ISSN: 1511-3701
Pertanika J. Trop. Agric. Sci. **32 (2)**: 267 - 291 (2009)

Deterministic Model Approaches in Identifying and Quantifying Technological Challenges in Rice Production and Research and in Predicting Population, Rice Production and Consumption in Malaysia

Ahmad Selamat[1, 2*] **and Mohd. Razi Ismail**[1, 3]
[1]*Department of Crop Science, Faculty of Agriculture, Universiti Putra Malaysia,*
43400 UPM, Serdang, Selangor, Malaysia
[2]*Institute for Mathematical Research, Universiti Putra Malaysia,*
43400 UPM, Serdang, Selangor, Malaysia
[3]*Institute of Tropical Agriculture, Universiti Putra Malaysia,*
43400 UPM, Serdang, Selangor, Malaysia
[*]*E-mail: ahmads@agri.upm.edu.my*

ABSTRACT

In general, rice production and sufficiency is the main concern to all Asian countries in currently facing the ever growing population and climatic uncertainties. The consumption in Malaysia relies largely on the locally produced (70%) and imported (30%) rice for years. The price hike of this staple food, which can be categorized as a security food crop with an annual production of 1.6 million tons (beras) yielded from about 650,000 ha of the harvested paddy irrigated- and non-irrigated growing areas nationwide, could possibly be expensive to the lower-income consumers. With "no further reduction" in the modelled per capita rice consumption (82.3 kg/person/ year) versus the increasing population, various efforts must be made in term of research and technological advancement, increased cropping hectarage, as well as active extension program to increase the production of rice for consumption, self-sufficiency and more importantly, for having strong rice stock-file accumulation. Based on the data gathered from the past 27-years (1980 – 2007), the deterministic mathematical models of the Malaysian population, rice per capita consumption and five rice yield models versus years (1980 – 2007 and 2008 – 2030) were developed and predicted. The proposed model was based on the national average yields over the years and the model could be used to predict the yield 'close' to the nation's rice production in the years ahead. The data on the crop cutting test or survey were used for comparison purposes. With the derivatives of the yield models, the quantitative technological advancement indexes were used in identifying the research objective, scope and areas, as well as in quantifying the contribution of crops and their management-related technologies in the past, present and predicted technological performances in rice production. To reach sufficient rice production at a relatively faster rate, the scope of the research's objective should be based on the high yield model, in which the averaged yield could reach 13.4 t/ha in the year 2030. The priority order of the research areas would be irrigation/water > crop establishment-related management > sustainability of the existing management technology > large plot production-related adaptive studies (technological uniformity studies) > continual varietal improvement. The local released varieties are ecologically suited to the Malaysian rice growing areas, where varietal development and improvement are generally time consuming. With the current planted hectareage, coupled with the inclusion of the planned additional 100,000 ha (assumed to be staggered), as planned by the Ministry of Agriculture and with the conversion of the non-fully to fully irrigated areas by 2012, the Malaysian rice self-sufficiency is predicted to be observed/achieved in 2012. The 'modified higher-order polynomial' yield model which was conditioned

---

Received: 8 September 2008
Accepted: 24 March 2009
[*]Corresponding Author

with the scope of the above research objective and the area priorities predicts the rice production of 2.0, 4.4 and 9.1 million t/ha in 2010, 2020 and 2030, respectively. With the modelled minimum per capita consumption (82.3 g/person/year) and the predicted population of 29.3 (2010), 36.7 (2020) and 45.7 million (2030), the respective consumption, surplus and self-sufficiency would be 2.4, 3.0 and 3.8 million tons, -0.4, 1.3 and 5.3 million tons and 83, 144 and 241%, respectively. The surplus could then be used for the stock-pile accumulation and export.

Keywords: Population model, rice production and technological advancement indexes and models, rice consumption, self-sufficiencies, irrigation and management related technologies, rice import and surplus

INTRODUCTION

The production of rice (*Oryza sativa*) in most Asian countries should increase in tandem with the continent's population growth. In 1997, the total production of rice in these countries was estimated at 574.2 million tones (Workman, 2008) with the estimated population of 3.73 billions in 2006 (UNESCAP, 2008). When narrowing down to the South East Asian countries, almost 100% of the population are taking rice in their daily diet. Literally, we could 'equate' the population growth with the increase in the production of rice for this particular region, or rice production is positively associated with its population. The population and rice production for this sub-continent are estimated at 564 million and 102 million tons, respectively in 2008 (USDA, 2008). The per capita rice consumption in the Southeast Asian countries (not including Malaysia) is currently ranging between 101 – 217 kg/person/year (NationMaster.com, 2008). The figure for Malaysia, calculated by the exponential decay curve model (i.e. based on the data from 1980 – 2007), has its lower plateau of 82.3 kg/person/year.

Recently, Malaysia is also facing the issue of shortages in the locally produced rice. The consumption in Malaysia relies heavily on the locally produced and imported rice (i.e. on the average of 70% and 30%, respectively) for years (DOA, 2007). Even though the self-sufficiency figure was initially set by the Government (National Agriculture Policy) in the earlier years, with the recent food global crisis, it is believed that Malaysia should have the 100% rice sufficiency because rice is a nationally and politically related crop. The later is probably evidenced by the Government's plan in opening an additional new rice growing land of 100,000 ha within two years (Bernama, 2008). The price hike of this staple food (categorized as a security food crop), with the annual production of 1.6 million tons (beras), obtained from about 650,000 ha of the harvested paddy irrigated- and non-irrigated growing areas nationwide (Ministry of Agriculture, 2007), is rather expensive to the lower-income consumers. With a model which indicates "no further reduction" in the per capita rice consumption (82.3 kg/person/year) versus the increasing population, the rice consumption will then be population dependent.

In general, this study attempted to identify, qualitatively and quantitatively, the direction, trend and areas of rice technological research and advancement in rice production so as to meet the Malaysian rice consumption at her highest self-sufficiency level. For this, a specific objective was then developed for the deterministic mathematical models and functions to be used in identifying and quantifying technological challenges in rice production and research, as well as in predicting population growth, rice production and consumption in Malaysia up to the year 2030. The rice self-sufficiency, in relation to the net import was also computed.

The data, which were mainly obtained from the Departments of Agriculture and Statistics and Malaysian Agricultural Research and Development Institute for the period between 1980 and 2007, were used for the development of the above model. In specific, the deterministic mathematical models of the population, the growth rate of the population, yield versus year, total and crop and management technology indexes, as well as per capita consumption, were also developed. The models were used in assessing and evaluating the past, present and future (prediction) of rice production, research and technology advancement, import and self-sufficiency. The yield and technology analyses were largely based on the national average data. The sensitivities of the models to: [i] planted hectareages [mean, additional new land, as planned by the Ministry of Agriculture (Bernama, 2008)] and the conversion of the existing paddy fields into fully irrigated areas) and [ii] five proposed technology index-related yield trends ('logistic', linear, exponential, polynomial-logistic and modified polynomial) were also computed.

Therefore, the models were developed based on mainly the national average rice yield data versus years to have a practical or 'real' implication. The data of the crop cutting tests (CCT) or surveys (CCS) were only used for comparative purposes.

POPULATION AND RICE CONSUMPTION

Population and Its Growth

As clocked on 21 May 2008, the Malaysian population stood at 27,486,789. Based on the data presented by United Nation Organization (UNEP, 2008), the world's population is predicted to grow with a logistic exponential growth function from 1750 to 2100. The population will reach the figure of more than 10 billion people in 2100. At present, the world is experiencing its liner phase of population growth and clocked at 6,674,551,067 on 16 June, 2008 (*U.S. Census Bureau, 2008).* Therefore, discussions on food distribution and shortages in certain developing and underdeveloped countries are the main concerns, especially in facing the issues of rapid population increase and food production against the global climatic and weather uncertainties (global warming) ahead.

Based on population from 1980 to 1996 (Anon, 2008), the deterministic Malaysian population model was developed. The model (*Fig. 1*) which contains the features of linear and exponential functions, which incorporate both the natural and planned (or forced) population growth rates (*Fig. 2*) were validated by the population figures for the years between 1997 and 2007, clocked on 21 May 2008 and projected for 2010 (Malaxi.com, 2008). Mathematically, the model could be written as follows:

$$y = (e^{-45.95182}e^{0.02801248x} + 476.8922x - 930968.8431)/2.013$$

$$\text{IF} \quad 1980 < x \leq 2034$$

and

$$y_t = y_{t-1}(1 + e^{3.424772105 - 0.048925316(x - 1980)}/100)$$

where t = year 2035, 2036, ..., 2050

$$\text{IF} \quad 2034 < x < 2050 \tag{1}$$

Where, y and x are population and year, respectively. The annual population growth rate was averaged at 2.6% during the period of 1980 – 1997 (Department of Statistic, 2001). Since Malaysia will become one of the developed nations at and after 2020, it is therefore assumed that the growth rate will decline from 2.2% in 2034 to merely 1.0% in 2050. The decline would possibly match with the rates, as planned by the Government under the family planning program. Conservatively, the developed and validated model could predict the population of Malaysia with a 'high accuracy' up to the year 2050. The projected Malaysian populations are 29.3, 36.7, 45.7 and 63.1 millions in 2010, 2020, 2030 and 2050, respectively. This trend is possibly in line with the government's target of achieving 70 million people when the country reaches the status of a fully developed nation.

Rice Consumption, Sufficiency and Stock-pile

The total amount of the nation's rice consumption is simply the product of population and the consumption per capita in a particular year, while self-sufficiency is the ratio of the net domestic rice production to the consumption. The data extracted from Padi Beras Nasional (BERNAS) and the Ministry of Agriculture

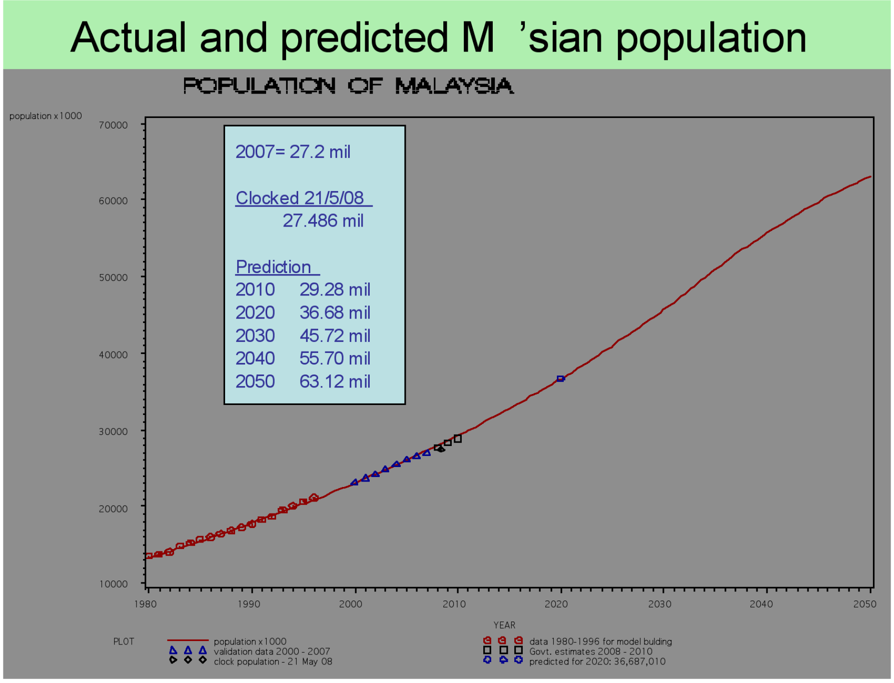

Fig. 1: Predicted Malaysian population until year 2050

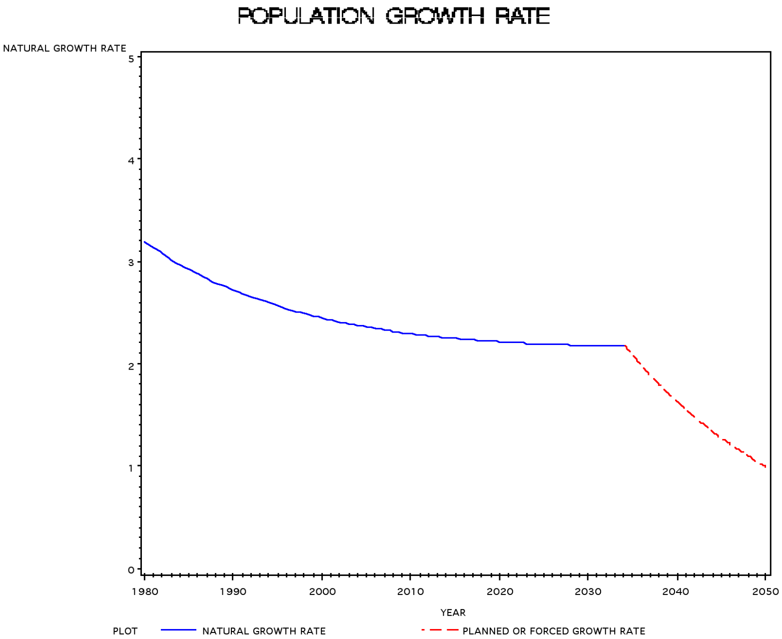

Fig. 2: Calculated malaysian population growth rate (natural and planned growth rate)

(2008), the rice production, rice consumption, import and self-sufficiency during the period of 1980 – 2007 are shown in *Fig. 3*. Based on the data, the rice import (167 – 843 thousand tons/ year) was needed to top up the locally produced rice (1,010 – 1,600 thousand tons/ year) in meeting the yearly consumption of 1,290– 2,230 thousand tons/ha. This led to the figures of 69 – 88 % rice self-sufficiency for the period. The highest sufficiency was recorded in 1980 and subsequently the figure was decreased with increasing population in the years approaching 2007. The figures did not reflect any active stock-pile in the country during the period mentioned. The recent government's announcement of the 3 month's rice stock is probably a short-term temporary measure in ensuring rice sufficiency locally. If in a situation, where the neighbouring rice-producing countries were taking a stringent action in exporting their rice, it was then presumed that the country would have a difficult situation of an accumulated rice shortage nationwide.

The above prediction would strongly suggest that programs and activities, i.e. research and development in generating advanced and sustainable technologies, improving the existing non-irrigated paddy fields and new land opening for rice cultivation, should mandatorily be accelerated. These will certainly increase the production of rice in Malaysia and it is also hoped that the rice self-sufficiency of >100% and the possibility of having 1-year stock-pile of the locally produced rice, be possibly achieved in the near future. This is crucial as rice has high significant implications in the social, political and economic stability in this country.

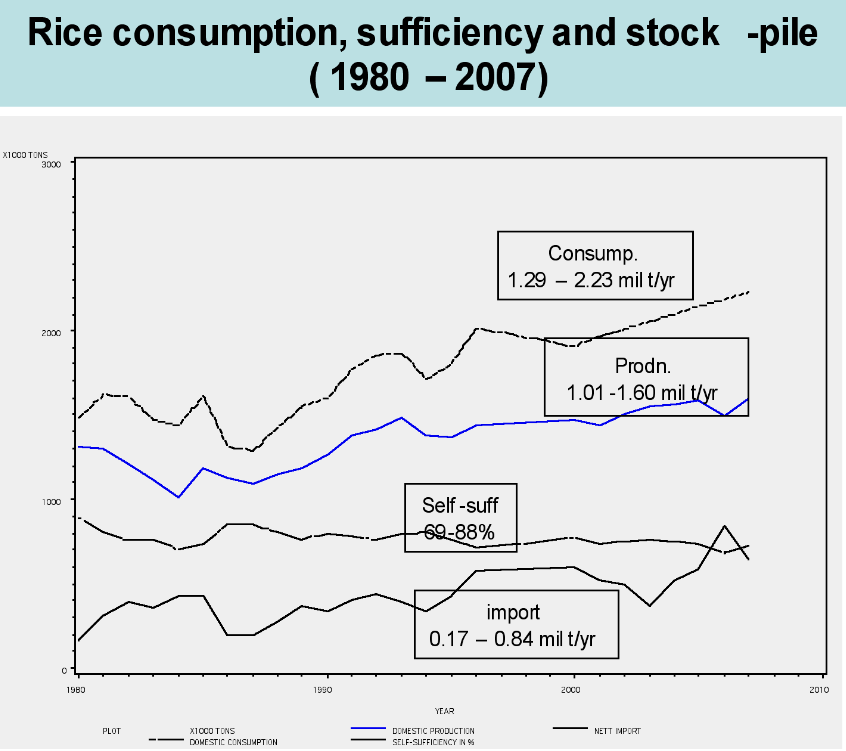

Fig. 3: Rice production, consumption, net import and self-sufficiency from years 1980 – 2007

RESEARCH AND DEVELOPMENT AREAS AND THEIR CHALLENGES

The parameter of yield per unit area (tons/ha) is the focal point of the technological advancement objective quantitatively set in any research and development (R&D) program. In this paper, rice (padi) yield in tons/ha was used in identifying and quantifying the effectiveness of the technologies generated by the past R&D programs and activities. In general, it was also used for identifying the future research areas which should be given a priority in achieving the national's good rice self-sufficiency and stock-pile at a relatively faster rate, to sustain the nation's exponential population growth.

The padi yields in tons/ha, from 1980 – 2007, were used in computing the technology advancement index (TAI) development in rice production. In brief, the TAI is defined as a change in tons/ ha/ year or the tangent at any point of the year when tons/ha is regressed over years. In other words, the instantaneous TAI is the kg/ha-vs.-year model dependence. The higher the TAI, the higher the technological advancement in affecting yield will increase over the time. Therefore, TAI is the total technological combination of crop (varietal development and improvement) and management components (irrigation, fertilization, crop establishment and distribution, pest and diseases control, etc.) in the production of rice.

Yield Models

Based on the average of the national yields (tons/ ha) versus years (1980 – 2007), five models developed in this study are shown in *Fig. 4*. The deterministic models were mathematically written as:

$$\text{Model 1: } y = 19060.4/(1 + 7.76e^{-0.0252\,(x\,-1980)}) \qquad (2)$$

$$\text{Model 2: } y = 2105.13 + 62.80(x\text{-}1980) \qquad (3)$$

$$\text{Model 3: } y = 2184.38e^{0.02123(x\,-1980)} \qquad (4)$$

$$\text{Model 4: } y = (4102731.93 + 4514.33\,(x - 1980)^{2.48})/(1758.3957 + (x - 1980)^{2.48}) \qquad (5)$$

$$\text{Model 5: } y = 2217.75 - 0.717(x\text{-}1980)^{0.7} + 7.96(x\text{-}1980)^{2} - 0.394\,(x-1980)^{3} + 0.00697(x\text{-}1980)^{3.98} \qquad (6)$$

where, y and x are tons/ ha and years starting from 1980, respectively. Models 1, 2, 3, 4 and 5 could be termed as the logistic growth, simple linear, exponential, 'logistic polynomial' and 'modified higher-order polynomial' functions, respectively. Based on these models, the increases of yield per ha over the years between 1982 – 2007 (which were due to technological advancement based on models 1, 2, 3, 4 and 5) were 94.6, 94.7, 94.8 , 94.5 and 93.6%, respectively. On the other hand, the respective figures (due to climatic fluctuations) were only 5.4, 5.3, 5.2, 5.5 and 6.4%. These figures suggest that the technological advancement was more dominant in the increase of yield per ha over the years, as compared to the climatic variability during the period. Thus, it would give an ample room for research and development program and activities to generate advanced technology in the effort to increase rice yield in the future!

The predicted yields in kg/ha, computed by the above models (Equations 2, 3, 4, 5, 6 and *Fig. 4*), are shown in Table 1. It is suggested that the yield should increase with Model 3 up to 2013, which subsequently then be switched to Model 5 to obtain a steady increase of higher yields over the years. Model 5 indicated that the overall yield could be increased to 13.2 tons/ha in 2030. The crop cutting test or survey also showed a potential yield of 14.0 tons/ha (Department of Agriculture, 2008). If research and extension activities were not geared to their highest capacities, we are in the opinion that the yield increase would only progress with Model 4, with the overall yield of about 4.0 – 4.3 tons/ ha. Even if the yield increased linearly (Model 2), the predicted yields in 2020 to 2030 would only be in the range of 4.6 – 5.2 tons/ha.

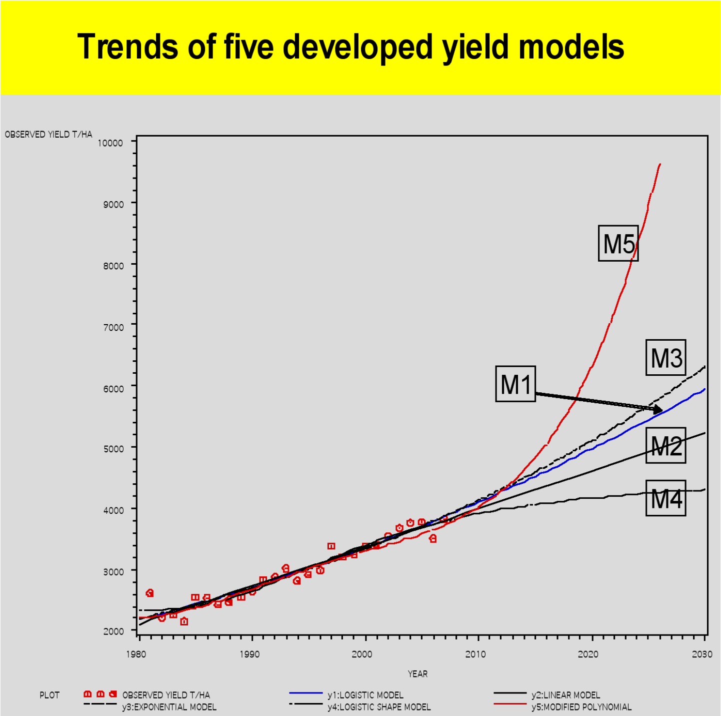

Fig. 4: Five developed yield models versus years (1980 – 2030) in Malaysian rice growing areas

TABLE 1
Predicted padi yields and technological advancement indexes (TAI) in 2010 – 2030, based on Yield models 1, 2, 3, 4 and 5

Models	Years									
	2010		2015		2020		2025		2030	
	Yield Kg/ha	TAI kg/ha/yr	Yield Kg/ha	TAI kg/ha/yr	Yield Kg/ha	TAI kg/ha/yr	Yield Kg/ha	TAI kg/ha/yr	Yield Kg/ha	TAI kg/ha/yr
1: logistic growth	4102	81	4523	86	4971	92	5351	98	5951	103
2: simple linear	3989	62	4303	62	4617	62	4868	62	5245	62
3: exponential	4129	87	4592	97	5106	108	5559	120	6314	134
4: 'logistic polynomial'	3910	36	4062	25	4169	17	4232	13	4301	9
5: 'modified higher-order polynomial'	4016	114	4819	217	6320	396	8300	667	13179	1050

Technology Advancement Index (TAI) and Its Partitioning to Crop and Management Technologies

By taking the derivative of each model, the trends of the TAIs from 2008 to 2030 are shown in *Fig. 5*, while the predicted TAIs for 2010, 2015, 2020, 2025 and 2030 are indicated in Table 1. Model 5 has higher predicted TAIs (114.1 – 1050.1 kg/ha/year) as compared to the other models. This suggests that the technology usage, refinement and development will be significantly reflected in the yield improvement. On the contrary, Model 4 shows that no further technological improvement would occur. This suggests that the scientists should use Model 5 as their research moving target versus years in quantifying the achievements of their research.

Based on limited available data, the technologies are broadly categorized into four groups, viz., crop (varieties), irrigation (with soil physical manipulation), crop establishment and other components (pooling effects of fertilizers and soil fertility, pest, disease and weed control and other practices on rice yield). Due to the limitation, the assumption on time duration required for technological advancement was made, particularly for irrigation and varietal improvement.

TAI Due to Varietal Improvement

Breeding research programs are generally aimed at producing and improving rice varieties in terms of yield quantity (productivity) and quality and/or crop type which is resistant to certain diseases or responsive to certain environmental factors. In this paper, the quantity (tons/ha) is emphasized since rice production and sufficiency are the pressing issues at present. Based on the yield data (national average) of MR84, MR185, MR211, MR219 and MR220 released

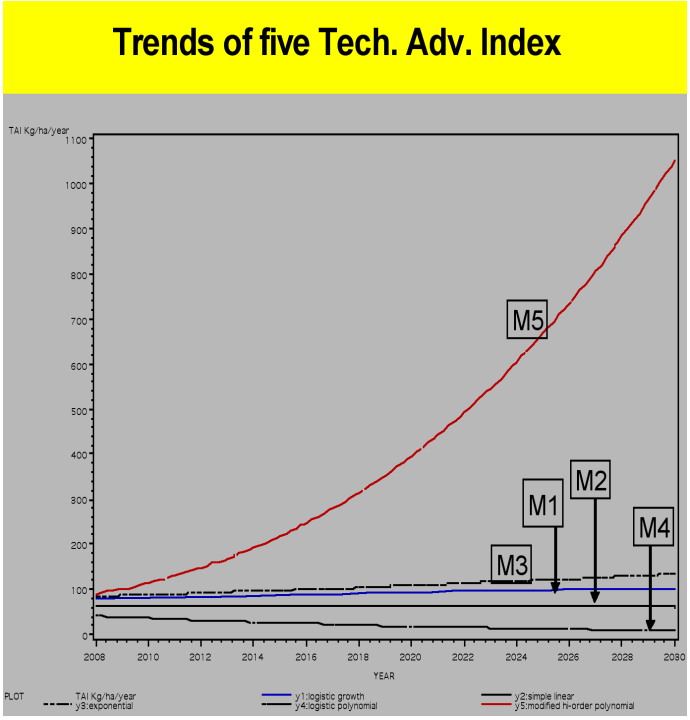

Fig. 5: Technological advancement indexes over years (2008 – 2030) as generated from five yield models

in 1977, 1999, 2001 and 2003, respectively, the yield improvement per year due to the newly released varieties is 41.5 kg/ha/year. The linear increase was assumed in this paper. If this improvement is consistent over the years (up to 2030), then the percentages of the contribution of varietal component in the TAI over the years (2010, 2015, 2020, 2025 and 2030) of five yield models are as indicated in Table 2.

TAI Due to Irrigation Technology and Improvement

Based on the data obtained in the off-seasons of 2005 and 2006 and the main-season of 2006/2007, the differences in the yield per ha between the areas, within the irrigation scheme (3.9 – 4.2 tons/ha) and outside scheme (3.2 – 3.3 tons/ha) were calculated. The average difference was 0.74 tons/ha. Thus, it could be implied that the yield difference was due to the irrigation/water related technology improvement. It is also assumed that if the areas outside the scheme were converted to the fully irrigated paddy fields, they would then achieve the yield level close to the areas full of irrigation. If the conversion would take in 2, 4, 6, 8 and 10 years' duration, the yield would increase the rates due to irrigation improvement which would then become 0.37, 0.18, 0.12, 0.09 and 0.07 tons/ ha/year, respectively.

TAI Due to Other Management Technologies and Improvement

After considering the two technologies above, the yield improvement could be contributed by the other component improvements, namely weed, pest and disease control, as well as fertilizer, crop establishment techniques and other soil and agronomic manipulations. The quantum of the technological improvements of these pooled components is based on the targeted yield increased, as based on the above five yield models. It was recorded that the crop cutting test had achieved the highest potential yield of 14.0 tons/ha, i.e., by the conversion from a smaller plot to per ha basis. This indicates that if the crop growth and performance is uniform throughout a large field, a higher average yield per ha should therefore be achieved. This suggests that crop establishment technology (for example, high density planting) and field planting environment should be researched further aggressively in obtaining uniform crop performance over larger growing areas.

Integrated Contribution of Technological Components to the Total TAI

Table 2 shows that the yearly varietal improvement will contribute to about 63% of the total TAI for each year, based on the simple linear yield model (Model 2). The contributions

TABLE 2

Contribution index of varietal improvement against total technology Index (TAI) over years 2010 – 2030 based on five yield models (1 = logistic growth, 2=simple linear, 3= exponential, 4='logistic polynomial', 5=' high order modified- polynomial) of rice production in Malaysia growing environment. Value greater than 100 indicates contribution index saturation of a particular model

Year	Model 1	Model 2	Model 3	Model 4	Model 5
– – – – – – – – – – – – – – contribution index to total TAI (%) – – – – – – – – – – – – – –					
2010	51.2169	66.1715	47.3965	115.150	36.4160
2015	47.8017	66.1715	42.6232	163.767	19.0686
2020	44.8712	66.1715	38.3306	231.068	10.4909
2025	42.3790	66.1715	34.4703	320.805	6.2272
2030	40.2855	66.1715	30.9988	437.064	3.9570

would be reduced from 51% in 2010 to 40% in 2030, when the logistic growth model (Model 1) was used. Model 3 (exponential) predicts the reduction from 36% to 10% for the same period. The high yield model (Model 5: 'modified higher-order polynomial') indicates a small respective varietal contribution to the total TAI (36% to 4%). These suggest that the higher the model, the higher the contribution of the other components will be (other than padi varieties) in the predicted rice yield in the Malaysian rice growing areas. As reported by Longping (Star, 2004), Othman (rice breeder) of MARDI, the varieties were not the factors causing lower yield production in Malaysia, but it was rather due to the poor farm management as compared to China (17 tons/ha). This was due to the different climates and better farm management in China. High temperatures have been indicated to cause higher percentage of spikelet sterility and hence producing lower yield (Battisti and Hinckley, 2008). Othman's statement could be confirmed by Model 4 ('logistic polynomial') which is predicted to be asymptotic over years, which likely to be dominated by the varietal performance. The current performance of rice in Thailand is mostly determined by the climate and management practices (Thailand Extension Authority, 2008).

With the existing improved varieties, rice production in Asian countries is ecologically and mainly associated with flooded paddy growing condition. In the case of water or irrigation requirements, 75% of the world rice is produced from irrigated growing areas (Science Daily, 2007). This particularly indicates the importance of water and irrigation in rice production. About 23% of the rice harvested hectareage in Malaysia is not from the fully irrigated areas. It is then suggested that these areas should be converted into fully irrigated growing areas. The conversion might involve the infrastructural improvement or in situ irrigation technological advancement techniques. If the required durations for the conversion are 2, 4, 6, 8 and 10 years, the calculated contributions of the irrigation and its related technologies to the total TAI are shown in Table 3. These calculations were made by assuming that both areas (inside or outside the scheme) had received equal crop and other-management technologies for rice growing. Even if the conversion would only take two years, Model 5 (high yield trend function) would still show that the increase yield rate would not saturate the yield level over time. A similar situation will also occur when the varietal and irrigation components are combined in causing the rice yield to increase, based on the high yield models, particularly with the extended years of the projection's period (Table 4).

This implies that there will be a room for yield improvement by contributions of other technological components, viz., crop establishment and weed, pest and disease control and soil and agronomic manipulation. For example, if the area gradually requires 10 year's period for the conversion, conditioned by the linear varietal improvement (41.5 kg/ha/yr), about 47 – 89% contribution will then be estimated (years 2015 – 2030) to the total TAI, based on the high yield trend (Model 5) which should be coming from other management technologies. In the IADA granary of Barat Laut Selangor, the average rice yield was 6.5 tons/ha versus about 4.0 tons/ha or less for the other areas in 2007 (IADA Barat Laut Selangor, 2008). It is important to note that the farmers in this area have been practicing good management of rice cultivation (especially with a high plant density planting and higher fertilizer rate application). Mansor (2008) indicated that a high paddy planting density (600 tillers that yield 500 panicles per sq. m) produced high yield obtained from the local verification trial plots (8-10 t/ha). Rice varieties, MRQ50, MR219 and MR220 released in 1999, 2001 and 2003 had local verification trial yields of 4000-5000, 6380 – 7980 and 5000 – 9600 kg/ha, respectively (MARDI, 2008).

This suggests that the yield gaps, among the management practices and the yield range within the same rice variety, indicated that the rice yields under the Malaysian growing condition could be further increased, i.e. above the level as dictated by the variety and water/irrigation components for the other factors. Since the

TABLE 3
Contribution index of irrigation technology improvement against total technology index (TAI) over years 2010 – 2030 based on five yield models (1= logistic growth, 2=simple linear, 3= exponential, 4='logistic polynomial', 5=' high order modified-polynomial) at five assumed durations of irrigation scheme completion period. Value greater than 100 indicates contribution index saturation of a particular model

Year	Irrigation scheme completion period (years)				
	2	4	6	8	10
contribution index to total TAI (%)					
Model 1					
2010	456.233	228.111	152.078	114.055	91.2417
2015	425.811	212.900	141.937	106.450	85.1575
2020	399.707	199.848	133.236	99.924	79.9370
2025	377.506	188.748	125.835	94.374	75.4972
2030	358.857	179.424	119.619	89.712	71.7676
Model 2					
2010	589.447	294.715	196.482	147.358	117.883
2015	589.447	294.715	196.482	147.358	117.883
2020	589.447	294.715	196.482	147.358	117.883
2025	589.447	294.715	196.482	147.358	117.883
2030	589.447	294.715	196.482	147.358	117.883
Model 3					
2010	422.201	211.095	140.734	105.548	84.4357
2015	379.681	189.836	126.560	94.918	75.9322
2020	341.444	170.717	113.815	85.359	68.2850
2025	307.057	153.524	102.352	76.762	61.4080
2030	276.133	138.063	92.044	69.031	55.2236
Model 4					
2010	1025.74	512.86	341.91	256.428	205.137
2015	1458.82	729.39	486.27	364.694	291.747
2020	2058.32	1029.13	686.11	514.566	411.642
2025	2857.68	1428.80	952.56	714.402	571.506
2030	3893.31	1946.60	1297.77	973.300	778.619
Model 5					
2010	324.388	162.190	108.129	81.0949	64.8742
2015	169.860	84.928	56.620	42.4640	33.9703
2020	93.451	46.724	31.150	23.3622	18.6893
2025	55.471	27.735	18.490	13.8674	11.0936
2030	35.248	17.624	11.749	8.8119	7.0493

yield per ha is directly and mathematically a function of planting density and fertilizer rate, the crop establishment and fertilization are therefore other important technologies to be further improved in obtaining high rice yield in relatively short time, in addition to the existing management practices (weed, pest and diseases control and other cultural practices).

Research Priority and Challenges

Based on the above five yield models and the related brief discussion, the main tasks and challenges faced by researchers and scientists are objectively in making the high yield model over time as their core research's target. By using the models, the research progress, output and success could be identified and quantified for the

TABLE 4
Contribution index of combined irrigation & variety technology improvement against total technology index (TAI) over years 2010 – 2030 based on five yield models (1= logistic growth, 2=simple linear, 3= exponential, 4='logistic polynomial', 5=' high order modified-polynomial) at five assumed durations of irrigation scheme completion period. Value greater than 100 indicates contribution index saturation of a particular model

Year	Irrigation scheme completion period (years)				
	2	4	6	8	10
contribution index to total TAI (%)					
Model 1					
2010	507.450	279.327	203.295	165.272	142.459
2015	473.612	260.701	189.739	154.251	132.959
2020	444.578	244.719	178.107	144.795	124.808
2025	419.885	231.127	168.215	136.753	117.876
2030	399.143	219.709	159.905	129.997	112.053
Model 2					
2010	655.618	360.887	262.654	213.529	184.055
2015	655.618	360.887	262.654	213.529	184.055
2020	655.618	360.887	262.654	213.529	184.055
2025	655.618	360.887	262.654	213.529	184.055
2030	655.618	360.887	262.654	213.529	184.055
Model 3					
2010	469.598	258.492	188.130	152.944	131.832
2015	422.305	232.459	169.184	137.541	118.555
2020	379.774	209.048	152.145	123.689	106.616
2025	341.527	187.995	136.823	111.232	95.878
2030	307.132	169.062	123.043	100.030	86.222
Model 4					
2010	1140.89	628.01	457.06	371.58	320.29
2015	1622.58	893.16	650.04	528.46	455.51
2020	2289.39	1260.20	917.18	745.63	642.71
2025	3178.49	1749.61	1273.37	1035.21	892.31
2030	4330.37	2383.67	1734.83	1410.36	1215.68
Model 5					
2010	360.804	198.606	144.545	117.511	101.290
2015	188.929	103.997	75.689	61.533	53.039
2020	103.942	57.215	41.641	33.853	29.180
2025	61.698	33.962	24.717	20.095	17.321
2030	39.205	21.581	15.706	12.769	11.006

assessment of the technological advancement. This is crucial since the arable land is becoming lesser in the future. For example, the global per capita arable land had decreased from 0.42 to 0.23 ha/person (1961 – 2002) [FAO, 2008] and this figure could become worsened when the global population would be estimated above 10 billions in 2100.

In a medium term (up to 2030), the technologies in the Malaysian rice production should be improved further at a reasonably rapid rate. In signifying the positive and additive effects of the technologies, research and management in sustaining the performances of existing technologies are equally important. In more specific, the scope of the medium terms and the priority of the Malaysian rice research are as followings:

(1) Use Model 3 (exponential) until 2013 and then switch to Model 5 ('modified higher-order polynomial') from 2013 onwards to form year-dependence moving quantitative objective or the target in all research programs and activities leading to the improvement or generation of relevant and applicable technologies. Avoid any research which quantitatively yield technologies that reflect the yield trend, as indicated in Model 4 ('logistic polynomial'). Based on the yield statistics of 1980 – 2007 (Dept. of Agric., 2008), Model 4 would likely be the trend to obtain the national average rice yield versus years until 2030. If this was true, i.e., without any additional hectareage of rice areas, Malaysia would face a high rice importation for the increased consumption, due to the growth in its population.

(2) Priority of research areas (*in the order of time-related importance*)

The suggested order of the priority of the research area is irrigation/water > crop establishment-related management > sustainability of existing management technology > large plot production-related adaptive studies > continual varietal improvement. A brief discussion is given below:

a. Research on the infrastructural and in-situ irrigation-related technological development, refinement and improvement. Infrastructural-related technology is mostly suited for upgrading and conversion of the rain-fed or not-fully irrigated areas into fully irrigated scheme, or for the opening of new rice growing areas. The in-situ research is probably suited to the existing fully-irrigated fields, especially in controlling water loss and seepage, controlling water level and technique used for reducing water evaporation loss and water quality in the paddy fields, as related to rice growth and development. The above research will definitely take into account the physical structure and type of soil and the climatic fluctuation of the locality.

b. Research on crop establishment, especially on the relationship of high planting density versus fertilizer rate in rice growth and development.

c. Research on sustainability of the existing management and cultural related technologies. Climatic uncertainties will, to certain extent, affect the performance and efficiencies of certain management technologies. The world is now facing the global warming trend in the years ahead.

d. Local verification and adaptive studies with increasing trial plot size (technological uniformity studies) should be carried out nationwide over all rice growing areas. These studies will determine the stability and modification of certain technologies over Malaysian rice growing areas. This is an effort to obtain a quite "uniform" rice yield performance over all rice growing areas and thus increasing the national average yield with high degree of confidence.

e. Apart from improving the quality of grains, varietal improvement works should be carried out continuously in obtaining an average nationwide yield increase rate of 42 kg/ha/year or higher. With a quite disadvantaged climatic condition relative to those in China and Japan for rice growing, the above yield increase rate could possibly be achieved annually. Most locally developed rice varieties are adapted well to the Malaysian rice growing areas.

PREDICTION OF RICE PRODUCTION, CONSUMPTION, SELF-SUFFICIENCY AND STOCK-PILE ACCUMULATION (2008 – 2030)

The mean, standard deviation and coefficient of variation of rice planted hectareage for the duration of between years of 1998 and 2007 were 674,548 ha, 12,144 ha and 1.8%, respectively, as shown in *Fig. 6* (Ministry of Agriculture, 2007). The respective values for the harvested areas were 656,805 ha, 26,763 ha and 4.1%. About 23% of the areas did not receive a full-irrigation system and it is also classified as the rain-fed rice growing areas. With the current local and global rice sufficiency, the Ministry of Agriculture has decided to open an additional area of 100,000 ha for rice cultivation (BERNAMA, 2008).

The developed per capita consumption model (*Fig. 7*), coupled with the developed population model (*Fig. 1*) was employed in the calculation of rice consumption per year. The per capita consumption had been decreased with an exponential decay function which yielded an averaged 'non-reducible' level at 82.3 kg/person/year after 2003 onwards.

Based on the above discussion and possibilities, the rice (beras) production, domestic consumption, net import and self-sufficiency were predicted for years 2008 – 2030, as shown in Tables 5, 6, 7, 8 and 9. The predictions were subjected to five predicted yield models (logistic growth, simple linear, exponential, 'logistic polynomial' and 'modified higher-order polynomial'), as well as the options of the planted hectareages for rice cultivation. The hectareage options are: [1] based on the planted hectareage mean for years 1998 – 2007, [2] as in (1) but with the inclusion of conversion of partially irrigated (or rain-fed) areas into fully-irrigated scheme by 2012, [3] as in (1) but with additional new rice growing land and [4] as in (3) but with full irrigation conversion. For a practical consideration, the additional new land for rice growing would be implemented in stages, i.e. 40,000, 40,000 and 20,000 ha in 2010, 2011 and 2012, respectively. According to Chang (2002), crop yield is a function of climate, technology, management and land.

Table 5 shows that the total nation's rice consumption was predicted to increase exponentially from 2.4 million tons in 2010 to 3.0 and 3.8 million tons in 2020 and 2030, respectively. This trend is in tandem with the population increase, whereby the predicted figures for 2010, 2020 and 2030 were 29.3, 36.7 and 45.7 million people, respectively. If the rice production was purely based on the current planted hectareage, the self-sufficiency would be

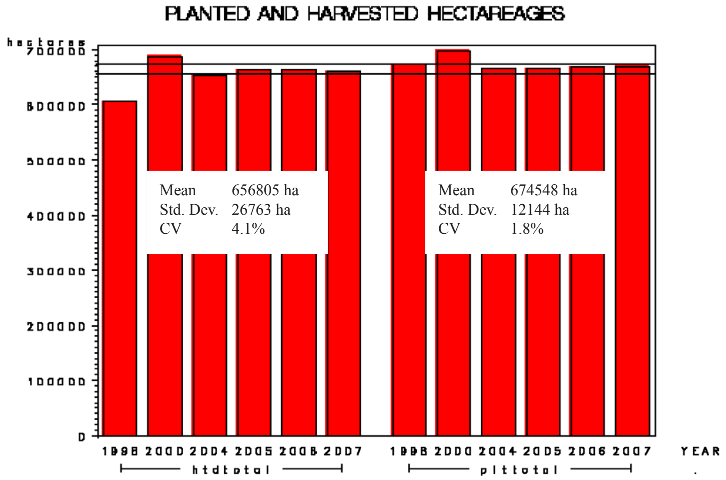

Fig. 6: Harvested and planted hectareages of rice growing in Malaysia from 1998 – 2007

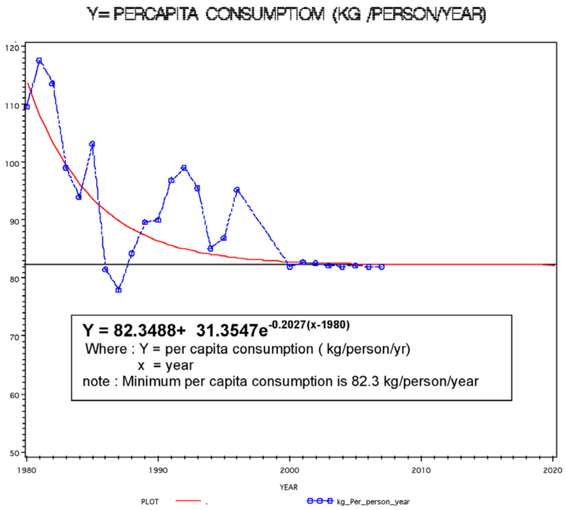

Fig. 7: Per capita rice consumption model. The model was developed based on the data gathered from 1980- 2007, from Department of Agriculture, Malaysia

TABLE 5
Predicted population, per capita rice and total consumption and mean planted rice hectareage

Year	Population (×1000)	Per capita consumption (kg/person/year)	Consumption (ton)	Planted (ha)
2008	27958.95	82.4563	2305391.38	674548
2009	28614.30	82.4366	2358864.89	674548
2010	29281.54	82.4205	2413398.24	674548
2011	29961.00	82.4073	2469006.04	674548
2012	30653.04	82.3966	2525705.82	674548
2013	31358.01	82.3878	2583517.73	674548
2014	32076.27	82.3807	2642464.27	674548
2015	32808.21	82.3748	2702570.04	674548
2016	33554.21	82.3700	2763861.61	674548
2017	34314.67	82.3661	2826367.32	674548
2018	35090.01	82.3630	2890117.22	674548
2019	35880.64	82.3604	2955142.90	674548
2020	36687.01	82.3582	3021477.51	674548
2021	37509.55	82.3565	3089155.60	674548
2022	38348.73	82.3551	3158213.17	674548
2023	39205.02	82.3539	3228687.59	674548
2024	40078.90	82.3530	3300617.58	674548
2025	40970.88	82.3522	3374043.22	674548
2026	41881.47	82.3516	3449005.93	674548
2027	42811.20	82.3511	3525548.50	674548
2028	43760.61	82.3507	3603715.06	674548
2029	44730.26	82.3503	3683551.13	674548
2030	45720.72	82.3500	3765103.62	674548

obtained in 2021, i.e. when Model 5 was used in estimating rice production (Table 6) and the rice surplus in 2030 would be 2.5 million tons (165% self-sufficiency). The level would not be achieved when the other four models were used in the yield prediction. In a situation where Hectareage option 2 was used (100% fully-irrigated rice growing areas), the self-sufficiency could be observed in 2012 for the yield Models 1, 2, 3 and 5 (Table 7). Due to the strength of the positive population growth, self-sufficiencies were short-lived in Models 1 and 2. In spite of Model 3 which was continually yielding surplus rice production, its figures were much lower than those of Model 5. With Hectareage option 3 (mean planted hectareage with new additional rice growing areas), self-sufficiency would be seen in 2017 when Model 5 was used. The predicted self-sufficiencies would be 109 and 190% in 2020 and 2030, respectively. This result was not shown in other yield models (Table 8). It reveals that Option 3 has yielded figures which lie between those of Options 1 and 2.

As hypothesized and predicted, Option 4 of rice hectareage (mean planted hectareage plus new additional rice growing areas and with 100% fully-irrigated areas) has resulted in promising figures (Table 10). The self-sufficiency was predicted for 2012. However, due to the relatively strong exponential population growth, the sufficiency would be ended in 2025 and 2017 for Models 2 and 4, respectively. The predicted surplus or negative net rice import for Model 5 in 2020 and 2030 were 1.3 and 5.3 million tons, respectively. The respective figures for Models 1 and 3 were less than a million ton (0.3 – 0.6 million tons). The above information suggests that the rice Hacterage for Option 4 had significantly provided a conducive environment for Model 5 in producing relatively high rice production, surplus and self-sufficiency in Malaysia. Based on the consumption figures of 2.4 – 3.7 million tons per year for 2010 – 2030, there would generally be (on the average) 2.0 and 1.0 million tons of the annual rice stock-pile and export, respectively, during the stated period.

TABLE 6
Predicted rice production, net import and self-sufficiency based on five yield models (1= logistic growth, 2 = simple linear, 3 = exponential, 4 = 'logistic polynomial', 5 = 'high order modified-polynomial) and mean planted hectareage

Year	Model 1	Model 2	Model 3	Model 4	Model 5
– production (tons) –					
2008	1866826.42	1829241.85	1874042.65	1814774.68	1806216.80
2009	1904414.43	1858975.26	1914253.91	1833751.10	1851082.01
2010	1942553.86	1888708.67	1955327.98	1851450.35	1901833.74
2011	1981244.57	1918442.08	1997283.37	1867949.89	1959490.70
2012	2020486.03	1948175.49	2040139.00	1883326.51	2025142.55
2013	2060277.38	1977908.90	2083914.18	1897655.10	2099949.94
2014	2100617.34	2007642.30	2128628.64	1911007.79	2185144.37
2015	2141504.26	2037375.71	2174302.54	1923453.36	2282028.21
2016	2182936.12	2067109.12	2220956.47	1935056.93	2391974.63
2017	2224910.44	2096842.53	2268611.44	1945879.76	2516427.59
2018	2267424.38	2126575.94	2317288.94	1955979.19	2656901.74
2019	2310474.63	2156309.35	2367010.92	1965408.71	2814982.44
2020	2354057.50	2186042.76	2417799.78	1974217.99	2992325.71
2021	2398168.82	2215776.17	2469678.41	1982453.15	3190658.15
2022	2442804.02	2245509.57	2522670.20	1990156.81	3411776.96
2023	2487958.05	2275242.98	2576799.03	1997368.38	3657549.90

Table 6 (*continued*)

2024	2533625.42	2304976.39	2632089.31	2004124.22	3929915.19
2025	2579800.21	2334709.80	2688565.94	2010457.85	4230881.57
2026	2626476.00	2364443.21	2746254.39	2016400.15	4562528.19
2027	2673645.93	2394176.62	2805180.66	2021979.59	4927004.64
2028	2721302.69	2423910.03	2865371.31	2027222.34	5326530.87
2029	2769438.48	2453643.44	2926853.47	2032152.54	5763397.19
2030	2818045.05	2483376.85	2989654.84	2036792.40	6239964.22
			net import (tons)		
2008	438564.96	476149.53	431348.73	490616.71	499174.59
2009	454450.46	499889.63	444610.98	525113.79	507782.89
2010	470844.38	524689.57	458070.26	561947.90	511564.50
2011	487761.47	550563.96	471722.67	601056.15	509515.34
2012	505219.79	577530.33	485566.82	642379.31	500563.26
2013	523240.35	605608.83	499603.55	685862.63	483567.79
2014	541846.93	634821.96	513835.62	731456.48	457319.90
2015	561065.77	665194.33	528267.49	779116.68	420541.83
2016	580925.49	696752.48	542905.14	828804.68	371886.97
2017	601456.88	729524.79	557755.88	880487.56	309939.73
2018	622692.84	763541.28	572828.27	934138.02	233215.48
2019	644668.27	798833.56	588131.98	989734.20	140160.46
2020	667420.01	835434.75	603677.73	1047259.51	29151.80
2021	690986.78	873379.43	619477.19	1106702.45	-101502.55
2022	715409.16	912703.60	635542.97	1168056.36	-253563.79
2023	740729.54	953444.60	651888.56	1231319.21	-428862.31
2024	766992.15	995641.18	668528.27	1296493.36	-629297.61
2025	794243.01	1039333.41	685477.27	1363585.37	-856838.35
2026	822529.93	1084562.72	702751.54	1432605.78	-1113522.26
2027	851902.56	1131371.88	720367.84	1503568.91	-1401456.15
2028	882412.37	1179805.03	738343.75	1576492.72	-1722815.81
2029	914112.65	1229907.70	756697.67	1651398.59	-2079846.06
2030	947058.58	1281726.78	775448.78	1728311.23	-2474860.59
			self-sufficiency (%)		
2008	80.9766	79.3463	81.2896	78.7187	78.348
2009	80.7344	78.8080	81.1515	77.7387	78.473
2010	80.4904	78.2593	81.0197	76.7155	78.803
2011	80.2446	77.7010	80.8942	75.6559	79.364
2012	79.9969	77.1339	80.7750	74.5663	80.181
2013	79.7470	76.5588	80.6619	73.4524	81.283
2014	79.4946	75.9761	80.5547	72.3192	82.693
2015	79.2395	75.3866	80.4531	71.1713	84.439
2016	78.9814	74.7906	80.3570	70.0128	86.545
2017	78.7198	74.1886	80.2660	68.8474	89.034
2018	78.4544	73.5810	80.1798	67.6782	91.931
2019	78.1849	72.9680	80.0980	66.5081	95.257
2020	77.9108	72.3501	80.0204	65.3395	99.035
2021	77.6319	71.7276	79.9467	64.1746	103.286
2022	77.3477	71.1006	79.8765	63.0153	108.029
2023	77.0579	70.4696	79.8095	61.8632	113.283
2024	76.7622	69.8347	79.7454	60.7197	119.066
2025	76.4602	69.1962	79.6838	59.5860	125.395

Table 6 (*continued*)

2026	76.1517	68.5543	79.6245	58.4632	132.285
2027	75.8363	67.9093	79.5672	57.3522	139.751
2028	75.5138	67.2614	79.5116	56.2537	147.807
2029	75.1839	66.6108	79.4574	55.1683	156.463
2030	74.8464	65.9577	79.4043	54.0966	165.732

-ve indicate surplus after consumption

TABLE 7
Predicted rice production, net import and self-sufficiency, based on five yield models (1 = logistic growth, 2 = simple linear, 3 = exponential, 4 = 'logistic polynomial', 5 =' high order modified-polynomial) and mean planted hectareage with the non-irrigated conversion into fully-irrigated areas

Year	ha	Model 1	Model 2	Model 3	Model 4	Model 5
			production (tons)			
2008	674548.00	1866826.42	1829241.85	1874042.65	1814774.68	1806216.80
2009	674548.00	1904414.43	1858975.26	1914253.91	1833751.10	1851082.01
2010	674548.00	1942553.86	1888708.67	1955327.98	1851450.35	1901833.74
2011	674548.00	1981244.57	1918442.08	1997283.37	1867949.89	1959490.70
2012	882564.91	2643562.92	2548953.27	2669276.46	2464106.18	2649655.42
2013	882564.91	2695625.10	2587855.86	2726551.02	2482853.42	2747531.88
2014	882564.91	2748405.09	2626758.44	2785054.52	2500323.80	2858998.54
2015	882564.91	2801900.72	2665661.03	2844813.32	2516607.33	2985759.39
2016	882564.91	2856109.31	2704563.62	2905854.37	2531789.21	3129611.06
2017	882564.91	2911027.67	2743466.21	2968205.17	2545949.59	3292442.78
2018	882564.91	2966652.04	2782368.80	3031893.82	2559163.48	3476236.31
2019	882564.91	3022978.12	2821271.39	3096949.05	2571500.86	3683065.90
2020	882564.91	3080001.05	2860173.98	3163400.16	2583026.76	3915098.22
2021	882564.91	3137715.41	2899076.57	3231277.11	2593801.46	4174592.36
2022	882564.91	3196115.20	2937979.15	3300610.49	2603880.78	4463899.74
2023	882564.91	3255193.81	2976881.74	3371431.56	2613316.25	4785464.05
2024	882564.91	3314944.08	3015784.33	3443772.23	2622155.45	5141821.27
2025	882564.91	3375358.23	3054686.92	3517665.11	2630442.24	5535599.57
2026	882564.91	3436427.89	3093589.51	3593143.51	2638217.04	5969519.29
2027	882564.91	3498144.08	3132492.10	3670241.44	2645517.05	6446392.88
2028	882564.91	3560497.21	3171394.69	3748993.67	2652376.57	6969124.89
2029	882564.91	3623477.10	3210297.27	3829435.67	2658827.14	7540711.91
2030	882564.91	3687072.94	3249199.86	3911603.72	2664897.84	8164242.54
			net import (tons)			
2008	674548.00	438564.96	476149.53	431348.73	490616.71	499174.59
2009	674548.00	454450.46	499889.63	444610.98	525113.79	507782.89
2010	674548.00	470844.38	524689.57	458070.26	561947.90	511564.50
2011	674548.00	487761.47	550563.96	471722.67	601056.15	509515.34
2012	882564.91	-117857.10	-23247.45	-143570.65	61599.64	-123949.60
2013	882564.91	-112107.37	-4338.13	-143033.29	100664.31	-164014.15
2014	882564.91	-105940.82	15705.82	-142590.25	142140.46	-216534.28
2015	882564.91	-99330.68	36909.01	-142243.28	185962.70	-283189.35

Table 7 (*continued*)

2016	882564.91	-92247.71	59297.98	-141992.76	232072.39	-365749.46
2017	882564.91	-84660.34	82901.11	-141837.84	280417.74	-466075.46
2018	882564.91	-76534.82	107748.42	-141776.61	330953.74	-586119.09
2019	882564.91	-67835.21	133871.52	-141806.14	383642.04	-727922.99
2020	882564.91	-58523.55	161303.53	-141922.65	438450.75	-893620.72
2021	882564.91	-48559.81	190079.03	-142121.51	495354.14	-1085436.76
2022	882564.91	-37902.02	220234.02	-142397.32	554332.39	-1305686.57
2023	882564.91	-26506.22	251805.85	-142743.97	615371.34	-1556776.46
2024	882564.91	-14326.51	284833.25	-143154.65	678462.12	-1841203.70
2025	882564.91	-1315.02	319356.30	-143621.90	743600.97	-2161556.36
2026	882564.91	12578.04	355416.42	-144137.58	810788.89	-2520513.36
2027	882564.91	27404.42	393056.40	-144692.95	880031.44	-2920844.38
2028	882564.91	43217.85	432320.38	-145278.61	951338.49	-3365409.83
2029	882564.91	60074.03	473253.86	-145884.54	1024723.99	-3857160.78
2030	882564.91	78030.68	515903.76	-146500.10	1100205.79	-4399138.91
self-sufficiency (%)						
2008	674548.00	80.977	79.346	81.290	78.7187	78.348
2009	674548.00	80.734	78.808	81.151	77.7387	78.473
2010	674548.00	80.490	78.259	81.020	76.7155	78.803
2011	674548.00	80.245	77.701	80.894	75.6559	79.364
2012	882564.91	104.666	100.920	105.684	97.5611	104.908
2013	882564.91	104.339	100.168	105.536	96.1036	106.348
2014	882564.91	104.009	99.406	105.396	94.6209	108.194
2015	882564.91	103.675	98.634	105.263	93.1190	110.479
2016	882564.91	103.338	97.855	105.137	91.6033	113.233
2017	882564.91	102.995	97.067	105.018	90.0785	116.490
2018	882564.91	102.648	96.272	104.906	88.5488	120.280
2019	882564.91	102.295	95.470	104.799	87.0178	124.632
2020	882564.91	101.937	94.661	104.697	85.4889	129.576
2021	882564.91	101.572	93.847	104.601	83.9647	135.137
2022	882564.91	101.200	93.027	104.509	82.4479	141.343
2023	882564.91	100.821	92.201	104.421	80.9405	148.217
2024	882564.91	100.434	91.370	104.337	79.4444	155.784
2025	882564.91	100.039	90.535	104.257	77.9611	164.064
2026	882564.91	99.635	89.695	104.179	76.4921	173.079
2027	882564.91	99.223	88.851	104.104	75.0385	182.848
2028	882564.91	98.801	88.003	104.031	73.6012	193.387
2029	882564.91	98.369	87.152	103.960	72.1811	204.713
2030	882564.91	97.928	86.298	103.891	70.7789	216.840

-ve indicate surplus after consumption

TABLE 8
Predicted rice production, net import and self-sufficiency based on five yield models (1= logistic growth, 2 = simple linear, 3 = exponential, 4 ='logistic polynomial', 5 =' high order modified-polynomial) and mean planted hectareage with new additional rice growing areas

Year	ha	Model 1	Model 2	Model 3	Model 4	Model 5
			production (tons)			
2008	674548	1866826.42	1829241.85	1874042.65	1814774.68	1806216.80
2009	674548	1904414.43	1858975.26	1914253.91	1833751.10	1851082.01
2010	714548	2057745.30	2000707.14	2071276.91	1961239.44	2014610.52
2011	754548	2216216.08	2145965.35	2234157.06	2089484.89	2191882.25
2012	774548	2320017.87	2236987.47	2342584.34	2162524.80	2325364.71
2013	774548	2365708.18	2271128.78	2392849.08	2178977.57	2411262.10
2014	774548	2412028.43	2305270.09	2444192.35	2194309.76	2509086.38
2015	774548	2458976.74	2339411.40	2496637.28	2208600.35	2620333.00
2016	774548	2506550.76	2373552.71	2550207.53	2221924.12	2746578.70
2017	774548	2554747.67	2407694.02	2604927.23	2234351.41	2889481.48
2018	774548	2603564.19	2441835.33	2660821.05	2245948.06	3050780.56
2019	774548	2652996.53	2475976.64	2717914.18	2256775.47	3232296.32
2020	774548	2703040.44	2510117.95	2776232.35	2266890.72	3435930.27
2021	774548	2753691.16	2544259.26	2835801.86	2276346.71	3663664.98
2022	774548	2804943.41	2578400.57	2896649.55	2285192.42	3917564.09
2023	774548	2856791.40	2612541.88	2958802.84	2293473.09	4199772.23
2024	774548	2909228.85	2646683.19	3022289.75	2301230.46	4512514.97
2025	774548	2962248.93	2680824.50	3087138.90	2308503.03	4858098.84
2026	774548	3015844.29	2714965.81	3153379.52	2315326.27	5238911.22
2027	774548	3070007.04	2749107.12	3221041.45	2321732.84	5657420.37
2028	774548	3124728.79	2783248.43	3290155.21	2327752.82	6116175.33
2029	774548	3180000.59	2817389.74	3360751.94	2333413.91	6617805.95
2030	774548	3235812.95	2851531.05	3432863.46	2338741.61	7165022.80
			net import (tons)			
2008	674548	438564.96	476149.53	431348.73	490616.71	499174.59
2009	674548	454450.46	499889.63	444610.98	525113.79	507782.89
2010	714548	355652.94	412691.10	342121.33	452158.80	398787.72
2011	754548	252789.96	323040.69	234848.98	379521.15	277123.79
2012	774548	205687.95	288718.34	183121.47	363181.01	200341.11
2013	774548	217809.55	312388.95	190668.65	404540.16	172255.63
2014	774548	230435.83	337194.17	198271.92	448154.51	133377.88
2015	774548	243593.29	363158.63	205932.75	493969.69	82237.04
2016	774548	257310.84	390308.89	213654.08	541937.48	17282.91
2017	774548	271619.65	418673.30	221440.09	592015.91	-63114.16
2018	774548	286553.03	448281.88	229296.17	644169.15	-160663.35
2019	774548	302146.37	479166.26	237228.72	698367.43	-277153.42
2020	774548	318437.06	511359.55	245245.15	754586.79	-414452.76
2021	774548	335464.44	544896.34	253353.74	812808.89	-574509.38
2022	774548	353269.77	579812.60	261563.63	873020.75	-759350.92
2023	774548	371896.18	616145.70	269884.75	935214.50	-971084.64
2024	774548	391388.72	653934.38	278327.82	999387.11	-1211897.40
2025	774548	411794.28	693218.71	286904.31	1065540.18	-1484055.62
2026	774548	433161.64	734040.12	295626.41	1133679.66	-1789905.29

Table 8 (*continued*)

2027	774548	455541.45	776441.38	304507.04	1203815.66	-2131871.87
2028	774548	478986.27	820466.63	313559.85	1275962.24	-2512460.27
2029	774548	503550.55	866161.39	322799.19	1350137.22	-2934254.82
2030	774548	529290.67	913572.57	332240.17	1426362.01	-3399919.18
			self-sufficiency (%)			
2008	674548	80.9766	79.3463	81.2896	78.7187	78.348
2009	674548	80.7344	78.8080	81.1515	77.7387	78.473
2010	714548	85.2634	82.9000	85.8241	81.2646	83.476
2011	754548	89.7615	86.9162	90.4881	84.6286	88.776
2012	774548	91.8562	88.5688	92.7497	85.6206	92.068
2013	774548	91.5693	87.9084	92.6198	84.3415	93.333
2014	774548	91.2795	87.2394	92.4967	83.0403	94.953
2015	774548	90.9866	86.5625	92.3801	81.7222	96.957
2016	774548	90.6902	85.8781	92.2697	80.3920	99.375
2017	774548	90.3898	85.1869	92.1652	79.0538	102.233
2018	774548	90.0851	84.4891	92.0662	77.7113	105.559
2019	774548	89.7756	83.7853	91.9723	76.3677	109.379
2020	774548	89.4609	83.0758	91.8833	75.0259	113.717
2021	774548	89.1406	82.3610	91.7986	73.6883	118.598
2022	774548	88.8143	81.6411	91.7180	72.3571	124.044
2023	774548	88.4815	80.9165	91.6410	71.0342	130.077
2024	774548	88.1420	80.1875	91.5674	69.7212	136.717
2025	774548	87.7952	79.4544	91.4967	68.4195	143.984
2026	774548	87.4410	78.7173	91.4286	67.1302	151.896
2027	774548	87.0788	77.9767	91.3628	65.8545	160.469
2028	774548	86.7085	77.2328	91.2990	64.5931	169.719
2029	774548	86.3298	76.4857	91.2367	63.3469	179.658
2030	774548	85.9422	75.7358	91.1758	62.1163	190.301

-ve indicate surplus after consumption

TABLE 9

Predicted rice production, net import and self-sufficiency based on five yield models (1 = logistic growth, 2 = simple linear, 3 = exponential, 4 = 'logistic polynomial', 5 =' high order modified-polynomial) and mean planted hectareage with new additional rice growing areas and with the non-irrigated conversion into fully-irrigated areas

Year	ha	Model 1	Model 2	Model 3	Model 4	Model 5
			production (×1000 tons)			
2008	674548.00	1866826.42	1829241.85	1874042.65	1814774.68	1806216.80
2009	674548.00	1904414.43	1858975.26	1914253.91	1833751.10	1851082.01
2010	714548.00	2057745.30	2000707.14	2071276.91	1961239.44	2014610.52
2011	754548.00	2216216.08	2145965.35	2234157.06	2089484.89	2191882.25
2012	982564.91	2943094.76	2837765.25	2971721.81	2743304.48	2949877.57
2013	982564.91	3001055.91	2881075.74	3035485.92	2764175.89	3058844.04
2014	982564.91	3059816.19	2924386.23	3100618.22	2783625.77	3182940.56
2015	982564.91	3119373.20	2967696.72	3167148.06	2801754.33	3324064.18
2016	982564.91	3179723.96	3011007.21	3235105.43	2818656.41	3484215.13

Table 9 (*continued*)

2017	982564.91	3240864.90	3054317.70	3304520.96	2834421.24	3665496.68
2018	982564.91	3302791.85	3097628.19	3375425.93	2849132.35	3870115.14
2019	982564.91	3365500.02	3140938.68	3447852.31	2862867.63	4100379.78
2020	982564.91	3428984.00	3184249.17	3521832.74	2875699.48	4358702.79
2021	982564.91	3493237.75	3227559.66	3597400.56	2887695.03	4647599.20
2022	982564.91	3558254.59	3270870.15	3674589.84	2898916.39	4969686.87
2023	982564.91	3624027.17	3314180.64	3753435.36	2909420.96	5327686.38
2024	982564.91	3690547.51	3357491.13	3833972.67	2919261.70	5724421.06
2025	982564.91	3757806.96	3400801.62	3916238.07	2928487.43	6162816.85
2026	982564.91	3825796.18	3444112.11	4000268.63	2937143.16	6645902.32
2027	982564.91	3894505.19	3487422.60	4086102.24	2945270.31	7176808.60
2028	982564.91	3963923.31	3530733.09	4173777.57	2952907.05	7758769.35
2029	982564.91	4034039.21	3574043.58	4263334.15	2960088.51	8395120.67
2030	982564.91	4104840.85	3617354.07	4354812.33	2966847.05	9089301.13
net import (tons)						
2008	674548.00	438564.96	476149.53	431348.73	490616.71	499174.59
2009	674548.00	454450.46	499889.63	444610.98	525113.79	507782.89
2010	714548.00	355652.94	412691.10	342121.33	452158.80	398787.72
2011	754548.00	252789.96	323040.69	234848.98	379521.15	277123.79
2012	982564.91	-417388.94	-312059.44	-446015.99	-217598.66	-424171.76
2013	982564.91	-417538.18	-297558.01	-451968.19	-180658.16	-475326.31
2014	982564.91	-417351.92	-281921.97	-458153.96	-141161.51	-540476.29
2015	982564.91	-416803.16	-265126.69	-464578.02	-99184.29	-621494.15
2016	982564.91	-415862.35	-247145.61	-471243.82	-54794.80	-720353.52
2017	982564.91	-414497.58	-227950.38	-478153.63	-8053.92	-839129.36
2018	982564.91	-412674.63	-207510.98	-485308.71	40984.87	-979997.92
2019	982564.91	-410357.11	-185795.78	-492709.40	92275.27	-1145236.87
2020	982564.91	-407506.49	-162771.67	-500355.23	145778.03	-1337225.28
2021	982564.91	-404082.15	-138404.06	-508244.96	201460.57	-1558443.60
2022	982564.91	-400041.42	-112656.98	-516376.67	259296.78	-1811473.69
2023	982564.91	-395339.58	-85493.05	-524747.78	319266.63	-2098998.80
2024	982564.91	-389929.94	-56873.56	-533355.10	381355.88	-2423803.48
2025	982564.91	-383763.74	-26758.41	-542194.86	445555.78	-2788773.63
2026	982564.91	-376790.25	4893.82	-551262.70	511862.77	-3196896.39
2027	982564.91	-368956.69	38125.90	-560553.74	580278.19	-3651260.10
2028	982564.91	-360208.25	72981.97	-570062.51	650808.01	-4155054.29
2029	982564.91	-350488.07	109507.55	-579783.01	723462.62	-4711569.54
2030	982564.91	-339737.22	147749.55	-589708.71	798256.57	-5324197.50
self-sufficiency (%)						
2008	674548.00	80.977	79.346	81.290	78.719	78.348
2009	674548.00	80.734	78.808	81.151	77.739	78.473
2010	714548.00	85.263	82.900	85.824	81.265	83.476
2011	754548.00	89.761	86.916	90.488	84.629	88.776
2012	982564.91	116.526	112.355	117.659	108.615	116.794
2013	982564.91	116.162	111.518	117.494	106.993	118.398
2014	982564.91	115.794	110.669	117.338	105.342	120.453
2015	982564.91	115.422	109.810	117.190	103.670	122.996
2016	982564.91	115.046	108.942	117.050	101.983	126.063
2017	982564.91	114.665	108.065	116.918	100.285	129.689
2018	982564.91	114.279	107.180	116.792	98.582	133.909

Table 9 (*continued*)

2019	982564.91	113.886	106.287	116.673	96.877	138.754
2020	982564.91	113.487	105.387	116.560	95.175	144.257
2021	982564.91	113.081	104.480	116.453	93.478	150.449
2022	982564.91	112.667	103.567	116.350	91.790	157.358
2023	982564.91	112.245	102.648	116.253	90.112	165.011
2024	982564.91	111.814	101.723	116.159	88.446	173.435
2025	982564.91	111.374	100.793	116.070	86.795	182.654
2026	982564.91	110.925	99.858	115.983	85.159	192.690
2027	982564.91	110.465	98.919	115.900	83.541	203.566
2028	982564.91	109.995	97.975	115.819	81.941	215.299
2029	982564.91	109.515	97.027	115.740	80.360	227.908
2030	982564.91	109.023	96.076	115.662	78.799	241.409

-ve indicate surplus after consumption

CONCLUSIONS

The predicted Malaysian population of 36.7 and 45.7 million people in 2020 and 2030 are ‘certainly’ to occur and thus the staple food (rice) consumption would then be in tandem with the population trend. The decay rice per capita consumption model had plateau values in the vicinity of 82.0 kg/person/year after 2003. With years ahead, the per capita arable land will decrease and based on the mean rice planted hectareage, the Malaysian per capita rice area in 2007 was 0.025 ha/person. It is envisaged therefore, the role of scientists in research and development is crucial in producing applicable technologies for higher rice production with limited land suitable for agriculture.

Based on the national (average) data for 1980 – 2007, the developed deterministic mathematical models in predicting population increase, rice production and consumption, rice-related (crop and management) technological advancement are then unlikely arbitrary in nature. Model applications which are subjected to several logical options and sensitivities will yield predicted figures with a high accuracy level!

The recoded paddy yields by the Department of Agriculture for 1998 – 2007 were less than 4.0 tons/ha (2.9 – 3.5 tons/ha). This trend is likely to reflect the lowest developed yield model (Model 4: ‘logistic polynomial’) in this paper. Even for 2030, the average predicted national average paddy yield is only 4.3 tons/ ha. If this continued to happen, the country would always be facing with high import for rice and thus rice stock-pile would be built from imported supplies (and not from the local). This is supported by the data which indicated that we were on the average of 70% self rice sufficiency for years. Stock-pile is important since rice is Malaysian security and staple food and it has the social and political implications for this country. Since rice is now one form of crisis globally, what will happen if the rice producing countries stop exporting their rice?

Model 5 yields a function (‘modified higher-order polynomial’) which provides quantitative moving target (over years) which should be used as a focal objective in research activities for generating advanced and applicable technologies for rice production. This would be used in research success and areas, respectively. Yield movement over time is basically driven by technology, whereby only about 5% is affected by the climatic fluctuation. Model 5 had predicted the national average yield of 13.4 tons/ha in 2030. This is comparable to the crop cutting test yield of 14.0 tons/ha.

Based on the average rice hectareage (674, 548 ha) which conditioned with the completed conversion of the non-fully to fully irrigated paddy fields (by 2012), the high yield model predicted the self-sufficiency would be firstly attained in 2012. The yearly rice production, surplus and self-sufficiency would be 2.6 – 8.2 million tons, 0.12 – 4.4 million tons and 104 – 216%, respectively from 2012 to 2030. With the inclusion of an additional of 100,000 ha new rice areas (40,000, 40,000 and 20,000 ha which would be implemented in 2010, 2011 and 2012, respectively), the respective figures would be 2.9 – 9.1 million tons, 0.42 – 5.3 million tons and 117 – 241 %, respectively.

In summary, the above prediction could be 'realized' if Model 5 ('modified higher-order polynomial') was used as the quantitative moving objective versus the years of the R&D programs and the activities in the Malaysian rice production. The order of priority of research areas would be irrigation/water related methods and technique > crop establishment related technology (especially high planting density with proper fertilization rate) > sustainability of existing management practices > large adaptive technology testing (technological uniformity studies) > continual varietal improvement and development. In the medium term, the existing released varieties are locally and generally well suited and adaptable in all the Malaysian rice growing environments.

ACKNOWLEDGEMENTS

The authors would like to thank the Director General and staff of the Department of Agriculture, Putrajaya, in providing the assistance in obtaining the relevant information for the preparation of this paper. The note of thank also goes to En. Mahbub Shah bin Gohar Shah for his assistance in the preparation of this manuscript.

REFERENCES

Anonymous. (2008). Table 3: Malaysia rice production, imports and self-sufficiency, 1980 – 1996. (Sources: Source: LPN, Annual Report, various issues. Ministry of Finance, Economic Report. Ministry of Agriculture, Paddy Statistics .Ministry of Agriculture, Statistical Handbook, Agriculture. http://www.econ.upm.edu.my/~fatimah/t3.htm

Anonymous. (2008). Food and soil: Arable and population. http://www.theglobaleducationproject.org/earth/food-and-soil.php

Battisti and Hinckley. (2008). Region versus globe: Impacts of climate change on food security. http://course.washington.edu/.../Envir100lect808

BERNAMA. (2008). Malaysia to put another 100,000 hectares under padi over the next two years. NNN-BERNAMA.

Chang C. (2002). The potential impact of climate change on Taiwan's agriculture. *Agricultural Economics, 27,* 51 – 64.

Department of Agriculture. (2007). Laporan penyiasatan pengeluaran padi Malaysia. Luar musim 2005.

Department of Agriculture. (2007). Laporan penyiasatan pengeluaran padi Malaysia. Musim utama 2006/2007.

Department of Agriculture. (2008). Laporan penyiasatan pengeluaran padi Malaysia. Luar musim 2008.

Department of Agriculture. (2008). Hasil pengeluaran padi negara (Report).

Department of Statistic. (2008). http://www.statistics.gov.my/

IADA Barat Laut Selangor. (2008). Purata hasil mengikut kawasan (Unpublished).

Mansor, P. (2008). Personal communication. Research rice division, MARDI.

MARDI. (2008). Agronomic characteristics of the released padi varieties (unpublished).

Ministry of Agriculture. (2007). Buku perangkaan pertanian 2007. Unit Penerbitan, Putrajaya.

Malaxi.com. (2008) 28.96 million Malaysian people in year 2010. http://www.malaxi.com/population_size_age_structure2001_2010.html

NationMaster.com. (2008). Agriculture statistics> grain>rice consumption (per capita) (most recent) by country. http://www.nationmaster.com

ScienceDaily (2007). Important rice production system under pressure. http://www.sciencedaily.com/release/2007/10/071009132035.htm

The Star. (2004). Roots of super rice hybrids. http://www.grain.org/hybridrice

U.S. Census Bureau. (2008). U.S. and World Population Clocks – POPClocks. http://www.census.gov/main/www/popclock.html

UNEP. World population development. www.sustainablescale/images/upload/population

UNESCAP. (2008). ESCAP population data sheet. http://www.unescap.org/ESID/PSIS/population/database/data_sheet/2006/list.aspx

USDA. (2008). USDA world agricultural rice production report. http://oryza.com/North-America/US-outlook-report

Workman, D. (2008). Top rice producing countries. http://internationaltradecommodities.suite101.com