A COMPUTATIONAL MODEL FOR WATER USE EFFICIENCY IN RICE PRODUCTION

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ABSTRACT

Rice farming is somewhat sentimental and many of the hard facts that intertwined with the complexity of farming are often taken for granted. The interrelationship of water use in the soil-crop-atmosphere with respect to the farming practices, the availability and economic. of water, the input cost and the profitability on rice production are attributes of this complexity. In the context of globalize trade and modernization, rice farming has to be not only more commercial but eco-efficient as well. The use of information technology (IT) to solve the burning issues of limited resource and the role of water to garnish the limited land for greater output of rice with minimum of capital input and environmental degradation is warranted. This paper present a model that address the efficiency of water use in rice production, allowing users to trends the possible limits, giving an intuitive feeling and what if situation in several probable scenarios. It explicitly deals with the aspect of water productivity due to variation in farming practices, giving tangible values relating yield, water use and its economics implication. It works on the frameworks of the boundary limit of the components of water balance at farm level, yield from crop varieties and farming practices adopted. The model is built using Visual C++ version 6 as the programming language and the model is implemented on Windows 95/98 platform. Managers and policy makers will use the model as DSS to make fair judgements on the value of water in rice production and realistic water use efficiency limit.

Keywords: productivity of water, water saving, rice production, IT, DSS.

1. INTRODUCTION

Many countries are entering the era of food and water shortage as we are cruising into the IT age. Scarcity of water for agriculture for some may be reaching critical limit as the available resources are given priorities to the other sectors (domestic, municipal, industrial and environmental needs). Rice production is a heavy consumer of water. Finding ways to increase productivity of water used is crucial. Potentials of water savings in rice production appear to be very large, not withstanding the use of IT. The future of rice production will therefore depend heavily on developing and adopting strategies and practices that will use water efficiently in irrigation schemes (Guerra et al, 1998). However, filtration of desirable theory into practice is tortuous. Findings by researchers to farmers or policy makers with regard to farming can be transmitted faster with IT albeit the right tool is available.

The complexity of the role of water in rice farm and the related eco-system is ordinarily daunting to account for. On the other hand over generalizations of its roles can be grossly misleading. The current paradigm on water as an economic good and the concern about eco-efficient farming requires the exorbitant use of water for rice production to be stopped (Seckler et al. 1998). The challenge to improve water management for the irrigated rice production system to grow more rice with less water is formidable (Tuong & Bhuiyan 1997). The issues of water use must be addressed holistically with full attention to interactions among them but practical enough to derive at a rational solution starting from the farm. A simple analytical framework for decision making to increase water use efficiency with respect to changing cultural practices, crop varieties, seasons, farm physical properties, water availability and the reflection of cost of water is warranted. This model is designed to converge complicated theory and simplified farming objective towards making a specific decision on water use in rice farming and the economic of water use. Input data is based on the local farm scenario and its production factors will determine the crop water utilization efficiency, the field water use efficiency, the productivity index of water; and the breakeven cost of irrigation water use and total water use. These output data are important parameters to indicate efficient use of water that can be deployed for decision-making.

The paper outlines the various perspectives of water use efficiency in rice production. It describes the content, mechanism and application of a model that calculates the outcome of changing various factors affecting efficient water use in rice production.

2. WATER USE EFFICIENCY

"Water-use efficiency" is intrinsically ambiguous in relation to crop production (Bhuiyan et al 1995; FAO 1979; Sharma 1989). In this paper the water-use efficiency of a crop production system can be grossly defined as the achievable crop yield/unit of water use. However, this will implicate different meaning of efficient water use, when price is factored into the crop's yield and of water use. The basic constraint in agronomic decision on the farm is made in response to the criterion of increase profitability, thus the objective of increasing water use efficiency cannot override this need. In view of the uncertainty in cost of water and return to crop production, both technical and economic aspect of water use efficiency must be considered concurrently. The terminology conventionally used as in Jensen (1980), FAO (1979) and Doorenbus & Pruitt (1992) for parameters associated with efficient water use is redefined to reflect the specific purpose in this model as follows:

CWUE	Crop Water use efficiency is defined as the ratio of crop yield (kg) per unit water use (cubic meter) by the crop due to evapotranpiration.
FWE	Field water application efficiency is defined as the % of total water required to total water supplied in the field
AFWE	The ratio of crop water requirement to total water supplied is referred to as apparent field water use efficiency
WPI	Water productivity index is the ratio of crop yield in kg per unit water supplied in cubic meter. It includes irrigation, rainfall and antecedent soil moisture
IWPI	Similar to WPI, except only irrigation water is considered as the input
BEIW	The cost of irrigation water per cubic meter that would make rice production just breakeven, this will indicate the upper limit of the value of irrigation water
BETW	The cost of total water per cubic meter that would make rice production just breakeven. This will give the added value of water (otherwise will just be an outflow from farm) due to rice farming productivity

3. METHODOLOGY

Many comprehensive models are available to determine the specific crop water requirement for examples; (CROPWAT, 1997) or crop growth and yield such as (SARP, 1994). However, these models do not address the issues related to water use efficiency. There is essentially no model that determines, simultaneously, the various indicators of water use efficiency as consequences of altering the factors affecting the water use. This model is developed on a window-based platform and designed to be more user-friendly.

The sequence of information or inputs required is partition into three distinct attributes of the system's water use efficiency. Figure 1 summarizes these factors. The FWE is determined by the water resources available (Rainfall and Irrigation) and the physical characteristic of field environment; the CWUE is determine by the biological attributes such as crop water consumption and crop yield; and the economic implication is attributed from the WPI and the return on crop production. The formulae relating the interacting factors are illustrated as in Table 2. In reality the interaction factors in each attributes are more complicated and specialized sub-model may be required.

The Visual C++ 6.0 programming software is used to develop the computational model. Figure 2 illustrates the model for Water Use Efficiency for Rice Production. The model consists of two modules, the WUE calculator and the WUE Document. The WUE Calculator is displayed on the left while the WUE Document is displayed on the right of the model.

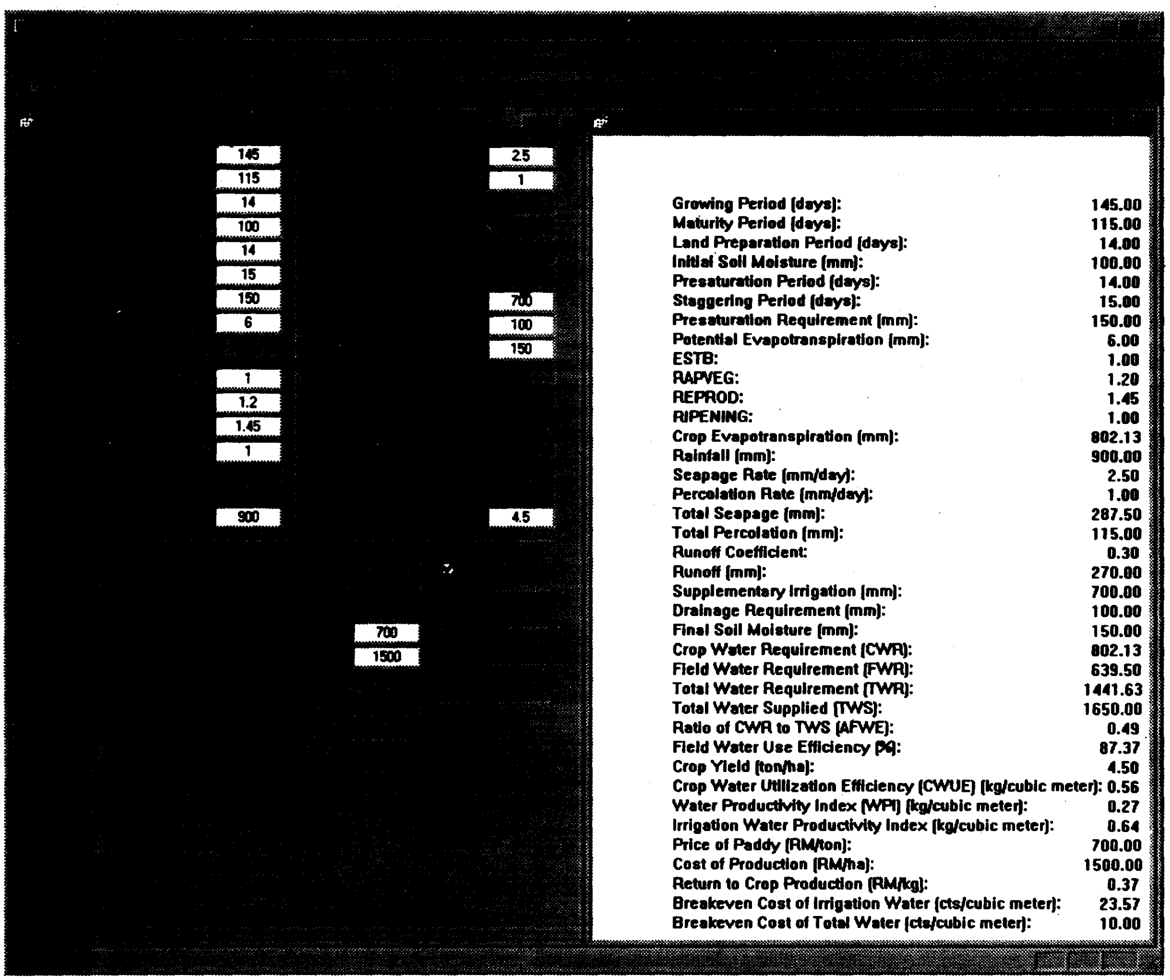

Figure 2: The Water Use Efficiency Model for Rice Production

Referring to the WUE Calculator, the input and output parameters are indicated by the bright and dark edit boxes respectively. The input parameters are listed in Table 1. They can be manipulated to calculate the values of the output parameters found in Table 6 based on the formulae and rules found in Table 2 to Table 5. The calculation can be done when required by clicking on the '*Calculate*' button. Furthermore, the user also has the option to enable '*Auto Update*' check box. '*Auto Update*' causes the model to calculate and display updated outputs whenever an edit box's value (input parameter) is changed. The user also can set the default (typical) values of the parameters by clicking on the '*Set Default Values*' button. This feature reduces the time required to key in the input parameter. The default values are shown in Table 7. In addition, the user can delete the parameter values by clicking the '*Clear All*' button. The parameter values on the WUE Document are updated with the values from the WUE Calculator when the user clicks on the 'OK' button. This document can be saved and opened for future use. Besides that, the document can also be printed. Some input parameters have upper and lower limit of values that must be adhered to. The ranges of boundary limits of the formula were experimentally field tested at MARDI Rice Research Center in Seberang Prai, Penang, Malaysia. Table 8 lists the associated parameters and their limits.

TABLE 1: THE INPUT PARAMETERS

1. Growing Period (days)	12. RIPEN
2. Maturity Period (days)	13. Rainfall (mm)
3. Land Preparation Period (days)	14. Seepage Rate (mm/day)
4. Initial Soil Moisture (mm)	15. Percolation Rate (mm/day)
5. Presaturation Period (days)	16. Supplementary Irrigation (mm)
6. Staggering Period (days)	17. Drainage Requirement (mm)
7. Presaturation Requirement (mm)	18. Final Soil Moisture (mm)
8. Potential Evapotranspiration (mm)	19. Crop Yield (ton/ha)
9. ESTB	20. Price of Paddy (RM/ton)
10. RAPVEG	21. Cost of Production (RM/ha)
11. REPROD	

where

ESTB: the crop coefficient at crop establishment stage, the time period is ¼ of the total growing period

RAPVEG : The crop coefficient at the rapid development (vegetative) stage of the sigmoid growth curve.

REPROD: The crop coefficient at the reproductive stage to flowering and heading stage

RIPEN: The crop coefficient at ripening stage, from grain filling to physiological maturity.

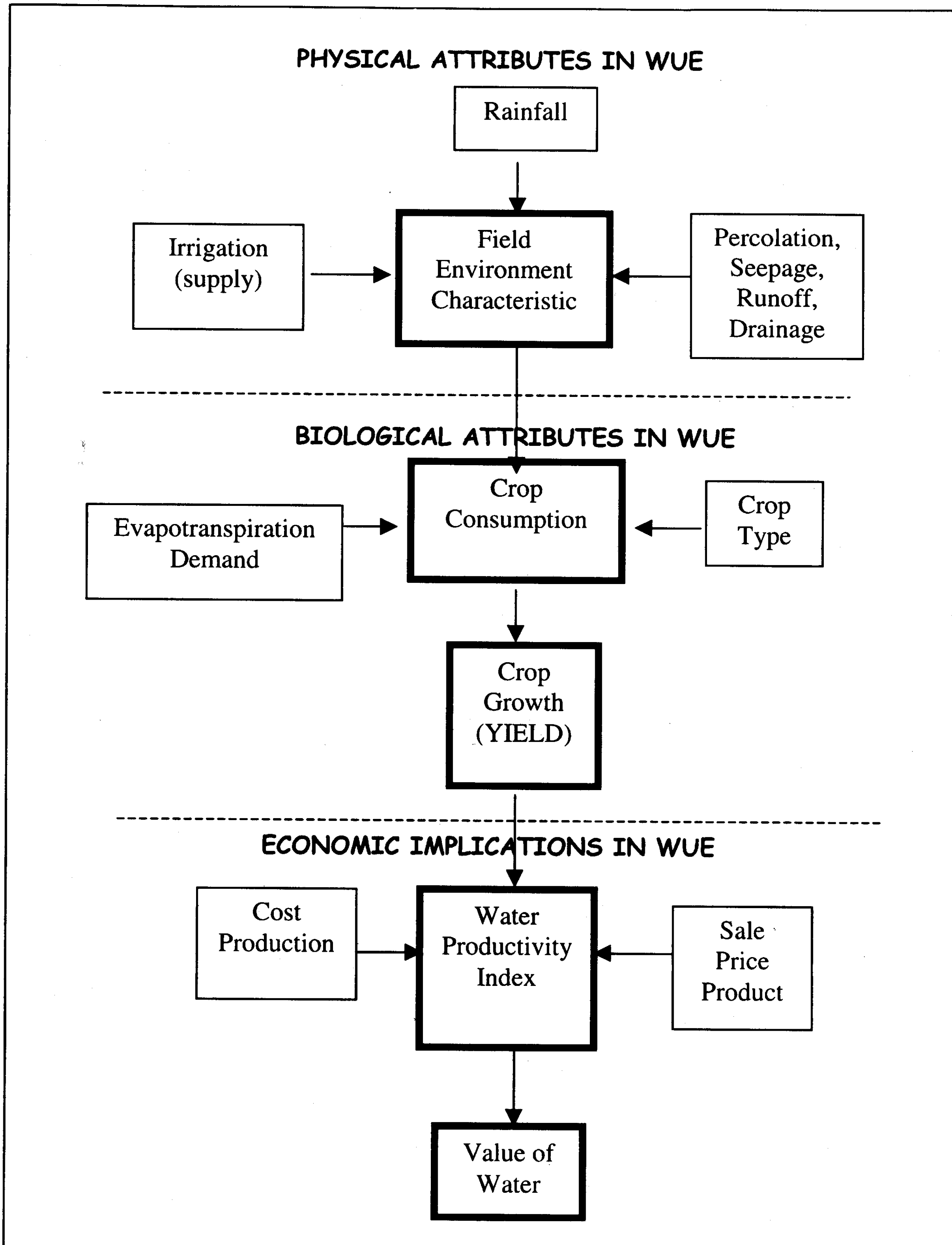

FIGURE 1. THE VARIOUS FACTORS AFFECTING WATER USE EFFICIENCY

TABLE 2: THE FORMULAE AND RULES RELATED TO WATER RESOURCES AND PHYSICAL FACTORS LEADING TO THE FIELD WATER USE EFFICIENCY

1. (Field Water Requirement (FWR)) = ((0.5*(Presaturation Period (days))*(Potential Evapotranspiration (mm)))+(0.5*(Staggering Period (days))*(Potential Evapotranspiration (mm)))+(Presaturation Requirement (mm)) +(Total Seapage (mm))+(Total Percolation (mm)));
2. (Total Seapage (mm)) = (Seapage Rate (mm/day))*(Maturity Period (days));
3. (Total Percolation (mm)) = (Percolation Rate (mm/days))*(Maturity Period (days));
4. if ((Rainfall (mm)) < 300.0)
   (Runoff Coefficient) = 0.0;
   else if (300.0 ≤ (Rainfall (mm)) ≤ 600.0)
   (Runoff Coefficient) = 0.2;
   else if ((Rainfall (mm)) > 600.0)
   (Runoff Coefficient) = 0.3;
5. (Runoff (mm)) = (Runoff Coefficient)*(Rainfall (mm));
6. (Total Water Supplied (TWS)) = (Rainfall (mm))+(Supplementary Irrigation (mm))-((Initial Soil Moisture (mm))-(Final Soil Moisture (mm)));

TABLE 3: THE FORMULAE RELATED TO BIOLOGICAL FACTORS LEADING TO CROP WATER USE EFFICIENCY

1. (Crop Water Requirement (CWR)) = (Crop Evapotranspiration (mm));
2. (Crop Evapotranspiration (mm)) = ((ESTB)+(RAPVEG)+(REPROD)+(RIPEN))*0.25*(Maturity Period (days))*(Potential Evapotranspiration (mm));
3. (Total Water Requirement (TWR)) = (Crop Water Requirement (CWR))+(Field Water Requirement (FWR));

TABLE 4: THE RULES RELATED TO INTERACTING FACTORS LEADING TO WATER PRODUCTIVITY INDEX

1. if ((Total Water Supplied (TWS)) ≠ 0.0) {
    (Field Water Use Efficiency (%)) = ((Total Water Requirement (TWR))/(Total Water Supplied (TWS)))*100;
    (Ratio of CWR to TWS (AFWE)) = (Crop Water Requirement (CWR))/(Total Water Supplied (TWS));
    (Water Productivity Index (WPI) (kg/m^3)) = ((Crop Yield (ton/ha))/(Total Water Supplied (TWS)))*100;
    }

2. if ((Crop Water Requirement (CWR)) ≠ 0.0)
    (Crop Water Utilization Efficiency (CWUE) (kg/ton)) = ((Crop Yield (ton/ha))/(Crop Water Requirement (CWR)))*100;

3. if ((Supplementary Irrigation (mm)) ≠ 0.0)
    (Irrigation Water Productivity Index (kg/m^3)) = ((Crop Yield (ton/ha))/(Supplementary Irrigation (mm)))*100;

TABLE 5: THE RULES AND FORMULAE RELATED TO FACTORS LEADING TO THE ECONOMIC IMPLICATION OF WATER

1. if ((Crop Yield (ton/ha)) ≠ 0.0)
    (Return to Crop Production (RM/kg)) = (((Crop Yield (ton/ha))*(Price of Paddy (RM/ton)))- (Cost of Production (RM/ha)))/((Crop Yield (ton/ha))*1000);

2. (Breakeven Cost of Irrigation Water (cts/m^3)) = 100*((Irrigation Water Productivity Index (kg/m^3))*(Return to Crop Production (RM/kg)));

3. (Breakeven Cost of Total Water (cts/m^3)) = 100*((Water Productivity Index (WPI) (kg/m^3))*(Return to Crop Production (RM/kg)))

TABLE 6: THE OUTPUT PARAMETERS

1. Crop Evapotranspiration (mm)
2. Total Seepage (mm)
3. Total Percolation (mm)
4. Runoff Coefficient
5. Runoff (mm)
6. Crop Water Requirement (CWR)
7. Field Water Requirement (FWR)
8. Total Water Requirement (TWR)
9. Total Water Supplied (TWS)
10. Ratio of CWR to TWS (AFWE)
11. Field Water Use Efficiency (%)
12. Crop Water Utilization Efficiency (CWUE) (kg/m^3)
13. Water Productivity Index (WPI) (kg/m^3)
14. Irrigation Water Productivity Index (kg/m^3)
15. Return to Crop Production (RM/kg)
16. Breakeven Cost of Irrigation Water (cts/m^3)
17. Breakeven Cost of Total Water (cts/m^3)

TABLE 7: THE DEFAULT/TYPICAL VALUES

1. (Growing Period (days)) = 145.0
2. (Maturity Period (days)) = 115.0
3. (Land Preparation Period (days)) = 14.0
4. (Initial Soil Moisture (mm)) = 100.0
5. (Presaturation Period (days)) = 14.0
6. (Staggering Period (days)) = 15.0
7. (Presaturation Requirement (mm)) = 150.0
8. (Potential Evapotranspiration (mm)) = 6.0
9. (ESTB Crop Coefficient) = 1.0
10. (RAPVEG Crop Coefficient) = 1.2
11. (REPROD Crop Coefficient) = 1.45
12. (RIPENING Crop Coefficient) = 1.0
13. (Rainfall (mm)) = 900.0
14. (Seepage Rate (mm/day)) = 2.5
15. (Percolation Rate (mm/day)) = 1.0
16. (Supplementary Irrigation (mm)) = 700.0
17. (Drainage Requirement) = 100.0
18. (Final Soil Moisture (mm)) = 150.0
19. (Crop Yield (ton/ha)) = 4.5
20. (Price of Paddy (RM/ton))= 700.0
21. (Cost of Production (RM/ha)) = 1500.0

TABLE 8: BOUNDARY LIMITS

i. $90.0 \leq$ (Maturity Period (days)) ≤ 140.0
ii. $1.0 \leq$ (Land Preparation Period (days)) ≤ 61.0
iii. $1.0 \leq$ (Presaturation Period (days)) ≤ 40.0
iv. $1.0 \leq$ (Seepage Rate (mm/day)) ≤ 20.0
v. $1.0 \leq$ (Percolation Rate (mm/day)) ≤ 20.0

4. RESULTS AND DISCUSSIONS

The input data to the model are derived from familiar data in rice farming, the detail are listed in Table 1. Among the most crucial inputs that are normally sensitive to the efficiency of water use include the crop maturity period, rainfall, Potential Evapotranspiration (ET), amount of irrigation water use and crop yield. While the sale and cost of crop production varies according to situation, the model will determine the economic benefit of water with and without irrigation. The changing scenario due to different crop choices, cultural practices, cropping seasons will give a wide range of selective input data that will implicate different ranges of water use efficiency and profitability. To validate our model we selected data from published field experiments (Morooka et. al 1996) conducted in the major granaries of Malaysia.

The output parameters (WUE, FEW, AFEW, WPI, IWPI) indicate the efficiency of water use from the technical viewpoint while (BEIW and BETW) indicate the economic limits of water pricing or irrigation of the production system, consequently determining its profitability. The values of each output parameter vary according to different farm management practices adopted. The technique can be used to gauge the efficiency of water use due to change in varieties, season of planting, cultural practices adopted, amount of irrigation use, the effectiveness of rainfall, the marketable yield, the market price of rice and the production cost. The model output would allow the users to draw up list of possible management alternatives based on the efficiency of water use, the added value of water due to irrigation and the cost implication of water that are most likely to be acceptable to the local situation.

Table 9 illustrates the trends in the progress of rice production in the past decades due to better crop varieties and water use pattern base on selected data input into the model. The resultant improvement in crop yield and reduce water use increased the water productivity index and subsequently the increased value that can be attached to total water use and irrigation water.

TABLE 9. THE EFFECT OF CHANGING VARIETIES AND WATER USE ON WATER PRODUCTIVITY INDEX AND THE VALUE OF WATER IN RICE PRODUCTION.

Crop Type	Water use (mm)	Yield (kg/ha)	Water Productivity Index (kg/m^3)	Total Water value (cts/m^3) [BETW]	Irrigation water value (cts/m^3) [BEIW]
Traditional variety (Long Maturity Period)	1660	2.5	0.15	1.5	-
Medium Maturity Period (1980's HYV)	1450	4	0.28	9.0	29
Short Maturity Period (1990's HYV)	1250	6	0.48	22	75
Recent released varieties (2000's HYV)	1250	9	0.72	38	133
(2000's HYV, with water saving technique)	1150	9	0.78	42	146
Super Rice variety *	1050	12.5	1.19	69	242

* The projected value base on current trends, the new "super Rice" variety is the next target of IRRI (International Rice Research Institute).

5. APPLICATION

The model is a Decision Support System (DSS) targeted for the policymakers, planners and farm managers of the public-sector irrigation schemes to more effectively allocate the increasingly scarce supply of water among competing uses. The model will give the intuitive feeling about the different objective of water management and its limitation and constraints in rice production. The model can specifically indicate the tangible gain in profit or effectiveness of water management. It is very useful when it comes to conflicting water use between urban and industrial water users verses agricultural users. The current notion that the former is accorded higher preference on the assumption that they are able to pay more may be in for a surprise. The output from the model indicated that the Water Use Efficiency (WUE) of rice production can leap frog from the current status, if we can successfully adopt new technology in water saving and use the super yield varieties. The model can be a new sources of reference to remedies the bias in valuing water in society.

TABLE 10. THE CURRENT SITUATION AND POTENTIAL IMPROVEMENT IN WATER PRODUCTIVITY INDEX IN MALAYSIA

Farm Performance	Water use (mm)	Yield (kg/ha)	Water Productivity Index (kg/m^3)	Total Water value (cts/m^3) [BETW]	Irrigation water value (cts/m^3) [BEIW]
Malaysian Average	1500	3-5	0.2-0.35	4-13	12-33
Potential Improvement	1200	9	0.75	40	160

Based on Table 10, for example, the current, productivity index of water in the major granaries of Malaysia ranges from 0.2 to 0.35 kg/m^3; based on the crop yield of 3 to 5 ton/ha, and water utilization of around 1500mm/ha. If the average yield are to be increased to 9 ton/ha and water utilization reduced to only 1200mm/ha then the Water Productivity Index (WPI) is increased to 0.75 kg/m^3. At current cost of production and sale price, the value of water (irrigation water and rainfall included) can be as high as 40 $cents/m^3$, and if 25% of it is from irrigation then the irrigation water is worth as much as 160 $cents/m^3$. This is very competitive compared to the current domestic water rate of about 100cts/m^3 . Of course, no farmer would want to pay the high price for the water, so does anybody else except when you are paying it indirectly by purchasing rice. The possibility of rice yield reaching 9 ton/ha had been proven experimentally, and the possibility of reducing irrigation water use to 25% of total water requirement is very realistic.

For planning purposes input data can draw from a varieties of possibility, starting from the default values in the model. The use of data from other generic models to calculate crop water requirements e.g CROPWAT (FAO, 1997) and rice yield e.g SARP (Kroff et. al 1994) and the associated cost of production will further enhance the model's application.

6.. CONCLUSION

Various water-saving practices and water efficient rice varieties are being introduced in many of rice farms, on the expectation of dwindling available water and stiff competition from other sectors at the expense of additional cost or reduction in rice production area. Often these new alternatives had not been properly appraised with respect to the water use efficiency technically or economically. This model, simple and comprehensive, will add a new dimension in assessing water management practices for rice farming as a choice among other models. It can indicate the certainty of the possible water cost (price) that farmers are willing to bear or defend their water right as a result of new practices or adopting better crop varieties.

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