WATER AND LAND PRODUCTIVITY IN PADDY CULTIVATION: CONCEPTS, INDICES, TARGETS AND CHALLENGES

PRODUCTIVITE DE L'EAU ET DE LA TERRE DANS LA CULTURE DU RIZ PADDY : CONCEPTS, INDICES, OBJECTIFS ET DEFIS

Loh Kim Mon[1]

ABSTRACT

This paper discusses the basic concepts and indices pertaining to water and land productivity for paddy cultivation. Terms like water productivity, yield and land productivity with reference to paddy cultivation are defined and explained. Particular reference is made to the Muda Irrigation Scheme as far as the water and land productivity are concerned. The Muda Irrigation Scheme covering some 100,000 ha of paddy land is the largest rice granary in Malaysia. Factors affecting the water productivity are identified as: effective rainfall; water use efficiency; agronomic practices; conditions of irrigation and drainage infrastructure; water pricing and usage of recycled water. Based on the data obtained over the past decade, the target for water productivity is hence set for the major rice granary areas in Malaysia.

The significant factors affecting the paddy land productivity are: soil types; seeds; agronomic practices; harvesting loss; water management and cropping intensity. Comparisons of paddy yield in some selected Asian countries are briefly discussed. Major challenges to increase the water and land productivity are identified as: competing use of water; weather conditions; pests and diseases; adequacy of irrigation and drainage infrastructure and farmers' response to technological adaptation. The present water productivity for paddy in Muda area is 0.5kg/m^3 whereas the land productivity is 12.0 tonnes/ha. These two indices are among the highest in the Malaysian granary areas and are deemed appropriate to be taken as the benchmarks for other rice granary areas to emulate.

Key words: *Water and land productivity; paddy cultivation; Muda Irrigation Scheme.*

1 Muda Agricultural Development Authority (MADA), MADA Headquarters, 05990 Alor Setar, Kedah, Malaysia, E-mail : lkm443@gmail.com

RESUME

Ce rapport discute les concepts de base et les indices concernant la productivité de l'eau et de la terre dans la culture du riz Paddy. Il explique les termes tels que la productivité de l'eau, le rendement et la productivité de la terre en ce qui concerne la culture de Paddy. La référence particulière est faite au Plan d'Irrigation de Muda en ce qui concerne la productivité de l'eau et de la terre. Le Plan d'Irrigation de Muda couvre une superficie de 100,000 ha de terre, et est le plus grand grenier de riz en Malaisie. Suivent les facteurs qui affectent la productivité de l'eau : précipitation efficace; efficience d'utilisation de l'eau; pratiques agronomiques; conditions d'infrastructure d'irrigation et de drainage; tarification d'eau et utilisation de l'eau recyclée. Compte tenu des données recueillies au cours de la dernière décennie, le rapport vise à planifier la productivité de l'eau des greniers majeurs de riz en Malaisie.

Les facteurs significatifs qui affectent la productivité de la terre de paddy sont : types de sol; graines; pratiques agronomiques; perte de récolte; gestion de l'eau et intensification de culture. Le rapport discute en bref les comparaisons de rendement de Paddy dans quelques pays asiatiques. Il identifie également les défis majeurs que pose l'augmentation de la productivité de l'eau et de la terre : concurrence pour l'utilisation de l'eau; conditions météorologiques; parasites et maladies; compétence d'infrastructure d'irrigation et de drainage; et réponse des fermiers à l'adaptation des technologies. La productivité actuelle de l'eau du Paddy dans la région de Muda est de l'ordre de 0,5kg/m^3 alors que la productivité de la terre est de 12,0 tonnes/ha. Ces deux indices sont parmi les plus hauts dans les secteurs de grenier malais et sont considérés appropriés pour tenir en tant que points de référence pour d'autres greniers de riz.

Mots clés: *Productivité de l'eau et de la terre, culture de Paddy; Plan d'irrigation de Muda.*

1. INTRODUCTION

Water and land are two basic prerequisites for any crop cultivation. Paddy cultivation, in particular, uses more water as compared to other crops. This is evident as water is required to first pre-saturate the entire paddy field and then a standing water depth has to be maintained during its growth stage. To ensure sufficient irrigation water for paddy cultivation, water resources from direct rainfall, dam storage, river, recycled drainage water as well as groundwater are as far as possible harnessed to their fullest. Since water is a finite resource, every effort should be made to conserve irrigation water consumption and reduce waste in paddy cultivation.

Most of the paddy in Asia is cultivated in the lowlands, though a small percentage is also grown in the hill terraces such as in Bali, Indonesia. Lowland paddy field, being generally flat, is ideal for farm mechanization and has the potential to increase its paddy productivity. The average paddy yield of 3.5 tonnes/ha represents only 35% of the achievable yield (10 tonnes/ha). Obviously there are ample rooms to increase paddy yield and hence the land productivity. Notwithstanding that, increase in paddy land productivity will help to achieve the goals of increasing farmers' income and ensuring food security for mankind.

In view of the scarcity of available water resources and limited suitable farmlands for agriculture, water and land productivity have always been given great emphasis by policy makers, irrigation service providers and farmers. Ways and means are continually explored to raise water and land productivity so as to increase the farmers' income and to ensure sustainable water supply for irrigation and other uses.

This paper discusses the basic concepts, indices and targets in relation to the water and land productivity for paddy cultivation. Factors affecting water and land productivity and challenges confronting the same are briefly discussed. Water and land productivity for paddy cultivation achieved for 2005-2009 in the Muda Irrigation Scheme, Malaysia is also presented in this paper.

2. CONCEPTS AND INDICES

(a) Water productivity (WP)

Water productivity (*WP*) is defined as *the total weight of the crop produced by a unit volume of water supplied*. The common unit used is *kg/m*^{3}. Hence, higher *WP* means more crop in terms of quantity can be produced by a cubic metre of water. For paddy, the water productivity is in the range of 0.3 - 0.6 *kg/m*^{3}.

WP, for a certain paddy area, can be obtained from the following equation:

***WP* = Total paddy produced (*kg*) / Total volume of water consumed (m^3)**

Total paddy produced denotes the weight of paddy harvested, whereas total volume of water supplied includes irrigation supply and rainfall. To calculate WP, it is essential that the daily volumetric measurement of irrigation water delivered to the irrigation block and daily rainfall records are collected for the entire irrigation period.

(b) Land productivity (LP)

Before introducing the concept of land productivity (*LP*), it is more appropriate to first define *yield. Yield is defined as the quantum of crop harvested per unit area of cultivated land* ***per season***. The unit for yield is *tonnes/ha* (*t/ha*).

LP is the total amount of crop produced per unit area of cultivated land ***per annum***. It has the same unit as yield (*t/ha*). For a given paddy area, *LP* can be obtained from the following equation:

***LP* = Total paddy produced per annum (*tonnes*) / cultivated area (*ha*)**

For double cropping areas, the total paddy produced per annum is the sum of paddy yield for both seasons. It is obvious that *LP* depends not only on yield but also the *cropping intensity*. Cropping intensity is *the weighted frequency in which the land can be cultivated annually*. For example, if 90% of the a certain paddy area was cultivated in the first season and only 50% was grown in the second season, then the cropping intensity for that area is

140% (1.4). A cropping intensity of 200% (2.0) means the whole area can be planted twice per annum. Therefore, for paddy cultivation, the land productivity is a function of yield and the cropping intensity.

3. FACTORS AFFECTING WATER PRODUCTIVITY OF PADDY

There are two ways to increase water productivity i.e. by either increasing the yield or reducing the volume of irrigation water supplied. Factors affecting paddy yield are discussed separately in Section 4. In this section, the factors that have significant impact on the quantum of irrigation water supply will be discussed.

Muda Irrigation Scheme is the largest rice granary in Malaysia. Covering some 97,000ha of paddy land, it is situated along the coastal plain in the northern states of Kedah and Perlis in the peninsular Malaysia. The area is a mono crop (paddy) area and double cropping of paddy was effected since 1970 with the completion of the Muda Irrigation Project (Figure 1).

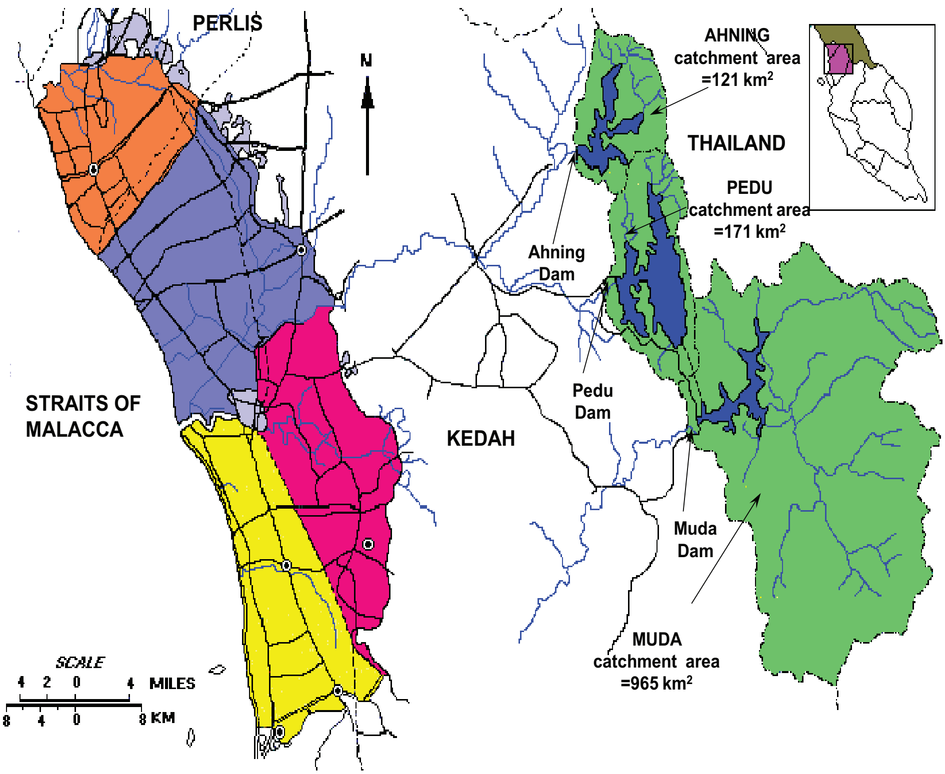

Fig. 1. General Layout Plan of Muda Area, Reservoir and Catchment Area

In Muda Area, the water requirement for the first (*off*) season crop is 1,300 mm and for the second (*main*) season crop is 1,100mm. Hence, the total water requirement for double cropping is 2,400mm. The water requirement is met from four sources, i.e. rainfall (52%), run of the river (10%), reservoir releases (30%) and recycled drainage water (8%). Since Muda Area is a "*water stress*" region, every effort is made to improve the water use efficiency so as to reduce the irrigation water consumption. Being the major water user, the irrigation sector consumes some 80% of the total water supply. Increase in water productivity, therefore, has a great impact in ensuring the sustainability of sufficient water supply for all sectors.

The main factors that affect the water productivity are: effective rainfall; water use efficiency; agronomic practices; irrigation and drainage infrastructure; pricing of water and use of recycled drainage water.

(i) **Effective rainfall.** The average annual rainfall for peninsular Malaysia is 2,400 mm and the value is 3,000 mm for Sabah and Sarawak. Rainfall intensity and patterns vary considerably from area to area. For double paddy cropping, more than 50% of the crop water requirement is usually derived from rainfall. It therefore makes sense to maximize the usage of rainfall for paddy cultivation as it is the most effective way of irrigation. For paddy cultivation, it is the *effective rainfall* that matters. Effective rainfall is the amount of rainfall that can be stored in the field for the purpose of irrigation. Effective rainfall in Muda Area is approximately 50% of the total rainfall. The higher the effective rainfall, the higher will be the water productivity as lesser irrigation from external sources of water is needed.

(ii) **Water use efficiency.** Water use efficiency is the *ratio (expressed as a percentage) of irrigation water requirement to the total irrigation water supplied* in an irrigation scheme. It is influenced by several factors such as conveyance losses; soil permeability; conditions of irrigation infrastructure and the farmers' participation in operation and maintenance of infrastructure. In Muda Area the average water use efficiency is 70%, which is relatively high as compared to other irrigation schemes in the country. This is due to the practice of water management which combines the state of the art water management techniques and the use of telemetric system whereby the available water resources are effectively and efficiently utilized. High water use efficiency means high water productivity as the overall water supply is less.

(iii) **Agronomic practices.** The prevalent cultural practice for paddy cultivation is wet direct seeding, though mechanized transplanting is fast gaining popularity. Dry direct seeding normally uses less water as compared to wet direct seeding. Wet direct seeding in standing water uses less water compared to the normal wet seeding. Hence, to increase water productivity we should promote the practice of dry direct seeding and direct seeding in standing water, if wet seeding is unavoidable. Dry direct seeding uses 5-10% less water, whereas seeding in standing water uses 10% less water as compared to wet direct seeding.

(iv) **Irrigation and drainage infrastructure.** The conditions of all irrigation and drainage infrastructures, especially the gates, should be well maintained to avoid water loss through leakage. Any canal or drain breach should be repaired immediately. Well maintained field ridges (*batasses*) are important as they can help to retain water in the field and hence increase water productivity.

(v) **Water pricing.** The pricing of irrigation water has significant influence on the volume of water used by farmers. If more water is being used, the more the farmer has to pay. However, the water rates in most Asian countries are based on the cultivated area rather than on the volumetric consumption. For example, the water rate in Muda Area is charged at *RM37.00/ha per annum*. This does not provide any incentives for the farmers to conserve water and hence leads to lower water productivity.

(vi) **Use of recycled drainage water.** One of the most effective ways to increase water resources is by recycling drainage water for irrigation. Recycling drainage water means re-using the drainage water in the drainage system for irrigation. If not re-used, the drainage water will eventually flow into the sea. It can be said that recycled drainage water is the water that has be used twice before it ends up in the sea. The more recycled drainage water is used, the higher will be the water use efficiency. In Muda Area, approximately 8% of the total irrigation requirement comes from recycled drainage water.

To compute water productivity, two important hydrological data are needed, viz. the volume of irrigation water delivered and daily rainfall. Hydraulic structures have to be installed with flow measuring device in order to compute the volumetric quantity of water supplied. Such structures include main regulator/headwork; intermediate control structure and off-take structure at the secondary canal.

To obtain representative daily rainfall for an irrigation block, it is necessary to have a good network of rainfall stations. In Muda Area, there are 59 automatic rainfall stations covering some 96,558 ha of paddy area. The density of rainfall stations in Muda Area is approximately one station per 1,600 ha. *Real-time* rainfall data can be retrieved anytime through the telemetry system.

4. FACTORS AFFECTING PADDY LAND PRODUCTIVITY

There are many factors that influence paddy land productivity. Some of the more significant factors are: soil types; seeds; agronomic practices; harvesting loss; good water management; and cropping intensity.

(i) Soil types. Land productivity depends a great deal on the soil types. The most suitable soil type for paddy cultivation is heavy loam with *pH* of 5.5 – 7.0. Generally, the soil in Muda Area is well suited for paddy cultivation. However, there are about 27% of acid sulphate soils which inhibit high paddy yield (MADA, 1977). Liming is usually carried out in these areas to neutralize the soil acidity.

(ii) Seeds. Good seeds play an important role in achieving high yield. High yielding varieties with good germination rates are especially crucial to produce high paddy yield. To obtain a good yield, there should be at least 600 plants per m^2 of area planted.

(iii) Agronomic practices. Good agronomic practices cannot be over emphasized in achieving high yield. The application of right amount of right agricultural input at the right time is the key to good agronomic practices of any crop cultivation. Pest and disease surveillance and control is equally important to prevent paddy loss. By reducing the unwanted weeds, high paddy yield will be reasonably assured.

(iv) Harvesting loss. Harvesting loss of paddy is in the range of 5-15%. By reducing the harvesting loss it is effectively increasing the yield and hence land productivity. Factors affecting harvesting loss are: harvester's conditions, machine operator, paddy plant and field conditions.

(v) Water management practice. Good water management practice is an essential component in ensuring good yield. Good water management means the application of irrigation water at the right amount at the right time and timely draining out excess water to avoid crop damage.

(vi) **Cropping intensity.** Land productivity is not only influenced by yield but also the *cropping intensity*. For the granaries, the average cropping intensity is about 180%. The availability of water resources is the single most important factor that governs the potential of double cropping. Areas outside the rice granaries, due to shortage of water, seldom can achieve cropping intensity of more than 150%. Therefore, the strategy is to sustain the cropping intensity of nearly 200% for the granary areas.

5. TARGETS FOR WATER AND LAND PRODUCTIVITY

(a) Water productivity

Water productivity of paddy in Muda Area for 2005-2009 is as shown in Table 1. The average water productivity for the last 9 seasons was ***0.49 kg/m³*** and it is above the world's average of ***0.35-0.40kg/m³***. Water productivity varies between ***0.35 kg/m³*** and ***0.60 kg/m³***. The exceptionally low water productivity of 0.35 kg/m³ was caused by the severe floods occurred in December 2005. The paddy yield per season in Muda Area fluctuates between 524,000 and 595,000 tonnes, whereas the total volume of water supplied ranges from 886-1,439 million m³.

Table 1: Paddy production, average yield and water productivity (WP) in the Muda Irrigation Scheme, Malaysia (2005-2009)

Cropping Season	Paddy Production (tonnes)	Average Yield (tonnes/ha)	Volume of Irrigation Water Consumed (10^6 m³)					WP (kg/m³)
			Effective Rainfall	Useful Uncontrolled Flow	Recycled water	Dam Supply	Total	
1/2005	586,558	6.08	502.32	48.93	160.64	401.42	1,113.31	0.527
2/2005	350,898*	3.93	526.14	406.37	42.04	39.11	1,013.66	0.346*
1/2006	576,725	5.98	437.50	153.52	95.37	269.73	956.13	0.603
2/2006	526,688	5.46	477.69	232.02	67.43	109.25	886.39	0.594
1/2007	564,768	5.85	453.15	192.93	120.09	242.26	1,008.43	0.560
2/2007	524,213	5.43	483.44	382.07	82.51	237.50	1,185.53	0.442
1/2008	576,482	5.97	503.68	163.13	78.81	487.40	1,233.01	0.468
2/2008	590,935	6.12	429.63	312.72	129.10	431.21	1,302.66	0.454
1/2009	595,763	6.17	705.86	203.42	113.55	416.76	1,439.59	0.414

Notes:
1. Total irrigated area = 96,558 ha.
2. Rainfall data based on the rainfall station at Kepala Batas, Alor Star.
3. Effective rainfall is taken as 50% of total rainfall during the irrigation period.
4. Useful uncontrolled flow is taken as 60% of the total uncontrolled flow.
5. Recycled water is the volume of recycled water from recycling pump stations.
6. Dam supply denotes the water released from Pedu and Ahning dams for the purpose of irrigation supply only.
7. Water productivity=Total paddy production (kg)/ volume of water supplied (m³).

* Low paddy yield of cropping season 2/2005 was caused by severe floods in Dec 2005.

Since the Muda Irrigation Scheme is the country's leading rice granary area as far as paddy production and efficient water management practices are concerned, its water productivity of paddy should be adopted as the benchmark for other irrigation schemes to emulate. Besides, the water use efficiency (70%) in the scheme is among the highest in the regions. Therefore, the target for water productivity for the granary areas can be reasonably set as ***0.50 kg/m³***.

(b) Land Productivity

The annual paddy production in 2002 for some selected Asian nations is as shown in Table 2. The world's average paddy yield in 2002 was **3.89 t/ha**, whereas the value for Malaysia was **3.24 t/ha**. The average paddy yield in Malaysia was 17% below the world's average, and it was only half of that of the developed countries like China, S. Korea and Japan (6.2-6.5 t/ha). China is the largest rice producing country (31.7%) and followed by India (19.5%).

Table 2. Paddy yield, area planted and annual production of selected Asian countries in 2002

Country	Average yield (t/ha)	Area planted (million ha)	Annual production (million tonnes)	% of world production
Japan	6.49	1.86	12.0	2.0%
S. Korea	6.31	1.05	6.6	1.1%
China	6.23	30.50	190.1	31.7%
Vietnam	4.55	7.49	34.1	5.7%
Indonesia	4.43	11.60	51.6	8.6%
Myanmar	3.53	6.20	21.9	3.7%
Malaysia	**3.24**	**0.68**	**2.2**	**0.4%**
India	2.91	40.00	116.6	19.5%
Thailand	2.50	9.80	18.5	3.1%
World	**3.89**	**153.80**	**598.9**	**100%**

Source: The Review of Paddy and Rice Industry in Malaysia, MoA (2004)

Malaysia currently produces some 2.38 million tonnes of paddy annually. The total area planted is about 676,000 ha with an average yield of 3.51 t/ha. More than two-thirds of the national paddy production comes from the granary areas. The breakdown of paddy production in Malaysia for the year 2007 is as shown in Table 3.

Table 3. Paddy yield, area planted and annual production in Malaysia in 2007

Paddy area	Area planted (ha)	Paddy yield (t/ha)	Annual paddy production (tonnes)
(i) Granary Areas	**387,650**	**4.17**	**1,616,500**
(ii) Peninsular	123,839	3.35	415,041
(iii) Sabah	41,443	3.24	134,384
(iv) Sarawak	123,179	1.70	209,679
Malaysia	**676,111**	**3.51**	**2,375,604**

Source: DOA Statistics (2010)

Considering the yield achieved by developed countries and the upward yield trend in the country in recent years, it is not unrealistic to target *the national average yield* of **4.5 t/ha**. To achieve that, the target for the eight granary areas has to be set at **6.0 t/ha**. The paddy yield for Muda Area has already achieved **6.12 t/ha** for the off-season of 2008, and **6.17 t/ha** for the main season of 2009. It is therefore incumbent for other granary areas to increase their yield to achieve the target.

6. CHALLENGES AHEAD

Nations throughout the world are confronted with the challenges to sustain the water and land productivity. Some of the more pressing challenges are briefly discussed as follows:

(i) **Competing use of water.** Irrigation water use accounts for 80% of the total water consumption (Facon, 1999). The remaining 20% is used for domestic, industrial, recreation and hydro power generation purposes. However, the water demand from domestic and industrial sectors will increase exponentially in the future and these sectors are always given high priority compared to other sectors, including agricultural. This may result in reduced water allocation for paddy cultivation. Therefore, it is of urgent need to increase water productivity so as to sustain sufficient water for paddy cultivation.

(ii) **Extreme weather conditions due to global warming.** Due to global warming, the weather conditions are getting more erratic and extreme. During the past decade, incidents of floods and droughts were also getting more frequent. For example, Muda Area has experienced annual flooding since 2005, compared with only two incidents of floods during 1988-2004 (17 years). The severity of flooding in some regions has reached unprecedented magnitudes, for example the floods in Johor in 2007. Both flood and drought pose serious challenges in sustaining land productivity. Floods destroy standing crops while droughts inhibit planting due to insufficient irrigation water.

(iii) **Pests and diseases.** Pests and diseases may pose great challenge for crop cultivation in the future. Excessive and indiscriminate use of chemicals for the control of pests and diseases may result in the emergence of new strains of pests and diseases that are resistant to chemical applications. The potential risk of major outbreak of pests and diseases which may result in wiping out substantial areas of the standing crop cannot be ruled out at any point of time. If this were to happen then he land productivity will be severely affected.

(iv) **Infrastructural requirements.** The level of infrastructural facilities in some of the rice granary areas is still low for optimum land productivity. For example, the density of canals, drains and farm roads in Muda area is 18m/ha and it is slightly better in Kemubu Area (24m/ha). Table 4 compares the densities of existing irrigation canals in the granary areas. The provision of tertiary irrigation facilities is considered the basic requirement conducive for good water management. However, the cost for such infrastructural development is exorbitant. This is due to the high construction cost of irrigation infrastructure as well as the need to acquire substantial land areas for the infrastructure construction.

Table 4. Comparison of irrigation canal densities in main granary areas, Malaysia

Item	Granary Area	Paddy Area (ha)	Density of Irrigation Canals (m/ha)
1	MADA	96,558	18
2	KADA	32,167	24
3	Kerian Sg. Manik	27,829	48
4	Barat Laut Selangor	18,482	32
5	Pulau Pinang	10,305	43
6	Seberang Perak	8,529	43
7	KETARA	5,156	37
8	Kemasin Semerak	5,220	38
Total/Average		**204,246**	**27.6**

Source: Annual Report IADA 2007

(v) **Farmers' response in adopting new technology.** The latest technology practices for paddy cultivation e.g. precision farming technique is readily available. However, precision farming is still not widespread in the granary areas due to the reluctance of farmers in adopting this new technology. Agriculture extension service has to be intensified to promote such technology to the farmers so as to increase water and land productivity.

7. CONCLUSIONS

Water and land productivity are two important performance indicators in crop production. These indicators are particularly more significant for paddy cultivation, as it is the major water consumer and at the same time rice is the staple food for the population. The focus of water and land productivity should centre on the granary areas as more than 70% of the country's paddy production comes from these areas.

The current water productivity of paddy in Muda Area (***0.50 kg/m³***) should be used as the benchmark for other granary areas to emulate as this area has been practising efficient water management and harnessing recycled drainage water for irrigation since 1983. The water use efficiency in this area is considered one of the highest in Asia.

For land productivity, it is important to increase the paddy yield as well as the cropping intensity. The average yield and cropping intensity in the granary areas should be increased from the present ***4.17 t/ha*** and ***1.8*** to ***6.0 t/ha*** and ***2.0*** respectively.

In order to achieve the targets of water and land productivity, concerted efforts have to be stepped up by all the players in the paddy industry. When these targets are achieved only then will the objective of producing paddy with "*more crop less drop*" be fulfilled.

REFERENCES

Department of Agriculture (2010). DOA Statistics. http://www.doa.gov.my/statistik/padi03-08htm.

Facon, T. (1999). Water Management in Rice in Asia: Some Issues for the Future, In: *Expert Consultation on "Bridging the Rice Yield Gap in the Asia-Pacific Region"*. 5-7 October 1999, Bangkok, Thailand.

IADA (2007). *Laporan Tahunan Kawasan Pembangunan Pertanian Bersepadu (IADA) 2007*. Ministry of Agriculture and Agro-Based Industry, Malaysia. (pp7 &19).

Ministry of Agriculture, Malaysia. MOA (2004). *The Review of Paddy and Rice Industry in Malaysia*. Chapter 5 (pp 129-168) & Chapter 6 (pp 170-272).

Muda Agricultural Development Authority. MADA (1977). *Feasibility Report on Tertiary Irrigation Facilities for Intensive Agricultural Development in the Muda Irrigation Scheme, Malaysia.*