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