Malays. Appl. Biol. (2014) 43(1): 81–89

PRELIMINARY STUDY ON SIMULATION OF CLIMATE CHANGE IMPACTS ON RICE YIELD USING DSSAT 4.5 AT TANJUNG KARANG, SELANGOR

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ABSTRACT

Weather plays a very important role in determining crop yields. There is a strong relationship between climate and crops. The growth requirements are different for every crop throughout the whole plant development process. Each crop and crop variety has specific climatic tolerances and optimal conditions. The objectives of this study were to determine the physico-chemical characteristics of soils for rice cultivation and the effects of climate towards rice yield through simulation using Decision Support System for Agro-technology Transfer ver 4.5 (DSSAT4.5). This study was carried out in Tanjung Karang, Selangor. Four plots with the size of 5 m x 5 m were planted with MR 219 seedlings. Three soil samples were taken from each plot at a depth of 0-20 cm for the upper layer and 20-40 cm for the second layer before planting activities. Physico-chemical characteristic of these soils such as particle size distribution, organic matter, bulk and true density, pH, electrical conductivity, cation exchange capacity and organic carbon contents were determined according to the standard methods. The soil texture in this area was silty clay for the upper layer and clay for the second layer. The percentage of soil organic matter was high at about 9.0% to 11.8%. Soil bulk density was in the range of 1.37 g cm^{-3} to 1.41 g cm^{-3}, whereas the true density was between 2.5 g cm^{-3} and 2.75 g cm^{-3}. Soil of this area was slightly acidic with pH value of about 5 to 6. Electrical conductivity recorded ranged from 2.13 mS cm^{-1} to 2.60 mS cm^{-1}, whereas cation exchange capacity was between 13.5 meq/100 g to 15.5 meq/100 g. Percentage of organic carbon was higher in the upper layer at 2.07-2.74% than in the second layer at 1.25-1.73%. To obtain the yield, ten matured rice plants were randomly selected and harvested. Yield recorded was 5.75 tons ha^{-1} and the weight of 1000 grains was 24.8 g. Yield simulation by using DSSAT 4.5 crop simulation model, indicated that yield was projected to decrease slightly as the daily solar radiation and rainfall decreased, and slightly increased as the temperature increased.

Key words: Climate change impacts, simulation, rice yield, DSSAT 4.5, Selangor

INTRODUCTION

Rice (*Oryza sativa* L.) is the second most important crop in the world after wheat, with about 522 million tons being produced from 148 m hectares in 1990 (Matthews *et al.,* 1997). Rice is one of the most important crops in Malaysia as rice is the staple food for the country. The largest production of rice is from Asia which produces about 94% of the total world production (Matthews *et al.,* 1997). The average potential yield of rice varieties is about 10 tons ha^{-1} in the tropic and over 13 tons ha^{-1} in temperate regions (Abul Quasem & Chamhuri, 2008). In Malaysia, the actual farm yields vary from 3-5 tons ha^{-1}, whilst potential yield estimated is around 7.2 tons ha^{-1} (Singh *et al.,* 1996). The most popular rice varieties used among farmers in Malaysia is MR 219 besides MR 220 and MR 232. This choice is based on the varieties potential high yield, resistant to disease, short maturity period and better taste (soft and fragrant rice). Rice can be grown in various weather conditions which covers the area of temperate to tropical regions. Malaysia possesses a typical tropical climate, where the temperature and humidity are high and fairly uniform, abundant rainfall, and small seasonal variation in solar radiation. Due to the effects of

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climate change, the average temperature for the country is projected to rise by 0.3ºC to 4.5ºC. The optimum temperature for rice cultivation in Malaysia is between 24ºC to 34ºC and the optimal average annual rainfall is not less than 2000 mm per year (Radziah Mat Lin *et al.,* 2010). Increase in temperature above the optimum value due to climate change will have negative impacts on rice production. Higher temperatures will reduce crop yields due to reduction rate of photosynthesis, increasing of respiration process and also shortened vegetative and grain-filling period (Radziah Mat Lin *et al.,* 2010). This may eventually reduce the yield and productivity rates.

Rice can be grown on various types of soil, from clay textured soil to sandy loam soil. Soil is formed through the physical, chemical and biological weathering process of the host rock (Sahibin *et al.,* 2008). All types of minerals in soils derived from rocks or parent material by various agents such as heat and rainwater (Othman & Shamsuddin, 1982). Soil serves as a growth medium which is very important to plants in terms of nutrient and water supply as well as medium support and development of plant root systems (Sahibin *et al.,* 2008). Soil texture is one of the most important physical characteristics of soil which can be determined by of soil particle size distribution as well as percentage of sand, silt and clay in the soil (Othman & Shamsuddin, 1982). Effective soil depth should be more than 25 cm and has no obstruction between 0-25 cm in order to ensure a good root growth. Besides that, other important soil physical properties are soil bulk and true density, soil organic matter content and soil porosity.

Chemical characteristics of soil are also important in controlling the plant growth as it directly affects the microbiological process by providing nutrients and organic matter. Among the soil chemical properties that help in the availability of nutrients in plants includes pH and cation exchange capacity (CEC). In addition, the electrical conductivity (EC) of the soil is also an important chemical features as EC reflects the concentration of salt in the soil. Soil should have a high cation exchange capacity of more than 10 meq/100g of soil. Soil for rice cultivation area must be at a pH interval between 5.5 and 6.5. If the soil pH is lower than the range, calcification process should be implemented.

The Decision Support System for Agrotechnology Transfer (DSSAT) was developed by the International Benchmark Systems Network for Agrotechnology Transfer (IBSNAT). DSSAT has been used since 15 years ago by researchers around the world in an effort to establish a system of best crop management to maximize the production of yield. DSSAT includes 16 types of crop growth model in which the soil and weather data can be accessed with specific crop management data and can be used to predict the growth rate and the expected results that may be acquired (Jones *et al.,* 2003). This model can be used for 16 different plant species (Sarkar, 2006) which consist of maize, wheat, rice, soybeans, and several types of beans, several types of grass, potatoes and tomatoes. The latest version of DSSAT crop model used at the present time is DSSAT 4.5.

The main objective of the study is to study the impact of climate variability towards rice yield production. Therefore, the model used in DSSAT 4.5 is CERES-Rice model which is specific only for rice (Jones *et al.,* 2003). CERES-Rice simulate growth, growth and yield, taking into account the influence of weather, plant genetics, soil water content, carbon and nitrogen content and crop management systems, irrigation and fertilizer (Ritchie *et al.,* 1998). CERES-Rice has been applied and evaluated its effectiveness extensively in Asia (Timsina & Humphreys, 2006) and involves not only certain areas or certain types of soil. Timsina and Humphreys (2006) concluded that the CERES-Rice has successfully predicted the important dates in the process of growth and yield of rice after reviewing the results of application of CERES-Rice in the rice and wheat in Asia and Australia. Farmers may adapt to climate change by shifting planting dates, choosing varieties with different growth duration or changing crop rotations (Wassmann & Dibermann, 2007). Many researches have shown that changing planting date of rice from present practice could be a very good solution to improve rice yield under the impacts of climate change (Desiraju *et al.,* 2010).

MATERIALS AND METHODS

This study was conducted at Tanjung Karang, Selangor. The study area was located at latitude 03º26’46.9" N and longitude 101º12’21.4" E. MR 219 was used for planting as this variety is the most popular among farmers. A total of four experimental plots (P1, P2, P3 and P4) with the size of 5 m x 5 m were used.

For determination of soil physico-chemical content, 1 kg of soil was taken using *Dutch Auger* and placed in a plastic bag then labeled. Three soil samples taken randomly in each of the plots at a depth of 0 to 20 cm (L1) and 20 to 40 cm (L2). Samples were then dried at room temperature, pounded with wooden mortar and sieved through 2 mm sieve size. Soil physical and chemical characteristics were determined in the laboratory. Soil physical characteristics determined includes particle size distribution, organic matter content, bulk density, true density and porosity whereas soil chemical characteristics determined included pH, electrical conductivity, cation exchange capacity and organic carbon content.

Soil physical characteristics such as particle size distribution was determined by pipette method together with dry sieving (Abdulla, 1966). Soil organic matter was determined by gravimetric method based on the loss on ignition (Avery & Bascomb, 1982). Organic carbon content was determined using Walkey and Black technique (Walkey, 1947). Soil pH was determined in distilled water with a ratio of 1:2.5 of soil: distilled water (Avery & Bascomb, 1982). The electrical conductivity was determined in saturated extract of gypsum using conductivity meter Model H 18819 Hanna. Cation exchange capacity (CEC) obtained from the sum of basic cations with acidic cations through summation method. Data on growth and yield, soil and weather were then exported into DSSAT 4.5 software for yield projection analysis based on simulation. Daily data of rainfall, maximum and minimum temperature, solar radiation and relative humidity for 20 years period since 1990 until 2010 was obtained from the Malaysian Meteorological Department. Yield projection analysis was determined using X-build programme and interpreted in a graph in G-build programme using DSSAT software.

RESULTS AND DISCUSSION

Yield Data

Four plots with the size of 5 m x 5 m were planted with MR 219. A total of 10 matured plants were randomly selected for harvesting in order to obtain the results which included the yield and the plant growth. Yield recorded is 5.75 tons ha^{-1} and the weight of 1000 grains was 24.8 g (Table 1). Yield recorded by this study was lower than the average value of yield recorded by MARDI which is usually in the range of 6 to 7 tons ha^{-1} for the area of Projek Barat Laut Selatan which included the area of Tanjung Karang (Alias, 2001). This occurrence may be influenced by the size of plots used for the experiment and the technical expertise. These data obtained was next imported into DSSAT 4.5 software to build crop management file (X-build) for yield simulation analysis.

Weather Data

Daily data of rainfall, maximum and minimum temperature, solar radiation and relative humidity obtained were imported into DSSAT 4.5 software to create a new weather station based on latitude and longitude points. These data was next used together with soil data and crop management data to run DSSAT 4.5 software to obtain simulation results on yield projection.

Soil Data

A total of three soil sampling points at two different depths of 0 to 20 cm for the upper layer (L1) and 20 to 40 cm for the lower layer (L2) were taken randomly in the plots before the planting activities. The effective depth for the growth of rice is about 25 cm in order to ensure a good root growth and this is the reason why soil sample was taken at that particular depth (Wan Darman *et al.,* 2008). The results of soil analysis are shown in Table 2 and 3 for physical properties and Table 4 for chemical properties. Soil data obtained was then imported into DSSAT 4.5 software to create soil type file (S-build) to complete the requirements for yield simulation analysis.

Physical characteristics of soil

Rice crops are affected by soil physical properties in terms of land preparation, water storage and soil aeration. Higher content of clay in the soil will cause more difficulties in plowing activities. However, soil with a fine texture will allow more water to be stored as there are much more micro pores. This stored water can be used as water supply during dry season. Rice is not likely to be affected by anaerobic conditions because rice is traditionally grown in watery areas. Such plants have an aerenchimatic system in which the presence of hollow spaces between cellular in the cortex allows the diffusion of oxygen horizontally from the top to the roots (Greenwood, 1969). Therefore oxygen will be derived from the air and channeled to the roots through the hollow stem. This is the reason why rice is not affected even though the roots are submerged in the water throughout the planting period. According to Wan Darman *et al.* (2008), rice

Table 1. Tiller numbers, length, height, grain numbers and grain weight

Plot	Tiller Number	Length (cm)	Height (cm)	Grain Numbers	Grain Weight (g)
P1	23±8	25.63±1.69	99.80±8.63	165.8±30.65	38.1±10.22
P2	14±4	25.44±3.49	94.13±8.60	139.90±36.70	30.10±9.59
P3	25±4	25.80±1.55	103.35±7.54	157.80±37.86	45.40±9.64
P4	16±5	25.43±1.90	103.20±10.03	134.50±30.44	30.10±8.41

Table 2. Particle size distribution and soil texture

Station	Depth	Sand (%)	Silt (%)	Clay (%)	Texture
S1	L1	3±0.02	50±0.06	47±0.06	silty clay
	L2	2±0.04	29±0.28	69±0.27	clay
S2	L1	2±0.06	48±0.34	50±0.30	silty clay
	L2	2±0.10	28±0.23	70±0.31	clay
S3	L1	2±0.09	50±0.24	48±0.31	silty clay
	L2	2±0.07	30±0.25	68±0.29	clay

Table 3. Organic matter content (OMC), bulk density, true density and porosity

Station	Depth	OMC (%)	Bulk Density (gcm^{-3})	True Density (gcm^{-3})	Porosity (%)
S1	L1	10.80±0.24	1.41±0.0	2.62±0.03	46.2
	L2	9.53±0.3	1.37±0.0	2.69±0.04	49.1
S2	L1	11.40±0.23	1.40±0.0	2.65±0.04	47.2
	L2	10.58±0.24	1.36±0.0	2.70±0.03	49.6
S3	L1	11.33±0.15	1.41±0.0	2.66±0.03	47.0
	L2	10.44±0.31	1.37±0.0	2.72±0.04	49.6

Table 4. pH, electrical conductivity (EC), cation exchange capacity (CEC), organic carbon

Station	Depth	pH	EC (mScm^{-1})	CEC (meq/100g)	Organic Carbon (%)
S1	L1	5.66±0.01	2.46±0.02	15.45±0.06	2.09±0.08
	L2	5.47±0.01	2.56±0.03	16.35±0.05	1.25±0.21
S2	L1	5.51±0.01	2.31±0.13	14.44±0.05	2.71±0.17
	L2	5.42±0.01	2.46±0.04	13.51±0.07	1.73±0.07
S3	L1	5.63±0.01	2.13±0.01	14.32±0.04	2.74±0.09
	L2	5.52±0.01	2.22±0.01	14.35±0.03	1.52±0.09

is suitable to be grown in soil with sandy-loam texture or a finer texture. The texture of soil in the study area is classified as clay based on the soil texture triangle as the clay content of the soil is more than 40%. Table 2 also shows that the clay content in soil is higher in the lower part. Higher clay content in the lower part enables higher water storage. Roots of rice plant may grow up to 25 cm in depth, thus water stored in the lower part can be consumed by the plant.

The mean of organic matter content recorded (Table 3) was within the range of 9.53% to 11.40%. The top-soil contains significantly higher amount of organic matter at 5% level compared to sub-soil. Fresh organic matter accumulation occurs in the top soil, thus account for this difference. According to the classification of Acres (Acres *et al.,* 1975), the organic matter in the soil is considered high. Organic matter is the source of food for soil microorganisms, source of nutrients for plants and also maybe associated with clay to form a good soil aggregation. The mean of soil bulk density recorded is high which ranged from 1.35 g cm^{-3} to 1.42 g cm^{-3}. Bulk density of soil in the sub-soil is lower than the top soil; however, there is no significant difference between the topsoil and subsoil values, showing that soil compaction does not occur at the bottom. These may allow the plant roots to grow without any obstruction.

The value recorded for the mean soil true density was between the range of 2.62 to 2.72 g cm^{-3}. In average, the values of soil true density in all sampling plots were in the same range, between 2.60 to 2.75 g cm^{-3}. Different value of soil true density depends on the type of minerals contained in the soil. Nevertheless, the law of averages and the normal preponderance in soils with quartz and quartz-like minerals (density about 2.65 g cm^{-3}) narrows the mean particle density of soils between about 2.55 and 2.75 g cm^{-3} (Dierickx, 2005).

If the soil contains too much of minerals that have high density values, such as magnetite, zikron, tourmaline and hornblende, the soil true density may reach over 2.75 g cm^{-3}. Based on the calculations, the porosity of the soil is at the range of 46.2% to 49.6%. This value is lower than the porosity value for aggregated soils such as forest soils. Based on statistical analysis implemented, there was a positive correlation between percentage of sand and porosity at the value of 0.4348 as high percentage value of sand will result in high percentage value of porosity. According to Tan (2005), soil with large particles will have the percentage value of porosity between 35% to 50% whereas soil with small particles will have the percentage value of porosity between 40% to 60%. Based on the percentage value of porosity recorded, it can be concluded that these soil have small particles and it can hold a large amount of water. This situation is expected as the method of rice cultivation was irrigated rice fields in order to hold water in the early stages of crop growth.

Chemical characteristics of soil

Chemical characteristic of soil is also important as it affects the nutrients balance in the soil. The most suitable pH range for rice cultivation is between 5.5 to 6.5 (Wan Darman *et al.,* 2008). At this pH level, nutrients are more available for the plant usage. pH range recorded for this study area was between 5.42 to 5.66, which is in the pH range suitable for rice cultivation. This value indicates that the soil is slightly acidic (Landon, 1991). A difference in pH value is controlled by different reactions that occurs. A high pH value is due to the reaction of water and calcium, magnesium and sodium to form hydroxyl ions (Plaster, 2009). Based on the statistical analysis done, there was a positive correlation between pH and organic matter at 5% level (r=0.4802, n=12), which means that increase in organic matter will result in low value of soil pH due to discharge of H^+ ions from humic acid when water and soil merged. Humic acid is one of the important acids that will be produced during decaying process of organic matter. However, in agricultural practice, these low pH conditions could be improved by liming.

Electrical conductivity (EC) is tested to determine the soil fertility due to the presence of salts which is soluble in the water and may infiltrate into the soil. EC values recorded for each layer of soil was approximately 2.13 mS cm^{-1} to 2.56 mS cm^{-1}. According to Dent and Ridgway (1986) electrical conductivity value of less than 3 mS cm^{-1} is included in the very suitable range (S1) for rice cultivation. Low value of EC will not cause any damage to the plant. EC values in the study area were low which indicated that the total amount of salt present in the soil is low. Higher amount of salt content in soil may induce higher potential damage in rice plants due to osmotic pressure.

Cation exchange capacity (CEC) recorded for the top-soil was from 14.32 to 15.45 meq/100g and from 13.51 to 15.35 meq/100g for sub-soil. The mean of CEC is similar for all sampling stations and does not show particular pattern between top-soil and sub-soil. CEC value is determined by the amount of clay and humus contained in the soil. The presence of clay and humus in the soil is very important because it acts as a cation reservoir which helps to improve the holding capacity of water and nutrient in soil. Higher CEC values reflect the higher availability of nutrients for plants to consume. The percentage values of soil organic carbon are significantly higher in the top-soil than the sub-soil. Percentage recorded for the top-soil is from 2.09% to 2.74% and from 1.25% to 1.73% for the sub-soil. High amount of organic content in the top-soil is due to fresh input of crop residue. Higher organic carbon content in the top-soil is contributed by humus which comes from decomposition of crop residues (Houghton & Hackler, 2000).

Yield Projection

The results of the projections showed that rice production was not significantly affected by the shifting of planting dates. Nine planting dates were simulated which started from S1 to S8. S1 to S8 represent different shifted planting dates based on the original date which is TS. S1 represents a week earlier than original date; S2, two weeks earlier; S3, a month earlier; S4, two months earlier while S5 represents delayed of a week than the original date; S6, delayed of two weeks; S7, delayed of a month and S8 delayed of two months. Generally, shifting of planting date may reduce the yield slightly (Fig. 1). However, these trends as shown in figure 1 were not consistent. S8 showed the lowest value of yield production which was only 3.85 tons ha^{-1}. This is maybe one of the effects of low value of average solar radiation recorded for that season coupled with very high amount of rainfall (Fig. 2). High amount of rainfall could be generated by long rainfall hours which naturally reduced the amount of sunshine received by the plants. As sunshine is also one of the important factors in the development and growth of the plants, thus short sunshine period reduces yield. Yields are correlated with the solar energy received during the 45 days that precede the harvest; therefore long periods of sunshine are essential for high yields. Mitin (2009) described the effects of solar radiation as more profound under conditions of which water, temperature and nitrogenous nutrients are not limiting factors. Based on this

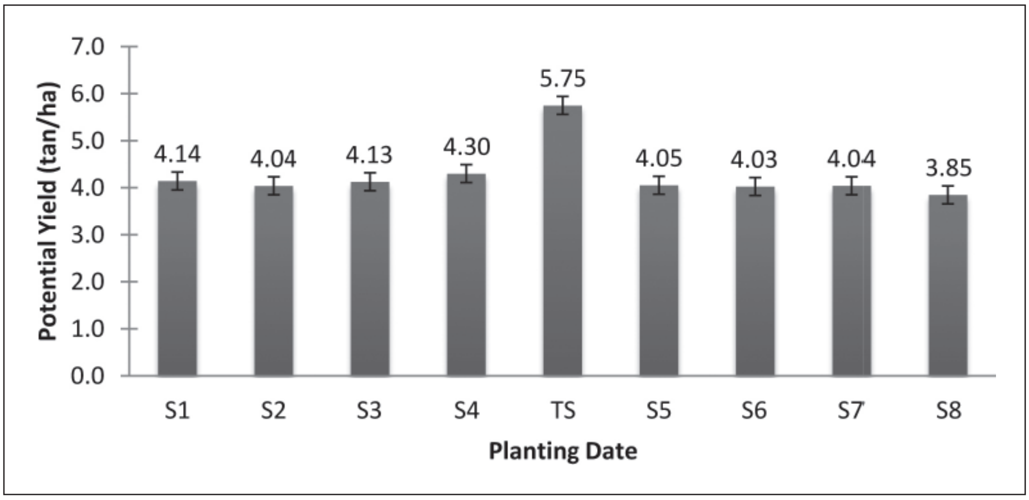

Fig. 1. Projection of rice production at different planting date

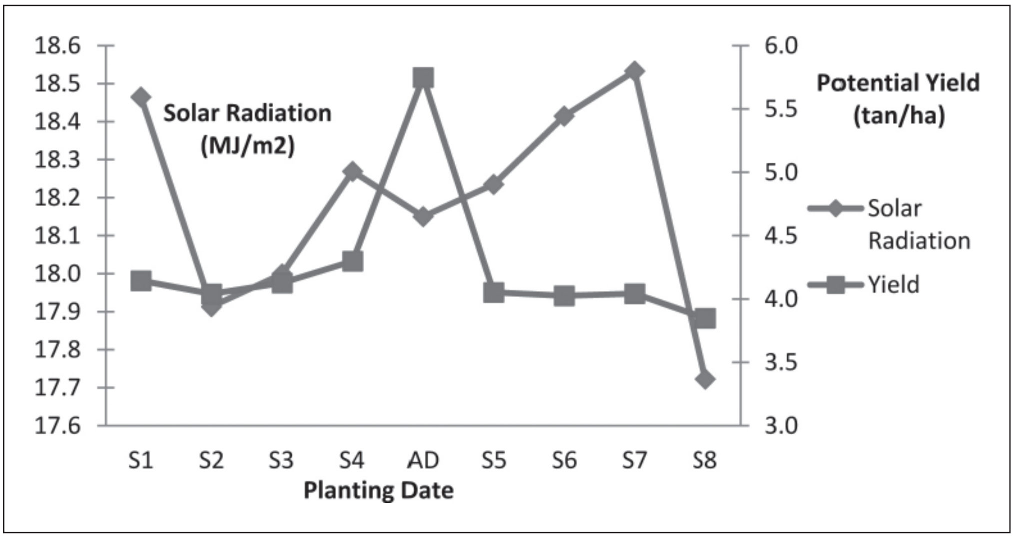

Fig. 2. Projected yield and solar radiation

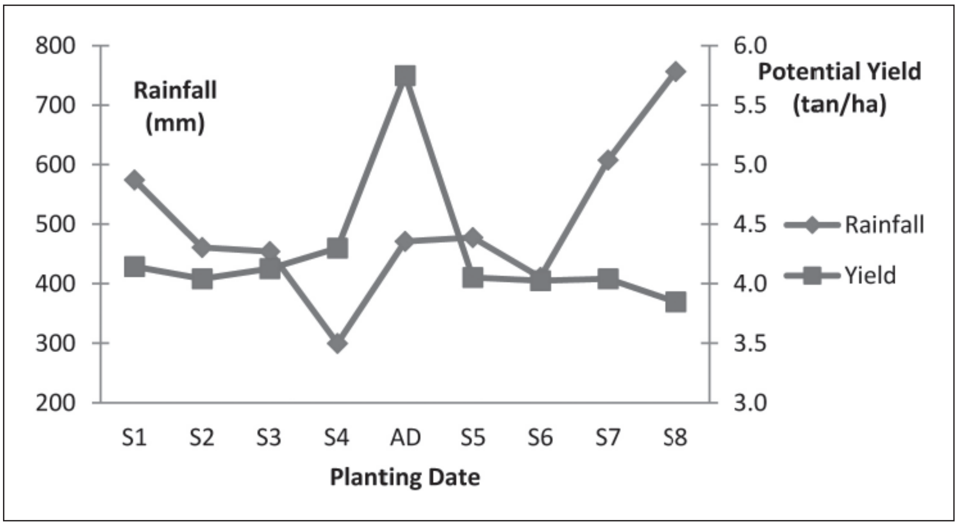

Fig. 3. Projected yield and rainfall

Table 5. Climatic requirement for rice cultivation

	Degree of Climatic Characteristics				
	None	Single	Moderate	Severe	Very Severe
Mean daily air temperature (°C)	28-25	24-22 29.3	21-20 31-22	19-18 33-34	<18 >34
Mean daily maximum air temp. (°C)	34-29	28-27 >34	26-24	23-22	<22
Mean daily minimum air temp. (°C)	>20	20-19	18-17	16-17	<16
Mean annual Rainfall (mm)	>2000	2000 -1750	1749 -1500	1499 -1250	<1250
Expected total rain interference (day/yr)	0-30	31-60	61-90	>90	
Sunshine length (hours/yr)	>2100	2100 -1800	1799 -1400	1399 -1000	<1000
Maximum wind speed (m/sec)	0-7	Aug-14	15-21	22-30	>30
Mean annual Relative Humidity	<80	80-100			
Length of dry season (months/yr)	0-1	2-3	4	5-6	>6

Source: Sys *et al.* (1993)

study, it is shown that there is weak positive correlation between solar radiation and the projected yield (r= 0.043, n=9).

Based on previous research by Zabawi (2010), the effects of climate change on rice production are mainly dependent on the variability in temperature and rainfall. Table 5 shows the climatic requirements for rice cultivation. Initial study using DSSAT4 has predicted that 2ºC increase in temperature may reduce the yield by about 12%, while increase and decrease in rainfall by 15% in the early growing stage will reduce the yield by almost 80% (Zabawi, 2010). However in this study, temperature was not a factor that influence the yield production as the average temperature recorded was from 27ºC to 29ºC which is considered as in the range of optimum temperature for rice growth. This is also true for rainfall as the total rainfall per annum was 2858.4 mm based on the data obtained from Meteorological Department of Malaysia, posed no limitation for rice cultivation when referred to suitability classification by Sys *et al.* (1993) in Table 5. Based on this study, it is shown that there is a weak positive correlation between temperature and yield projection (r=0.1773, n=9) and a weak negative correlation between rainfall and yield projection (r= -0.2493, n=9).

Generally, optimum temperature for rice cultivation is between 24ºC to 34ºC, while optimum rainfall is not less than 2000 mm per year. Surface air temperature has direct effect on yield, particularly on increasing total crop biomass. It determines crop photosynthesis and respiration losses, both of which contributed to yield and plant biomass (Peng *et al.,* 2004). Temperature affects rice growth in two ways, first, a critically low or high temperature defines the environment under which the life cycle can be completed; secondly, within the critically low and high temperature range, temperature influences the rate of development of leaves and panicles and the rate of ripening, thereby fixing the duration growth of a variety under a given environment and eventually determining the suitability of the variety to the environment (Siwar *et al.,* 2009). In addition, other studies that had been done indicated that grain yield is negatively correlated with air temperatures above 35ºC during the reproductive phase of growth (Arifin *et al.,* 2001). At high temperature, spikelet sterility is induced almost exclusively on the day of anthesis (Baker & Reddy, 2001). Temperatures greater than 35ºC for more than 1 hour induce a high percentage of spikelet sterility (Aktar *et al.,* 2006).

Water deficit may affect rice growth and reduces grain yield and quality (Carlos *et al.,* 2008). Water is a major constituent of plant tissue as reagent for chemical reactions and solvent for translocation of metabolites. Therefore, water deficit may affect many of the physiological processes such as photosynthesis and transpiration resulting in reduced growth and contributes towards low grain filling (Samonte *et al.,* 2001). Even though the value of total rainfall recorded for S8 is the highest, the yield predicted is the lowest as the value of solar radiation is low. Sunshine is another important factor in the development and growth of the plants. Long periods of sunshine are essential for high yields.

CONCLUSION

The physico-chemical characteristics of soils determined in the study area are suitable for rice cultivation. The texture of soil which is clay soil and silty clay soil, percentage of soil organic matter and soil organic content, soil acidity, electrical conductivity, cation exchange capacity, and bulk density values indicated that the study area suitable for rice cultivation. The actual rice yield from the plot experiment was 5.75 tons ha^{-1} which was within the range of national average for rice production. Simulation of rice yield using DSSAT 4.5 crop simulation model showed that daily solar radiation, rainfall and daily temperature have different effects towards rice production. Yield was projected slightly decrease as the daily solar radiation and rainfall decreased, and slightly increased as the temperature increased.

ACKNOWLEDGEMENTS

The authors wish to thank Universiti Kebangsaan Malaysia for the awards of research grants OUP-2012-110 and UKM-GUP-KPB-08-33-137, and to the MOSTI for the awards of research grant LRGS/TD/2011/UKM/PG/01 to enable this research to be completed. The school of Environmental and Natural Resource Sciences, Faculty of Science and Technology, Universiti Kebangsaan Malaysia is duly acknowledged for the support of research facilities.

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