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Rice Production and Water use Efficiency for Self-Sufficiency in Malaysia: A Review

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ABSTRACT

Rice is one of the most important staple foods for the World's population ranking third after Wheat and Maize in terms of production and consumption. Asia accounts for over 95% of global rice production with Brazil, ranked ninth as the only non-Asian nation among the World's top ten producers. China (194.3 million tonnes) and India (148.3 million tonnes), ranked first and second, respectively are by far largest producer of rice, producing half of the World's rice. Malaysia is currently ranked 25th with a production capacity of 2.4 million tonnes and fairly constant cultivable land of about 0.7 million hectares since the 1980s. Even though the land area for rice production has remained rather constant, rice productivity has been increasing every year from 2.1 in 1961 to 3.6 ton ha^{-1} in 2008 with an annual increase of 2.0% per year or about 28,000 tonnes per year. This has not in any way, guaranteed self sufficiency as over 700,000 tonnes or 30% of its rice needs were being imported from their neighboring countries annually. The study therefore, examines rice production with respect to growing population for self-sufficiency in Malaysia. This is considering past trends in rice production, water use efficiency, eating habits and prosperity level by 2015.

Key words: Rice, self-sufficiency, water use efficiency, productivity, paddy areas

INTRODUCTION

Rice constitutes one of the most important staple foods of over half of the world's population. Globally, it ranks third after wheat and maize in terms of production (Bandyopadhay and Roy, 1992). Food security in the world is challenged by increasing food demand and threatened by declining water availability. More recently, the increase in area under biofuel crops at the cost of food crops is also threatening (Rijsberman, 2006). In 1987, about 457.51 million metric tons of rice was produced from 144.55 million hectares of land all over the world. The most extensive areas of cultivation are within latitude 50°N and 40°S of the equator. The highest yields are recorded between latitudes 30°S and 45°N of the equator and countries like China, Japan, South Korea, Turkey, Spain and Egypt lie within this region (Bandyopadhay and Roy, 1992). Countries in the league of top ten largest producers of rice are as follows: 1. China (194.3 million tonnes), 2. India (148.3), 3. Indonesia (60.3), 4. Bangladesh (46.9), 5. Viet Nam (38.7), 6. Myanmar (30.5), 7. Thailand (30.5), 8. Philippines (16.8), 9. Brazil (12.1) and 10. Japan (11.0) (Teh, 2010). Both China and India are, by far, the two largest producers of rice, producing half of the world's rice.

Indian rice is highly appreciated in the world market for its taste and suitability. Rice is not only a rich source of carbohydrate and proteins but also provides vitamins, minerals and fibre. It is cultivated in the humid tropical and sub-tropical climate characterized by high temperature and high relative humidity, resulting in changes in genetic integrity (Kapoor *et al.*, 2011). In terms of rice productivity, it is a known fact that Australia is the world's most efficient producer of rice, producing an average of 8.7 tonnes of rice per hectare per year from 2000-08, followed by Japan (6.4) and China (6.3). Lying in the 25th place is Malaysia with a total rice production of 2.4 million tonnes. Malaysia's mean rice productivity, though increasing each year, is only 3.3 ton ha^{-1} per year. Malaysia's productivity is lower than that for Viet Nam (4.7), Indonesia (4.6) and Philippines (3.5), but higher than that for India (3.1) and Thailand (2.8) (Teh, 2010). Even though, Australia is the most efficient rice producer in the world, its productivity fluctuates widely year-on-year. This is probably due to the frequent water shortages (i.e., droughts) in Australia. Japan also sees a large annual variation in its rice productivity but this variation is much less than that for Australia. China's rice productivity, however, is a rapid and steady increase throughout the years, from a low 2.1 in 1961 to 6.6 ton ha^{-1} in 2008 (Akinbile, 2009).

On the continent of Africa, Egyptian rice yield is one of the highest in the world (9.1 tons ha^{-1} as of 2001) and also a major rice exporter. Egypt is the largest rice producer in the Near East region and as at today, rice production takes place only in the Lower Valley of the Nile River. Due to the intrusion of sea-water, about 25 to 30% of the land in the lower Nile Valley is affected by different degrees of salinity. The high solar radiation, the long days and the cool nights between May and September are favourable to a high rice yield (Akinbile, 2009).

Rice is the largest user of water in Asia, probably accounting for more than half of irrigation water withdrawals, Irrigation water is the largest user of water in the world (Rosegrant and Cline, 2003). Approximately 56% of total world irrigated area is in Asia. Water is a key driver of agricultural production and its most precious input. Since the very beginning of plant cultivation, over 10,000 years ago, irrigation water has enabled farmers to increase crop yields by reducing their dependence on rainfall patterns, thus boosting the average crop production while decreasing the inter annual variability (Turner, 2004). Irrigation has helped increasing agricultural yields and outputs in semi-arid and even arid environments and stabilized food production and prices (Hanjra *et al.*, 2009a, b; Cai and Rosegrant, 2003) and the revenue from the agriculture sector (Sampath, 1992). Only 19% of agricultural land cultivated through irrigation supplies 40% of the world's food (Molden *et al.*, 2010) and has thus brought substantial socioeconomic gains (Evenson and Gollin, 2003). Rice the basic food of Malaysia, is the most important source of employment and income of the rural population. Currently, the self-sufficiency level of rice is about 73%. Thus, there is growing concerns that inefficient water use caused change in climate would affect the productivity of rice crop (Tao *et al.*, 2008). This study therefore, examines rice production trends and water use efficiency pattern for self-sufficiency in Malaysia and projects the future considerations for sustainable livelihoods.

Rice production in Malaysia: Rice is the third most important crop in Malaysia after rubber and palm oil which were the first and second respectively in terms of production and is mainly grown in the eight granary areas in Peninsular Malaysia covering an area of about 209,300 ha (Azmi and Mashhor, 1995). The total rice production in Malaysia as at 2006 was 2154 thousand tons and growing area was 645 thousand hectares (USDA, 2008). The two major rice growing areas are Muda Agriculture Development Authority (MADA) and Kemubu Agriculture Development

Authority (KADA) and the latter was only able to produce 230,000 tonnes of padi while it was expected to increase to 260,000 tonnes in 2010. IRRI (2008) also confirmed the Malaysia's economic report that rice production was expected to achieve 86% self-sufficiency level (SSL) by 2010 following additional allocations to maintain food security. The report further stated that padi plantation acreage was projected to expand following the development of new padi areas, especially in Sarawak, Sabah and Pahang, land rehabilitation and improved agriculture infrastructure, including irrigation systems. Currently, Malaysia has reached SSL at 73% for rice. The report said padi production is expected to grow by 0.4% in 2007 (10.3%), largely on account of improved productivity. Rice is grown in Malaysia mainly under flood irrigation and there are five varieties of rice grown currently. These include, MR 219, MR 220, MR 230, MR 185 and MR 211 with their maturity days ranging between 105 and 120 days. Numerous studies have shown that improvement in water productivity with respect to Evapotranspiration could be achieved by variety selection and agronomic manipulation of the rice crop to reduce ET and increase yield (Lafitte *et al.*, 2005, 2004). The adoption of early maturing, high-yielding varieties of rice during the last 25-50 years have increased the average yield of irrigated rice from 2-3 to 5-6 t ha^{-1} and reduced crop duration from about 140 days to 110 days or 21% reduction in ET (Tuong and Bhuiyan, 1999; Bouman and Tuong, 2001). It is in line with this that a new rice variety (MRQ76) was developed by the Malaysian Agricultural Research and Development Institute (MARDI), which has 80% similar attributes to foreign fragrant rice, thereby enabling it to tap the higher-end rice market. The focus is to cultivate this variant in rain-fed areas, leveraging its drought tolerant attributes (Rukunudin, 2009). The Government of Malaysia had invested over RM 26.6 million in 2011 to produced MRQ76 with a projected GNI impact of RM 133 million by 2020, creating jobs for potential 5,000 people. This is to reduce the cost of rice importation which stood at RM 10 billion as at 1997 when compared with RM 4.6 billion spent in 1990 with rice taking significant share of the importation costs. Malaysia's land for rice remained fairly constant at no more than 0.7 million hectares since the 1980s (Wong *et al.*, 2010). Even though the land area for rice has remained rather constant, Malaysia's rice productivity increases every year from 2.1 ton ha^{-1} in 1961 to 3.6 ton ha^{-1} in 2008. Thus, Malaysia's total rice production would also increase each year. Since 1985, Malaysia sees an average increase in total production of about 28,000 tonnes per year. Although Malaysia's rice production and productivity increase each year, its yield per capita declines each year. From a high of 174.6 kg of rice per capita in 1974, rice yield per capita has since fallen steadily, falling to 86.0 kg of rice per capita in 2008 (World Bank, 2010).

Water as a major rice production factor: Water is essential for rice cultivation and its supply in adequate quantity is one of the most important factors in rice production (Akinbile, 2010a; Mondonedo, 2008; Rosegrant *et al.*, 2002c). In Asia and other parts of the world, rice crop suffers either from too little water (drought) or too much (flooding or submergence). Most studies on constraints to high rice yield shows that water is the main factor for yield gaps and yield variability from experiment stations to farm (Papadimetriou, 2001). Irrigated agriculture is the dominant use of water, accounting for about 80% of global and 86% of developing countries water consumption as at 1995 (Rosegrant *et al.*, 2002c). By 2025, global population will likely increase to 7.9 billion, more than 80% of whom will live in developing countries and 58% in rapidly growing urban areas (IWMI 2000). About 250 million ha, representing 17% of global agricultural land, is irrigated worldwide today, nearly five times more than at the beginning of the 20th century. This contributes about 40% of the global production of cereal crops (Rosegrant *et al.*, 2002b). Irrigation has helped boost agricultural yields and outputs, stabilize food production and prices. In 1999, about 57% of the world's rice harvested area came from irrigated ecologies, 28% from rain fed lowland ecologies, 11% from upland ecologies and 4% from other ecologies such as deepwater and tidal wetland or mangrove (Duwayri, 2001). While irrigated lowlands only comprise about 12% of West Africa's rice area, these ecologies have the highest yield potential and contributed 26% to the regional rice supply (Raemackers, 2001; FAO, 1996). Irrigated rice was responsible for about 75% of the world's total rice production. A sustainable increase in irrigated rice production however faces a number of critical technical and development factors. Land and water resources for irrigated rice production especially in Asia have been increasingly lost to the expansion of urban and industrial sectors. This view was corroborated by Kumar *et al.* (2008) who also opined that the major concern in rice production systems is the dwindling trend of availability of fresh water resources. In other continents such as Africa, the high cost of development of irrigation infrastructures is the major constraints to the expansion of irrigated rice production. Inappropriate management of irrigation has contributed, not only to food insecurity but also to environmental problems including excessive water depletion, water quality reduction, water logging and salinization (Rosegrant *et al.*, 2002a). During the crop growth period, the amount of water usually applied to field is often much more than the actual field requirement. This leads to a high amount of surface runoff, seepage and percolation which accounts for about 50-80% of the total water input into the field (Guerra *et al.*, 1998). Therefore, the water crisis being experienced today is not about having too little water to satisfy our needs especially in agriculture but a crisis of proper management.

As fresh water becomes increasingly scarce, the demand for available water from urban and industrial sectors is likely to receive priority over irrigation. About 88% of the total rice area of 69,238 ha is irrigated wetland rice areas located in Peninsular Malaysia (Vaghefi *et al.*, 2011). Irrigated rice, in particular, is a heavy consumer of fresh water and is less efficient in the way it uses water compared to other crops (Sariam *et al.*, 2002). Similarly, water demand from non-agricultural sectors will keep increasing in both developed and developing countries. About 40% of the land in the world is under arid and semi-arid climatic conditions (Gamo, 1999). With a rapidly increasing world population, the pressure on limited fresh water resources increases. Since rice cultivation requires large amounts of water and due to growing scarcity of water in arid and semi-arid regions, farmers are shifting to cultivation of less water-demanding crops (Thiyagarajan, 2001; Kijne *et al.*, 2003). The total physical paddy area (covering irrigated and non-irrigated) in Malaysia is about 598.483 ha in 1993. About 322,000 hectares or 48% of the total paddy areas in the country are provided with extensive irrigation and drainage facilities while the remaining are rainfed areas (Table 1). Of the irrigated areas, 290,000 hectares are found in Peninsula Malaysia, 17,000 hectares in Sabah and 15,000 hectares in Sarawak. About 217,000 hectares of irrigated areas in Peninsular Malaysia have been designated as main granary areas while another 28,000 hectares located all over the country are classified as mini-granary areas.

Water for agriculture is critical for future global food security. However, continued increase in demand for water by non agricultural uses, such as urban and industrial uses and greater concerns for environmental quality has put irrigation water demand under greater scrutiny and threatened food security. Water scarcity is already a critical concern in parts of the world (Fedoroff *et al.*, 2010). Furthermore, there are growing public concerns that the footprints (i.e. negative impacts) of food security on the environment are substantial (Khan *et al.*, 2009a, b). Continued increase in demand for irrigation water over many years has led to changed water flows, land clearing and therefore deteriorated stream water quality. Addressing these environmental concerns and fulfilling urban

Table 1: Distribution of paddy areas (hectares)

State	Irrigated areas	Non-irrigated areas	Total
Perlis	22,039	3,648	25,687
Kedah	93,670	24,857	118,527
Pulau Pinang	14,895	225	15,120
Perak	49,029	4,225	53,284
Selangor	19,583	106	19,689
Negeri Sembilan	8,680	1,449	10,129
Melaka	6,183	3,435	9,618
Johor	3,055	746	3,801
Pahang	17,388	13,796	31,184
Terengganu	14,843	12,173	27,016
Kelantan	40,032	25,382	65,414
Sabah	17,163	33,639	50,802
Sarawak	15,136	153,076	168,212
Total	321,696	276,787	598,483

Source: http://www.icid.org/v_malaysia.pdf

and industrial water demand will require diverting water away from irrigation. This will reduce irrigated area and its production and impact on future food security.

In the past decades, increasing population, urbanization and industrial development, have increased demand for water which has resulted into considerable decrease in annual renewable water resources per capita. To sustain the rapidly growing world population, agricultural production will need to increase (Howell, 2001), yet the portion of fresh water currently available for agriculture (72%) is decreasing (Cai and Rosegrant, 2003). Hence, sustainable methods to increase crop water productivity are gaining importance in arid and semiarid regions (Debaeke and Aboudrare, 2004). In recent years, focus has shifted to the limiting factors in production systems, notably the availability of either land or water. Several studies have shown that deficit irrigation has been widely investigated as a valuable strategy for dry regions (Pereira *et al.*, 2002; Fereres and Soriano, 2007) where water is the limiting factor in crop cultivation. We review recent research on the maximization of productivity per unit of water. Most of the agricultural water use is for paddy rice irrigation. However, the agricultural sector is expected to face increased competition for water from other sectors in the future due to environmental considerations and economic growth (Chung *et al.*, 2011).

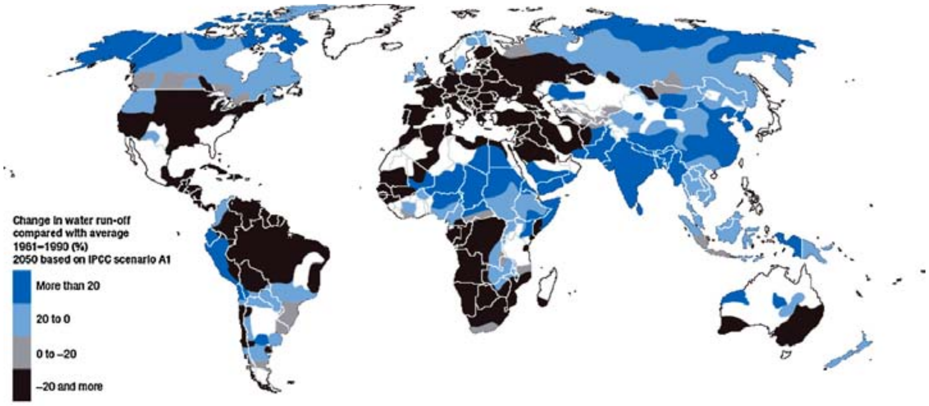
Water resources in Malaysia: Malaysia receives an annual average rainfall of over 2500 mm, mainly due to the Southwest and Northeast monsoons. The country is therefore rich in water resources when compared to the other regions of the world. The average annual water resources on a total land mass of 330,000 km^{-2} amount to 990 billion m^{-3} (Tubiello, 2005). Out of which, 360 billion m^3 or 36% returns to the atmosphere as evapotranspiration, 566 billion m^3 or 57% appear as surface runoff and the remaining 64 billion m^{-3}, or 7% go to the recharge of groundwater. Of the total 566 billion m^{-3} of surface runoff, 147 billion m^3 are found in Peninsular Malaysia, 113 billion m^3 in Sabah and 306 billion m^3 in Sarawak (Wong *et al.*, 2010).

Irrigation water demand which totalled 9.0 billion m^3 in 1990 accounted for about 78% of the total consumptive use of water. Until 1960, irrigation schemes were designed for single crop rice production during the wet season as a supplementary source of water supply. Since then, irrigation development has rapidly expanded into the double cropping of paddy to meet the dual objectives of increasing food production and to raise the income levels of the farmers. There are some 564,000 hectares of wet paddy land in Malaysia, of which 322,000 hectares is capable of double cropping. Farmers in irrigation and drainage areas are required to pay water rates ranging from RM 10-15 per ha which represent less than 10% of the annual recurrent operation and maintenance cost (Sariam *et al.*, 2002).

Malaysia is drained by a dense network of rivers and streams (there are about 150 major river basins), the longest being the Pahang River which follows a course of 434 km before reaching the South China Sea. It drains a catchment area of 29,000 km^2. Other major rivers that also drain into the South China Sea are the Kelantan, Terengganu, Dungun, Endau and Sedili rivers. Major river basins in the east of Malaysia tend to be larger than those in peninsula Malaysia. Malaysia's longest river is the Rajang River (563 kilometers) in Sarawak. Out of an annual rainfall volume of 990 cubic, 360 km^3 (36%) are lost to evapotranspiration. The total surface runoff is 566 km^3 and about 64 km^3 (7% of the total annual rainfall) contribute to groundwater recharge. However, about 80% of the groundwater flow returns to the rivers and is therefore not considered an additional resource. The total internal water resources of Malaysia are estimated at 580 km^3 year^{-1}. Major floods occurred in 1967, 1971, 1973 and 1983. Some 29,000 km^2 are considered as flood-prone areas, affecting about 2.7 million people (Seckler *et al.*, 1998).

Climatic change and irrigation: Ongoing changes in global and local climates will exacerbate many problems and will drive change in irrigation investment patterns in its own right. Changes in temperature, the most predictable of the climatic change impacts, will increase water losses from lakes and reservoirs and raise evapotranspirative demand for water, while increasing atmospheric moisture content. Rising temperatures will therefore increase crop water demand, deplete soil moisture faster and increase irrigation demand (Peng *et al.*, 2004; Singh *et al.*, 1996). Increased levels of atmospheric CO_2 will increase the rate of biomass formation and mitigate water demand to some extent, as will shorter growing seasons and faster crop development. However, the benefit of CO_2 enhancement is predicted to level off as other factors such as nutrients and water become limiting (Chung *et al.*, 2011; Chandler and Le Page, 2007).

Changes in rainfall patterns are expected to exacerbate current rainfall deficits in dry regions and increase rainfall in currently humid regions, leading to severe droughts on the one hand and more intensive flooding on the other (Vaghefi *et al.*, 2011; Tao *et al.*, 2008). Changes will occur in the average annual amount, temporal distribution and intensity and duration of individual events. The effects will be felt directly, in the case of rain-fed agriculture and indirectly, through their effect on watershed hydrology and runoff, in the case of irrigated agriculture. River hydrology in most irrigating regions of the world will be affected and impacts on stream hydrology will likewise be mixed. Watershed responses to reduced rainfall and higher temperatures are typically amplified, for example, a 20% reduction in rainfall might yield a 50% reduction in runoff (Arnell, 2003). Predicted patterns of global changes in runoff are illustrated in Fig. 1 (IPCC, 2007). Agriculture activities are very sensitive to climate and weather conditions. Srivani *et al.* (2007) noted a general decline in crop production in the last decade of the 20th century. According to the researchers, it was due to degradation of aerial, edaphic and hydro-environments arising from the effect of climate on several aspects of crop production in farm management. Malaysia is characterized by a humid tropical climate with rainfall (2540 mm p.a. and above), average daily temperatures of 21-32°C and humidity averaging about 85% caused by small seasonal variation in incoming solar radiation, the annual difference in day length is only 2 min along the equator and 49 min in northern regions,



Note: The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.
Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties.
Source: Arnell 2004.

Fig. 1: Changes in runoff based on IPCC Scenario A1, 2050 compared with 1961-1990 average

giving a day length of 12.30 hours year round. Other new approaches are being explored to increase water economy without compromise on yield. These include the incorporation of the C_4 photosynthetic pathway into rice to increase rice yield per unit water transpired, the use of molecular biotechnology to develop rice varieties with improved water-use efficiency, Transpiration Efficiency (TE), drought tolerance and the development of varieties for aerobic system, to achieve high and sustainable yields in non-flooded soil (Farooq *et al.*, 2009).

Rice yield and water use efficiency (WUE) for increased productivity: Assessing the scope for gains in water productivity requires an understanding of basic biological and hydrological crop-water relations. How much more water will be needed for agriculture in the future is governed, to a large extent, by links between water, food and changes in diets (Rosegrant *et al.*, 2002c). The amount of water required for field crops and its relation to yield dominates the equation on the need for additional water for food. Exploring ways to produce more rice with less water is essential for food security. Water-saving rice production systems, such as aerobic rice culture, System of Rice Intensification (SRI), ground-cover rice production system (GCRPS), raised beds and Alternate Wetting and Drying (AWD), can drastically cut down the unproductive water outflows and increase Water-Use Efficiency (WUE). However, these technologies can sometimes lead to some yield penalty, if the existing lowland varieties are used (Farooq *et al.*, 2009).

For a given crop variety and climate, there is a well-established linear relationship between plant biomass and transpiration (Steduto *et al.*, 2007; Tuong and Bhuiyan, 1999; Allen *et al.*, 1998; Doorenbos and Pruitt, 1992). Different kinds of plants are more water efficient in terms of the ratio between biomass and transpiration. More biomass production requires more transpiration because when stomata open, carbon dioxide flows into the leaves for photosynthesis and water flows out (Chandler and Le Page, 2007). Water out flow is essential for cooling and for creating liquid movement in the plant for transporting nutrients. Stomata close during drought, thereby limiting transpiration, photosynthesis and production. Through the adoption of water-saving irrigation technologies, rice land will shift away from being continuously anaerobic to being partly or even completely aerobic. These shifts will produce profound changes in water conservation, soil organic matter turnover, nutrient dynamics, carbon impounding, weed flora and greenhouse gas emissions (Akinbile, 2010b; Akinbile and Sangodoyin, 2009). Although some of these changes could be positive, for example, water conservation and decreased methane emission, others might be negative, for example, release of nitrous oxide from the soil and decline in soil organic matter. The challenge will be to develop effective integrated natural-resource-management interventions which would allow profitable rice cultivation with increased soil aeration, while maintaining the productivity, environmental safety and sustainability of rice-based ecosystems (Akinbile *et al.*, 2007; Farooq *et al.*, 2009).

Water Use Efficiency (WUE) or water productivity emerged from the ideas of drought resistance and tolerance (Boutraa, 2010). The term could be used on a wide range of scales, for example, in Agriculture, WUE can be used at leaf level (photosynthesis rate per transpiration rate), at whole plant level,(ratio of total dry mass to water use) and at the final economic yield (crop grain per unit area to transpiration) (Ali and Talukder, 2008). Since the study of Doorenbos and Kassam (1979), different expressions (WUE, crop water productivity) have been proposed and discussed by Akinbile (2010a), Bouman (2009), Carriger and Vallee (2007), Hsiao *et al.* (2007), Turner (2004), Zwart and Bastiaanssen (2004), Hundertmark and Abdourahamane (2003), Pereira *et al.* (2002) and Gregory *et al.* (2000) with different efficiencies which is a function of among many other factors, location, time of the year, extraterrestial radiation and wind speed. In general, WUE can be written as follows:

$$\text{WUE (kg m}^{-3}\text{)} = \frac{\text{Yield}}{\text{Water consumed}} \tag{1}$$

Yield in equation can be indicated by two parameters, both expressed in kg m^{-2}: (1) global dry matter yield; (2) marketable crop yield.

Boutraa (2010) expressed her own WUE from the economic angle as:

$$\text{WUE} = \frac{\text{Crop Yield (usually the economic yield)}}{\text{Water used to produce the yield}} \tag{2}$$

The available water for irrigation, however, is becoming increasingly scarce due to decreasing resources and quality and increased competition from non-agricultural water users. For food security, it is essential to "produce more rice with less water" (Carriger and Vallee, 2007). Appropriate water management for rice thereof becomes important and the effective and efficient use of water can never be more emphasized, especially in free water-to-irrigator systems, as practiced widely in Asia (Farooq *et al.*, 2009).

In discussing strategies required for increasing farm-level water use efficiency and the challenges of up scaling from on-farm to system-level water savings, Tuong and Bhuiyan (1999) suggested the holistic approach to irrigated rice production as a total entity rather than the convectional notion of separately treating the issues as 'farm level' and 'irrigation system level'. Tuong and Bhuiyan (1999) gave the range of Water Use Efficiencies (WUEs) over a period of time to be ranging from 0.22 to 0.69 as cited by different researchers within a five year period of experimentation (1990-1995). Akinbile (2010a), in his experiment in Ibadan, a city in south western part of Nigeria, West Africa reported similar ranges of values for Upland rice in a two year experiment. The values ranged from 0.17 to 0.08 for crop water use values ranging from 3047 and 1792 mm. The WUE increased as water use increased.

Cabangon *et al.* (2002) showed that in a field experiment conducted in Muda, Malaysia to estimate water productivity of wet-seeded rice and dry-seeded rice. The authors showed that water productivity for the amount of irrigation water range from 0.62 to 1.48 kg rice m^3 water. In Malaysia, the estimated average water requirement for irrigated rice crop is 1,240 mm per season. However, in reality, most irrigated rice is supplied with much more than the field requirement because farmers maintain a continuous flooding system from crop establishment to maturity (Streck, 2005). In the irrigated low land rice growing areas, the field is sometimes flooded as early as 30 days before crop establishment (which is also known as the pre-saturation period) until the period near maturity. Farmers prefer to maintain a relatively higher depth of water during the crop growth period in order to control weeds, as insurance against future water shortages and to reduce the frequency of irrigation. This led to higher amount of surface runoff, seepage and percolation (Molden *et al.*, 2010).

The change from transplanting to direct seeding offers opportunities to improve water use efficiency (WUE) in rice cultivation by reducing the irrigation water inflow requirement during soil preparation. In the field experiment by Cabangon *et al.* (2002), it was reported that direct-seeded rice in lowland consumed less water than transplanted rice under same conditions as for soil preparation and crop water irrigation. It was also reported that the total water use dropped from 2195 mm for transplanted rice to 1700 mm under direct-seeded rice in wet conditions.

Fujii and Cho (1996) in an experiment conducted in the Muda Irrigation Scheme, Malaysia to reduce irrigation system for rice crop, with same quantity of water from 140 to 105 days. Researchers discovered that reduction in irrigation duration increased water use from 1836 to 1331 mm in the wet direct-seeded rice. De Vries *et al.* (2010) also in an experiment conducted in Africa concluded that it is possible to attain major savings of irrigation water with little yield penalties in a Sahelian environment. Between 480 and 1060 mm of irrigation water was used in the water-saving treatments compared with 800-1490 mm in the flooded-rice treatment. Rice yields ranged from 2.3 to 11.8 t ha^{-1} in the water-saving treatments, whereas in the flooded control the yields ranged from 3.7 to 11.7 t ha^{-1}. It can, therefore, be concluded that in the Sahel during the wet season irrigation water savings of 22-39% are possible for rice with no or little yield loss. In the dry season, the flooded treatments produced on average 1.0 t ha^{-1} more than any combination of flooded and AWD and 1.8 t ha^{-1} more than the season-long AWD treatment.

Future considerations for productivity self sufficiency: While Malaysia is moving rapidly towards industrialization, food production, particularly in case of its staple food (rice) will continue to receive desired attention. Also, the growth of population and the expansion of industrial and manufacturing sectors have led to rapid increase in food and water demand in the country. The increase in food production can only be achieved if there are adequate measures to develop and manage water resources to meet the present and future needs of the sector. Currently, Malaysia's rice productivity increases only by an average of 2.0% per year, not the required 4.9% per year. At this current level, Malaysia will only hit 2.6 million tonnes of rice in 2015, a rice productivity of 3.8 ton ha^{-1} and a rice yield per capita of 82.3 kg per capita. All this translates to an expected self-sufficiency level of only 78% in 2015. For Malaysia to be 100% self-sufficient in rice production by 2015, it is estimated that the rice yield per capita must increase to at least 106 kg of rice per capita by 2015. This is derived from taking into account past trends in rice production, rice productivity, and self-sufficiency levels, as well as Malaysia's expected population, eating habits and prosperity level by 2015. Assuming no change in land area for rice (which essentially has not changed since the 1980s), Malaysia must achieve the following rice yields to reach 106 kg of rice per capita by 2015; thus, becoming 100% self-sufficient in rice and up scaling total production to 3.3 million tons (40% increase from 2.4 million tons in 2008). This infers that the productivity must have 40% increase from 3.6 (in 2008) to 5.0 ton ha^{-1} in 2015. To obtain the 3.3 million ton and 5.0 ton ha^{-1} of rice by 2015, Malaysia's rice productivity must increase by at least 4.9% per year. However, even at 2.0% increase in rice productivity per year, it is still possible to achieve 100% self-sufficiency in rice, provided that the land area for rice in 2008 increases by more than 70% to reach 1.14 million per ha in 2015. In other words, more than 436,000 ha of new land area must be found for rice fields.

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