Predicting paddy rice production under an integrated cropping system on Malaysian east coast

Conference Paper · January 2015

4 authors:

Yuveena Gopalan
University of Technology Sydney
4 PUBLICATIONS **11** CITATIONS
SEE PROFILE

Sue Walker
Agricultural Research Council, South Africa
172 PUBLICATIONS **3,885** CITATIONS
SEE PROFILE

Ebrahim Jahanshiri
Crops for the Future UK
57 PUBLICATIONS **268** CITATIONS
SEE PROFILE

Salvatore Virdis
Asian Institute of Technology
73 PUBLICATIONS **520** CITATIONS
SEE PROFILE

Full Paper

PREDICTING PADDY RICE PRODUCTION UNDER AN INTEGRATED CROPPING SYSTEM ON MALAYSIAN EAST COAST

Y. Gopalan[1*], S. Walker[1,2], E. Jahanshiri[1], S.G.P. Virdis[1,2]

*yuveena@cffresearch.org

[1]Crops For the Future, Semenyih, Malaysia
[2]University of Nottingham Malaysia Campus, Semenyih, Malaysia

Abstract

Rice (*Oryza sativa*) is planted extensively and plays a major role in the country's food security. This study considers potential to expand rice cultivation with legume rotation, bambara groundnut (*Vigna subterranea*) to promote a sustainable system along the Pahang coast. As water can be a limiting factor for rice cultivation, FAO-AquaCrop, water-driven model was used to predict rice yields and assess risk of growing rice. Openly available weather and soil data were obtained from NASA and ISRIC - World Soil Information at 1 km^2 grid. The model used climate data from 1997 – 2014 on two soil types (fluvisols and histosols) for November and May planting seasons under two water treatments to obtain potential yields for both crops. Production variations were observed across soil types and water treatments. Fluvisols soil had less yield variations under irrigation compared to histosols soil. Rice yields were higher with less variations in both seasons when fully irrigated (mean yields: 5.3 – 6.8 t/ha) and were lower with higher yield variation during rainfed conditions (mean yields: 2.7 – 6.0 t/ha). Bambara groundnut yields varied less compared to rice, however yields were lower in both seasons (mean yields: 2.5 – 3.4 t/ha) when irrigated and (mean yields: 1.9 – 3.2 t/ha) under rainfed conditions. Risk analysis indicates lowest risk for irrigated May planting for both crops (rice yields > 6.0 t/ha and bambara groundnut > 3.0 t/ha). Highest risk observed was for rainfed November planting for both crops on fluvisols soil (70% yields > 3.0 t/ha for rice; and 58% yields > 2.0 t/ha). Bambara groundnut however gave higher gross income compared to rice. Rice rotation cropping with bambara groundnut could reduce nitrogen fertilisation amounts required and improve land fertility. Findings indicate that the combination of irrigated rice and bambara groundnut crops grown in rotation produces the highest gross income.

Keywords: crop productivity, risk analysis , AquaCrop, water requirement, multi-cropping

1.0 INTRODUCTION

Pahang state has about 10,360 hectares of paddy planted area, with 68.6% of the area planted during the main season and 50.7% during off season [1]. However, rice production is similar for both seasons, with 10,405 metric tonnes produced during main season and 10,052 metric tonnes during off season [1]. The Rompin district's paddy cultivation area however is prone to disease attacks which have destroyed 500 ha and floods destroying 400 ha in 2013 [1]. Therefore, a study on the potential of paddy cultivation in the area with a diversification option would allow more sustainable use of the agriculture area.

This paper aims to predict potential yields and assess the risk of growing rice and bambara groundnut in a region of Rompin district, along Pahang coast of Malaysia using the FAO-AquaCrop model. The paper also considers the potential income generation for rural farmers from both crops.

1.1 Rice

Rice is the third major crop planted in Malaysia after oil palm and rubber [1]. It is an important commercial crop which contributes significantly to income generation for the rural farmers as well as to national food security. In 2013, a total area of 688,207 ha of paddy rice was harvested in Malaysia [2]. The annual average yield is between 3 – 5 tha^{-1} with potential yield of 7.2 tha^{-1} [3]. According to Abu [4], yields higher than 8 tha^{-1} have been achieved under certain conditions in a few areas. Although annual rice yield is increasing, the country is still importing roughly a third of the rice required due to increasing population [1]. The main challenges faced are mainly from shortage in labor, increased production cost and low quality and productivity of crop [5].

As Malaysia is targeting to be self-supporting for rice demands by 2020 [6], the Malaysian government has introduced policies, incentives and subsidies aimed at increasing production, quality of rice and income generation for rural farmers [7]. The government also guarantees the rice purchase price for farmers. The farm gate price for freshly harvested paddy was set at MYR 1,200 per ton in 2014 [2]. Most paddy farmers rely only on income generated from cultivating paddy on a small scale with an average area of 1 ha per farmer [8]. The average farmer's net income in Kedah is under MYR 2,000/month [9].

With low agricultural profitability from cultivating paddy and poor land fertility from mono-cropping, most paddy farmers in Selangor are moving towards multi-cropping as a means of extra income and better land management [10]. Increasing paddy yield could be through identification of new areas for cultivation and/or cultivating varieties producing higher potential yields. However, future production will need to optimise production with limited resources [11], as there are large uncertainties with the effects of climate change on rice productivity. Vaghefi [12] showed that rising temperature and declining rainfall could contribute to decreasing paddy yields of between 9 – 30%. Therefore, farmers depending solely on mono-cropping will be impacted directly when crops produce lower yields under future climatic scenarios [10].

1.2 Bambara groundnut

Bambara groundnut (*Vigna subterranea*) is an underutilised grain legume native to West Africa [13]. It is known as a drought tolerant crop that can withstand high temperatures, grow in areas with an annual rainfall between 600 – 1200 mm [14] and under poor soil conditions [15]. The crop can be cultivated in wet or dry tropical areas, and subtropical dry summer climate zones, as the optimal temperature is between 19°C – 30°C and it can grow on soils with pH between 4.3 – 7.0 [16]. The crop usually yields an average of 3 tha^{-1} [17].

The crop is cultivated in Africa, Indonesia, Thailand and in Malaysia, where it is found in the northern region of Peninsular Malaysia in the State of Kedah. It is cultivated as an intercrop with rubber during an early stage (CFF, 2015). In Indonesia the price of freshly harvested bambara groundnut is IDR 6000 – 8000 (MYR 1.7/kg – MYR 2.2/kg) [18], and in Malaysia the price is higher at MYR 4/kg [19].

This legume has high nutritional content, as it contains high amounts of protein and carbohydrate [15], a good calcium, amino acids and iron content [20]. From studies conducted in the Mpumalanga Province of South Africa [21], the legume can contribute from 4 – 200 kg/ha Nitrogen to the soil and has better water use efficiency under climate change scenarios. For farmers, it can provide an alternative source of income and act as biofertiliser lowering the nitrogen fertiliser requirement for rice, according to [22] as about '20 kg of N is needed for the production of 1 tonne of rice'. The legume could potentially be instrumental in promoting soil fertility on land degraded from mono-cropping activities and reduce potential agricultural risk due to climate change.

2.0 METHODOLOGY

This suitability study for growing rice and bambara groundnut along the coast of Rompin district, Pahang was conducted by estimating yield with openly available weather and soil data using FAO-AquaCrop. The crop model used climate data from 1997 – 2014 according to soil types for the planting seasons under two water treatments to obtain a range of potential grain yield. Estimated incomes for both crops were calculated using farm gate prices. The potential for cultivating these crops along Rompin district coast were evaluated using land cover and soil data.

2.1 Area description

The study area is located within the Rompin district in the Southern part of the East Coast State of Pahang in Peninsular of Malaysia (Figure 1). It is one of 2 districts in Pahang located along the coast. The area is low lying (at an altitude of less than 70 m above average sea level) and covered with secondary regrowth tropical rain forest and near a designated wildlife reserve (Endau-Rompin National Park) area, large parts of the park are located in the neighbouring state of Johor. Apart from agriculture mainly from oil palm and rice, the state also depends on tourism.

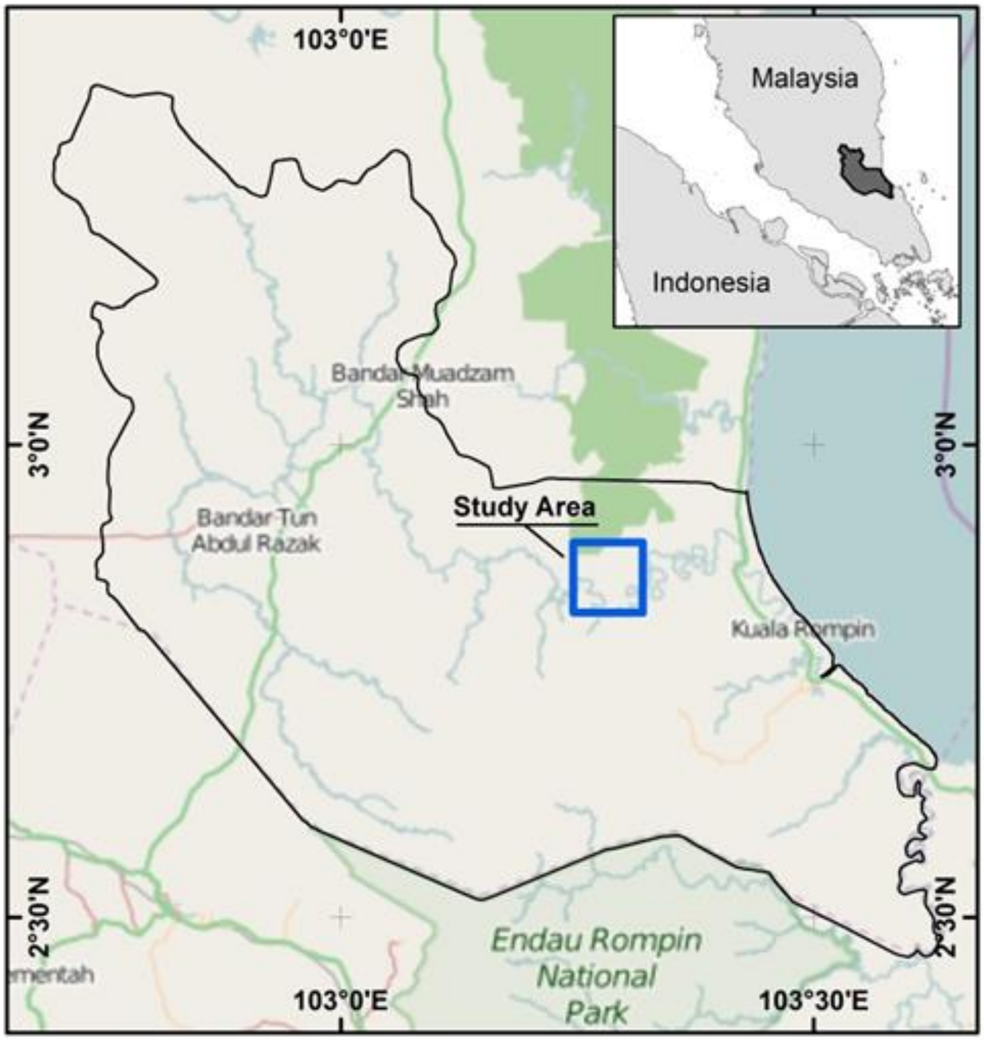

Figure 1: Location of study area (reference system WGS84) [23]

2.2 Climate data

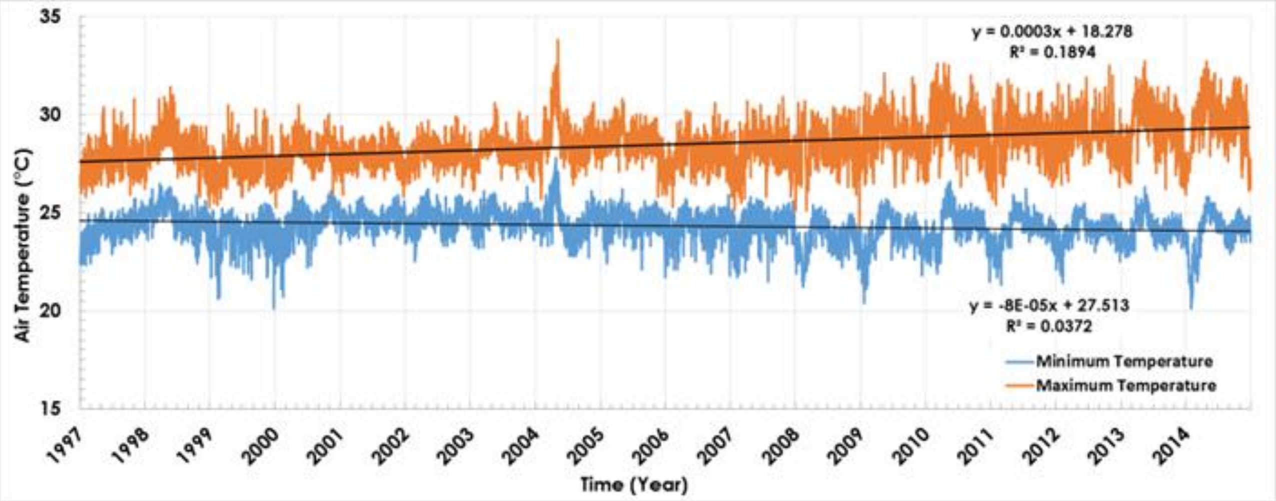

Figure 2: Daily changes in NASA climate dataset for daily maximum and minimum air temperatures (°C)

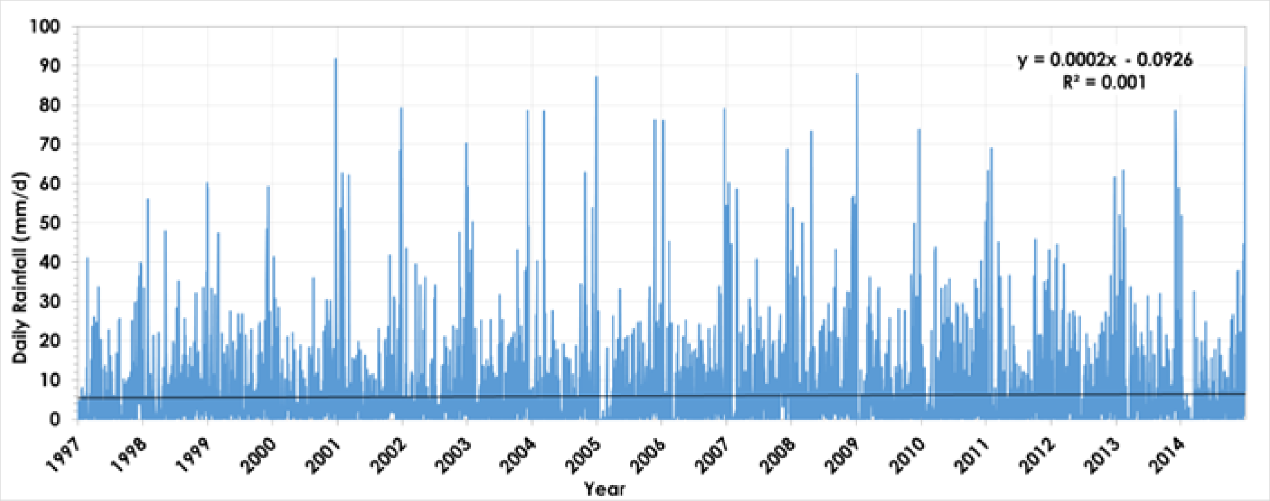

Figure 3: Daily changes in NASA climate dataset for daily precipitation (mm)

Long-term reanalysis climate data (Figure 2 and 3) was obtained from NASA website [24]. The large-scale meteorological data (1° latitude by 1° longitude grid, approximately 110 km) provides predicted daily climate data of precipitation (mmd^{-1}), minimum air temperature (°C), maximum air temperature (°C), relative humidity (at 2m, %), wind speed (at 10m, ms^{-1}) and radiation (MJm^{-2}day^{-1}). For this study, climate data for 17 years from January 1997 until December 2014 were acquired for the location at 2.87N and 103.257E; elevation 69m.

2.3 Soil data

Soil data for the site was acquired from ISRIC - World Soil Information at large scale at 1km2 grid [25]. Soil information includes predicted soil parameters for 6 different soil horizons (0-200 cm) with minimum, maximum, average and 90% prediction interval values for organic carbon (fine earth fraction) (gkg^{-1}); sand%, clay%, silt% content mass fraction; coarse fragments >2 mm, pH in H2O; cation exchange capacity (cmolkg^{-1}) and bulk density (kgm^{-3}) [25]. As per data from USGS Mineral Resources Data System [26] the coastal area of Rompin District is predominantly histosols (peat and muck soils) and fluvisols (soils developed in alluvial deposits) this study will examine the yield potential for these two soil types. The land cover from MODIS [27] was examined for accuracy using qualitative method by evaluating their spatial and category correctness by comparing with google map images. The map provides good representation of agriculture area for both soil group types where rice and bambara groundnut can be cultivated (Figure 4). Therefore, this study will examine the yield potential for these two soil types.

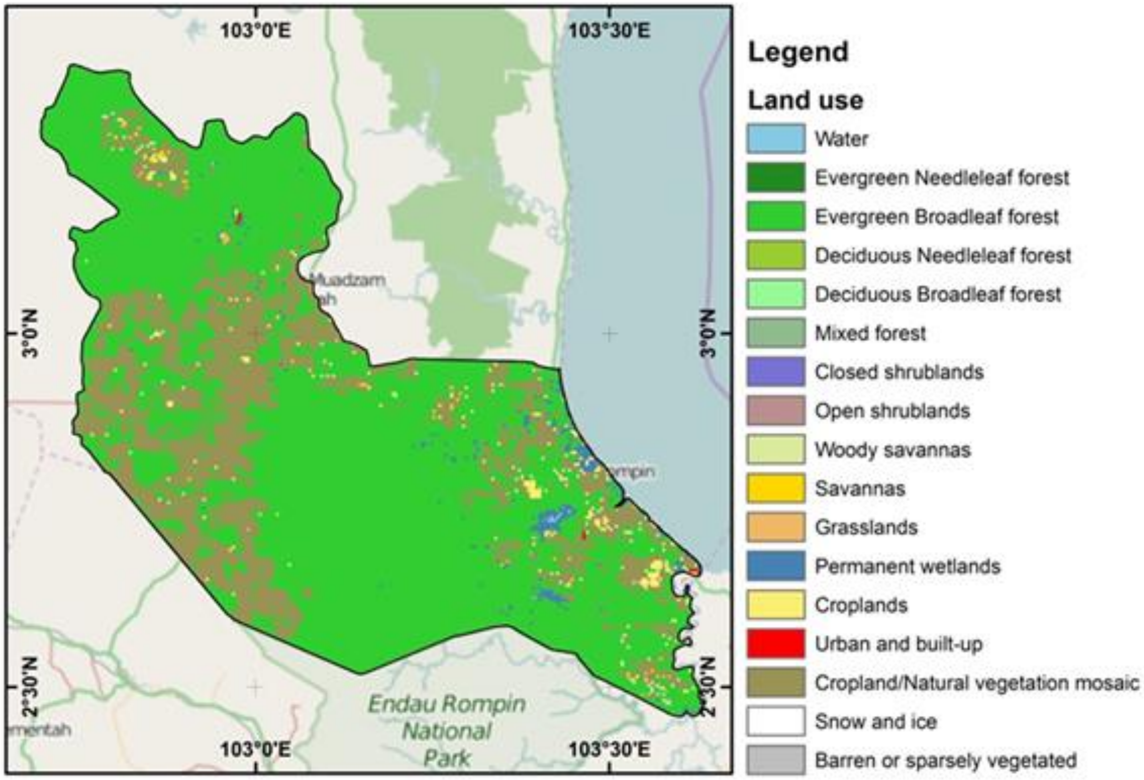

Figure 4: Land use map with classification for Rompin district [23] [27]

2.4 Crop modelling

FAO-AquaCrop (Version 4), used for this study, has been calibrated using data for paddy rice from Los Banos, Philippines and bambara groundnut from Botswana, in Southern Africa. The climate and soil data derived from public databases required preprocessing to create climate files for AquaCrop. Daily evapotranspiration was calculated from FAO-ETO calculator [28] using FAO Penman-Monteith equation and data gaps were filled through interpolation in excel. Soil dataset for AquaCrop was reduced to 5 layers by combining the top two soil layers, as the model can only accept 5 soil layers. The soil water holding capacity and hydraulic conductivity were determined using USDA-ARC Hydraulic Properties Calculator [29]. The input parameters used for the USDA-ARC Hydraulic Properties Calculator were sand%, clay%, organic matter% and gravel% to derive texture class; saturated hydraulic conductivity; % volume for wilting point, field capacity and saturation, as input into AquaCrop soil files. Two planting seasons were defined for rice where the main planting season is between August and February, and the off planting season is between March and July [1]. For this study the planting dates for rice were selected as 1st November for main planting season and 1st May for the off planting season.

2.5 Assumptions

The AquaCrop model used in this study has not been calibrated nor validated for paddy rice and bambara groundnut with Malaysian datasets. The results obtained serve as an indication of the possible yields, however this requires further validation. As the soil and climate data used are from publicly available large scale databases, therefore these should be considered preliminary results for the study area.

3.0 RESULTS AND DISCUSSION

3.1 Crop yields

Rice produced higher yields for each planting season, soil type and water treatment compared to bambara groundnut which showed less variability across the cropping seasons and planting conditions (Figure 5). Both crops planted under irrigated conditions produced higher yields with less variation, with slightly higher yields obtained on histosols soil. On average rice yields were 2.5 – 3.5 tha^{-1} higher than bambara groundnut.

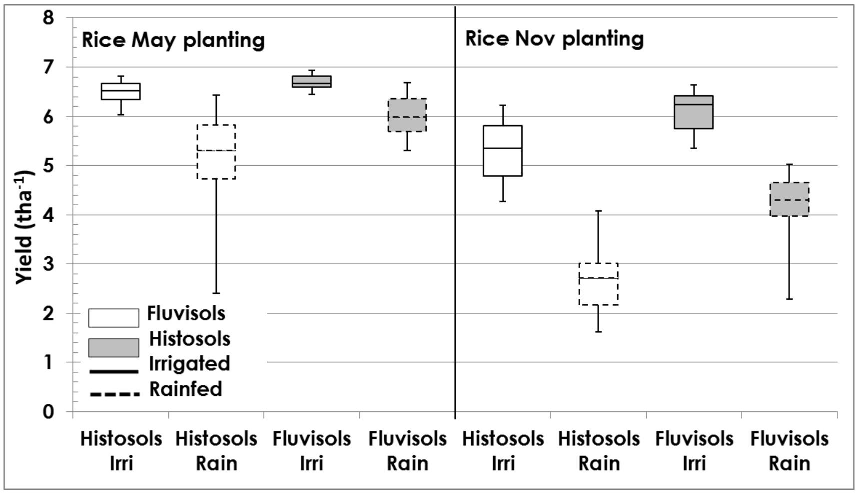

Figure 5: Rice average yields for May and November planting seasons on fluvisols and histosols soils

Less yield variation was observed for rice in both planting seasons under irrigated conditions compared to rainfed conditions, showing that the availability of water is critical for stable productivity. Rice planted in early May on average produced higher yields compared to the November planting. Higher yields of 1.5 tha^{-1} and 0.7 tha^{-1} were achieved under irrigation for May planting on fluvisols and histosols soils respectively with less yield variation compared to rainfed conditions. For November planting, rice yields were 2.6 tha^{-1} higher on fluvisols soil and 1.8 tha^{-1} higher on histosols soil under full irrigation. Although yields are higher than the national average of 3-5 tha^{-1} for both seasons under irrigation, yield in the range between 5-8 tha^{-1} and as high as 10 tha^{-1} have been recorded in paddy fields in North-west Selangor area due to good resource management [10].

Rice cultivated in May produced yields in the range of 6.0 – 6.8 tha^{-1} (irrigated) and 2.4 – 6.4 tha^{-1} (rainfed) on fluvisols soil, and 6.5 – 6.9 tha^{-1} (irrigated) and 5.3 – 6.7 tha^{-1} (rainfed) on histosols soil. The November planted rice gave yields between 4.3 – 6.2 tha^{-1} (irrigated) and 1.6 – 4.1 tha^{-1} (rainfed) on fluvisols soil and 5.4 – 6.6 tha^{-1} (irrigated) and 2.3 – 5.0 tha^{-1} (rainfed). As observed, adequate water availability shows a direct contribution towards higher rice yield production, therefore, farmers would be able to produce higher rice yields under irrigated conditions. Hence a good irrigation scheduling plan should take into consideration the crop requirement in order to benefit the farmers.

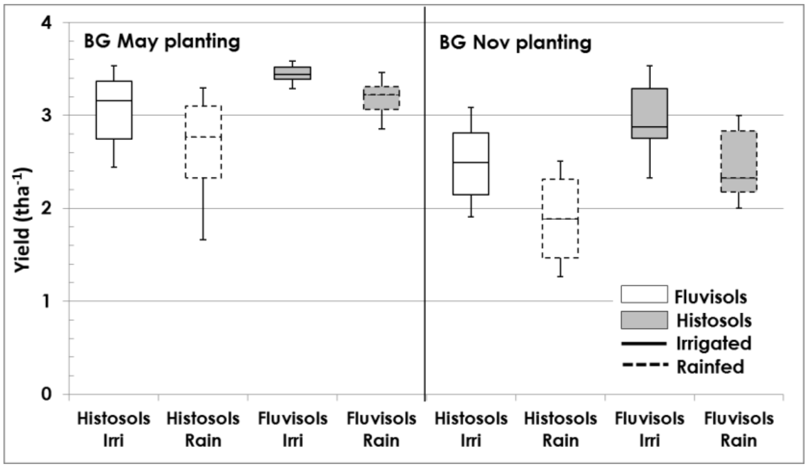

Figure 6: Bambara groundnut average yields for May and November planting seasons on fluvisols and histosols soils

Bambara groundnut showed higher yield averages for May planting season, under both soil types and water treatments (Figure 6). Although rice produced higher yields, bambara groundnut showed less yield variation under rainfed conditions when compared with rice. Bambara groundnut mean yield of about 3 tha^{-1} under irrigation for both planting seasons and soils. The May planting bambara groundnut produced an average of 0.5 tha^{-1} higher yields compared to the November planting.

Average bambara groundnut yield for May planting on fluvisols soil were 3.0 tha^{-1} (yield range: 2.4 – 3.5 tha^{-1}) under irrigation and 2.6 tha^{-1} (yield range: 1.7 – 3.3 tha^{-1}) under rainfed conditions, and 3.4 tha^{-1} (yield range: 3.3 – 3.6 tha^{-1}) and 3.2 tha^{-1} (yield range: 2.9 – 3.5 tha^{-1}) for histosols soil under irrigated and rainfed conditions respectively. November planting for bambara groundnut gave lower yields with higher variations, with 2.5 tha^{-1} (yield range: 1.9 – 3.1 tha^{-1}) under irrigation and 1.9 tha^{-1} (yield range: 1.3 – 2.5 tha^{-1}) under rainfed conditions on fluvisols s soil, and 3.0 tha^{-1} (yield range: 2.3 -3.6 tha^{-1}) and 2.5 tons/ha (yield range: 2.3 -3.6 tha^{-1}) under irrigated and rainfed conditions.

Although bambara groundnut produced higher yields with less yield variation under irrigated conditions, the average yield variations were similar for both water treatments. Under irrigated conditions, bambara groundnut yields were ranged between the yield difference between of 0.3 – 1.3 tha^{-1} and 0.6 – 1.6 tha^{-1} under rainfed conditions. Rice however showed higher yield variation, with yield differences of between 1.4 – 4.0 tha^{-1} under rainfed conditions compared to 0.5 – 1.9 tha^{-1} under irrigated conditions. Thus, bambara groundnut as an alternative crop provides more stability to the cropping system.

The results show that bambara groundnut is less water dependant and more drought tolerant compared with rice, requiring a minimum of 750 mm of annual rainfall (Ecocrop, 2015), which is half the water requirement of rice. Therefore, bambara groundnut can be cultivated in projected low rainfall seasons under future climate change scenarios, thus providing an alternate source of income to farmers and providing a food security option for the country.

3.2 Crop risks

Both soils show higher yield variation for paddy rice compared to bambara groundnut (Figure 7 and 8). Rice grown in May under irrigation has the highest yield with least variability for both soils. However, rice grown under rainfed conditions in November has the highest production risk.

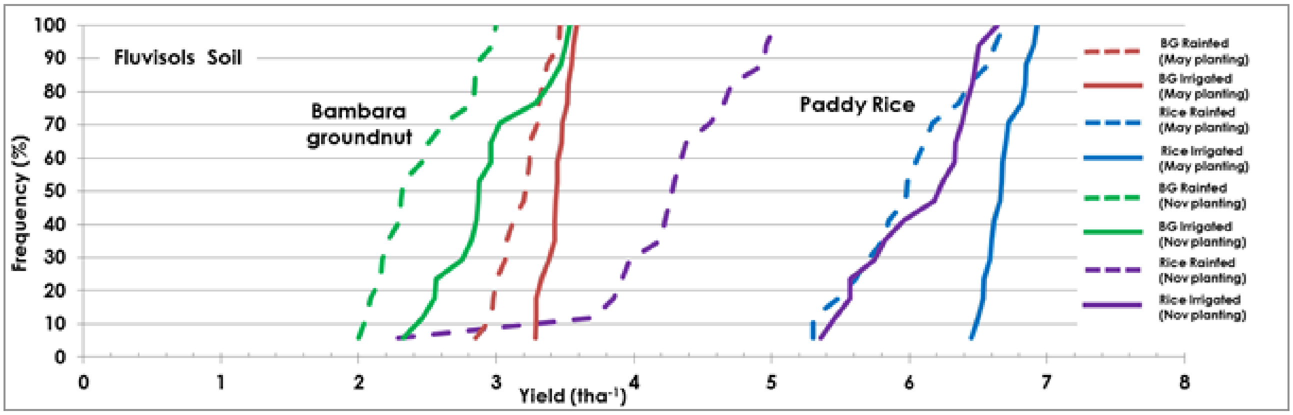

Figure 7: Rice and bambara groundnut cumulative distribution frequency for May and November planting seasons on fluvisols soil at Rompin

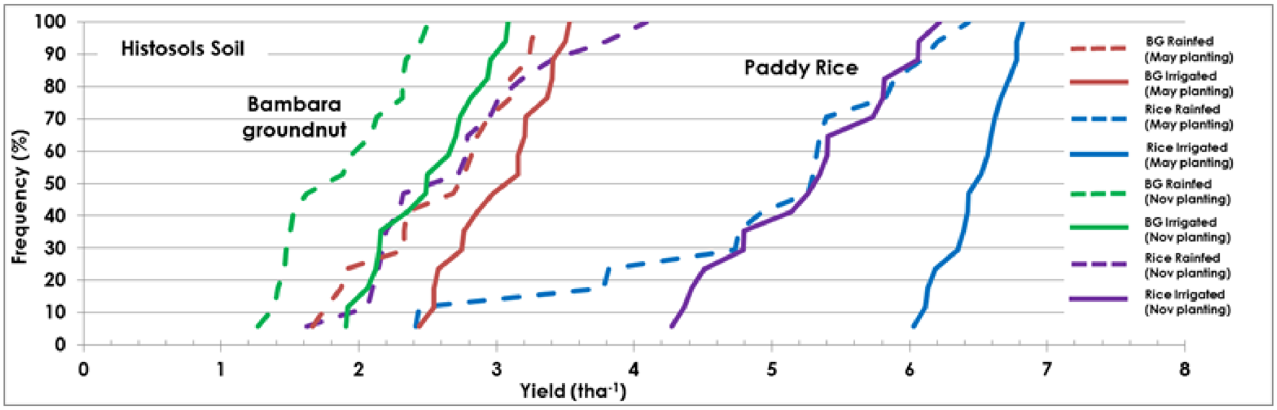

Figure 8: Rice and bambara groundnut cumulative distribution frequency for May and November planting seasons on histosols soil at Rompin

Rice planted in May shows the lowest production risk as it has the smallest yield variation with high yields, always above 6.0 tha^{-1} under irrigated conditions for both soil types. For fluvisols soil, yields above 6 tha^{-1} are possible for rice grown under irrigation for November with 60% probability and in May under rainfed conditions with 50% probability. By making the baseline for yields at 3.0 tha^{-1}, this would mean that for May planting under rainfed conditions for fluvisols soil, there is a 12% chance (1 out of 10 years) which would produce poor yields, thus farmers need to prepare for this. Rice cultivated in November under rainfed conditions produced the lowest yield when cultivated on either soil type. Maximum yields of 5.0 tha^{-1} were achieved on histosols soil with only 35% probability of yields below 4 tha^{-1}. Lower yield were recorded on fluvisols soil for November planting under rainfed conditions, with maximum yields of 4.1 tha^{-1} with 70% probability of yields below 3 tha^{-1} with poor yields.

Bambara groundnut planted in May also shows the highest yields and lowest production risk, yields are always above 3.0 tha^{-1} for histosols soil and yields above 2.5 tha^{-1} for fluvisols soil under irrigation. The November rainfed combination bambara groundnut planting for both soils shows the highest risk with lowest yield. On fluvisols soil, yields lower than 2.0 tha^{-1} occur 23% (2 out of 10 years) under rainfed conditions for May planting. For November planting the risk is 12% (1 out of 10 years) for yields lower than 2.0 tha^{-1} occurring under irrigation and 58% (6 out of 10 years). In May, for histosols soil the average yields are always above 2.8 tha^{-1} and 2.0 tha^{-1} for November planting under both water treatments.

Therefore, for farmers who are risk adverse, the combination of May planting for each crop under irrigation would provide highest average yields which have the least opportunity for failure. Both crops cultivated in November also have lower risk under irrigation conditions. Therefore farmers would benefit from higher yields through cultivating rice and bambara groundnut under irrigation.

3.3 Gross income

As the farm gate price for bambara groundnut is MYR 4,000/t which is much higher than the price fixed for rice which is at MYR 1,200/t, the gross income for farmers is larger with bambara groundnut despite yields being lower (Figure 9). The average gross income for rice planted in May is MYR 7,896 under irrigation and MYR 6,563 rainfed; and in November is MYR 6,807 and MYR 4,162 under irrigation and rainfed conditions. The gross income achieved with bambara groundnut during irrgated and rainfed conditions are MYR 11,719 and MYR 10,510 for May planting; and MYR 9,903 and MYR 7,824 for November planting. The gross income for May planting is higher compared to November planting synonymous with the higher production in May.

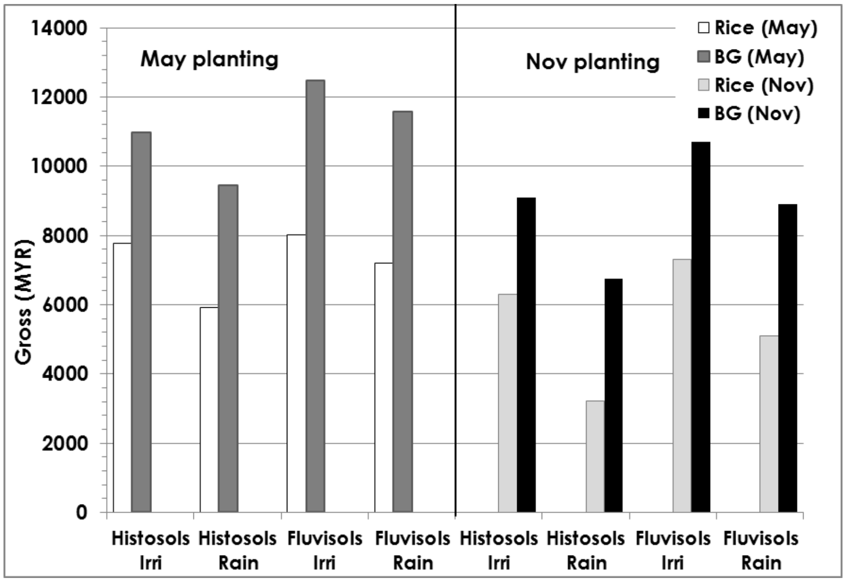

Figure 9: Rice and bambara groundnut gross income for May and November plantings

As bambara groundnut can provide additional saving to farmers as it has nitrogen fixing properties, it would be beneficial for farmers to practice crop rotation. Rice planted after bambara groundnut would then require a lower inorganic nitrogen fertiliser application to achieve similar yields with lower input costs. In addition, the legume crop could provide additional income from these alternative crops especially for farmers who are relying on income from a single crop.

From the gross income values, the most advantageous cropping combination of planting rice and bambara groundnut in rotation under different water treatment options can be derived. Options for gross income for both crops on either water treatment and combination irrigation is given in Table 1 and 2. Combination cropping with both crops cultivated under irrigation provides the highest gross income for both soils. The gross annual income is approximately MYR 3,000 – MYR 4,500 higher for both crops cultivated under irrigation compared to rainfed, and approximately MYR 1,500 – MYR 2,000 higher in gross income compared with a combination of irrigated and rainfed condition cropping system. Better determination of these options can be obtained by the farmer when incorporating labour and irrigation cost.

Table 1: Gross income from rice and bambara groundnut under either irrigation or rainfed rotations

	Rice planting conditions	**Gross (MYR)**	**Bambara groundnut planting conditions**	**Gross (MYR)**	**Sum Gross (MYR)**
Histosols soil					
Option 1	May planting, Irrigated	7771.76	Nov planting, Irrigated	10023.06	17794.82
Option 2	Nov planting, Irrigated	6311.36	May planting, Irrigated	12092.94	18404.31
Option 3	May planting, Rainfed	5924.82	Nov planting, Rainfed	7440.24	13365.06
Option 4	Nov planting, Rainfed	3221.79	May planting, Rainfed	10415.53	13637.32
Fluvisols soil					
Option 1	May planting, Irrigated	8020.02	Nov planting, Irrigated	11812.71	19832.73
Option 2	Nov planting, Irrigated	7303.48	May planting, Irrigated	13748.00	21051.48
Option 3	May planting, Rainfed	7201.48	Nov planting, Rainfed	9812.24	17013.72
Option 4	Nov planting, Rainfed	5101.55	May planting, Rainfed	12758.82	17860.38

Table 2: Gross income from rotations combining irrigation and rainfed options for rice and bambara groundnut

	Rice planting conditions	**Gross (MYR)**	**Bambara groundnut planting conditions**	**Gross (MYR)**	**Combination Gross (MYR)**
Histosols soil					
Option 5	May planting, Irrigated	7771.76	Nov planting, Rainfed	7440.24	15212.00
Option 6	Nov planting, Irrigated	6311.36	May planting, Rainfed	10415.53	16726.89
Option 7	May planting, Rainfed	5924.82	Nov planting, Irrigated	10023.06	15947.88
Option 8	Nov planting, Rainfed	3221.79	May planting, Irrigated	12092.94	15314.73
Fluvisols soil					
Option 5	May planting, Irrigated	8020.02	Nov planting, Rainfed	9812.24	17832.26
Option 6	Nov planting, Irrigated	7303.48	May planting, Rainfed	12758.82	20062.31
Option 7	May planting, Rainfed	7201.48	Nov planting, Irrigated	11812.71	19014.19
Option 8	Nov planting, Rainfed	5101.55	May planting, Irrigated	13748.00	18849.55

4.0 CONCLUSION AND RECOMMENDATIONS

Findings indicate the importance of adequate available water and soil assessment before planting to ensure continuous high productivity. As rice yields vary greatly under rainfed conditions, therefore requiring better irrigation planning and study of local climate and soil conditions to understand the reasons contributing to yield variability.

AquaCrop model calibration for Malaysia is significant as through this initiative better and more accurate assessment could be conducted to study rice and legume rotations for cultivation in Malaysia. Proper planning of an area, including effects of natural resources on crop production under diverse agro-ecological zones are essential before a decision to select alternative crops can be made. Therefore crop models as shown in this study, can provide indicative potential crop productivity, including for rotation cropping option. It is important to note that models only provide an estimate, however with long term field data and monitoring of conditions, better decision making and assessment with higher accuracy is possible.

References

[1] DOA. 2013. Paddy Statistics of Malaysia 2013. Malaysia: Communication Section, Extension, Consultation, Investment, Agro-based Industry Division, Department of Agriculture, Peninsular Malaysia, pp.140.

[2] Hassan, Z. A. 2014. "Issues and Challenges Issues and Challenges – Strategies to Sustain Rice Industry through R&D: Status of Rice Industry," Presented at the International Plantation Industry Conference and Exhibition (IPiCEX2014), Kuching, Sarawak, Malaysia, November 2014.

[3] Alam, M., Siwar, C., Toriman, M., Molla, R. and Talib, B. 2011. Climate change induced adaptation by paddy farmers in Malaysia. Mitigation and Adaptation Strategies for Global Change, 17(2), pp.173-186.

[4] Abu, N. 2012. "Paddy and rice policy transformational: a historical policy analysis," [M.S. Thesis] Asia Pacific University, Malaysia.

[5] Dardak, R. 2015. Transformation of Agricultural Sector in Malaysia Through Agricultural Policy (FFTC Agricultural Policy Articles). [Online] Ap.fftc.agnet.org. Available at: http://ap.fftc.agnet.org/ap_db.php?id=386 [Accessed 20 Jul. 2015].

[6] Muazu, A., Yahya, A., Ishak, W. and Khairunniza-Bejo, S. 2015. Energy Audit For Sustainable Wetland Paddy Cultivation in Malaysia. Energy, 87, pp.182-191.

[7] Umar, H.S., Abdullah, A.M., Shamsudin, M.N and Mohamed, Z.A. 2014. Time series econometric estimation of supply equation for Malaysian rice sector, Asian Journal of Empirical Research, 4, issue 9, p. 455-467, http://EconPapers.repec.org/RePEc:asi:ajoerj:2014:p:455-467.

[8] Toriman, M., Er A., Lee, Q., S. S. A., Jali, F., Mokhtar, M., R. Elfithri, Gasim, M., Yusop, Z., Aziz, N., Ahmah, H. and Jusoh, H. 2013. 'Paddy Production and Climate Change Variation in Selangor, Malaysia', ASS, 9(14)

[9] Hussin, F. and Wahab Mat, A. 2013. Socio-economic level of paddy farmers under the management of MADA: A case study in the Pendang District, Kedah. Journal of Governance and Development.

[10] Alam, M., Siwar, C., Toriman, Murad, W., Molla, R. and Toriman, E. 2010. Socieconomic profile of farmer in Malaysia: Study on integrated agricultural development area in North-west Selangor. Agricultural Economics and Rural Development, New Series, 5(2), p. 249–265.

[11] Bala, B., Alias, E., Arshad, F., Noh, K. and Hadi, A. 2014. Modelling of food security in Malaysia.Simulation Modelling Practice and Theory, 47, pp.152-164.

[12] Vaghefi, N., Shamsudin, M., Radam, A. and Rahim, K. (2013). Impact of Climate Change on Rice Yield in the Main Rice Growing Areas of Peninsular Malaysia. Research Journal of Environmental Sciences, 7(2), pp.59-67.

[13] Hepper, F. (1963). Plants of the 1957-58 West African Expedition: II. The Bambara Groundnut (Voandzeia subterranea) and Kersting's Groundnut (Kerstingiella geocarpa) Wild in West Africa. Kew Bulletin, 16(3), p.395.

[14] Baryeh, E. (2001). Physical properties of bambara groundnuts. Journal of Food Engineering, 47(4), pp.321-326.

[15] Jørgensen, S., Liu, F., Ouédraogo, M., Ntundu, W., Sarrazin, J. and Christiansen, J. (2010). Drought Responses of Two Bambara Groundnut (Vigna subterranea L. Verdc.) Landraces Collected from a Dry and a Humid Area of Africa. Journal of Agronomy and Crop Science, 196(6), pp.412-422.

[16] Ecocrop. (2015). FAO - Food and Agriculture Organization. Data sheet: Bambara groundnut [online] Available at: http://ecocrop.fao.org/ecocrop/srv/en/dataSheet?id=10830 [Accessed 8 Jul. 2015].

[17] Abu, H. and Buah, S. (2011). Characterization of Bambara Groundnut Landraces and Their Evaluation by Farmers in the Upper West Region of Ghana. Journal of Developments in Sustainable Agriculture, [online] 6(1), pp.64 - 74. Available at: http://doi.org/10.11178/jdsa.6.64 [Accessed 8 Jul. 2015].

[18] Redjeki, E. (2015). Bambara groundnut - farm gate price. [email].

[19] CFF, 2015. BamYIELD Programme: Trip to Kedah Perlis and Thailand. Back to Office Report. Semenyih, p.2.

[20] Eltayeb, A., Ali, A., Abou-Arab, A. and Abu-Salem, F. (2015). Chemical composition and functional properties of flour and protein isolate extracted from Bambara groundnut (Vigna subterranean). African Journal of Food Science, 5(2), pp. 82 – 90.

[21] Mohale, K., Belane, A. and Dakora, F. (2013). Symbiotic N nutrition, C assimilation, and plant water use efficiency in Bambara groundnut (Vigna subterranea L. Verdc) grown in farmers' fields in South Africa, measured using 15N and 13C natural abundance. Biol Fertil Soils, 50(2), pp.307-319.

[22] Roy R.N. and Misra R.V. 2002. FAO Corporate Document Repository: Economic and environmental impact of improved nitrogen management in Asian rice-farming systems [online] Available at: http://www.fao.org/docrep/006/y4751e/y4751e0k.htm [Accessed 10 Jul. 2015].

[23] OpenStreetMap. 2015. OpenStreetMap. [online] Available at: http://openstreetmap.org [Accessed 10 Jul. 2015]

[24] NASA – POWER (2015). Prediction Of Worldwide Energy Resource (POWER: Agroclimatology Daily Averaged Data [online] Available at: http://power.larc.nasa.gov/ [Accessed 11 May 2015].

[25] ISRIC (2015). ISRIC World Soil Information. ISRIC SoilGrids1km visualisation and distribution website. [online] SoilGrids1km. Available at: http://soilgrids1km.isric.org/ [Accessed 11 May. 2015].

[26] Global Species. 2015. Global Species: Land Use Data for Latitude 2.75 Longitude 103.25. [online] Available at: http://www.globalspecies.org/weather_stations/landuse/567/186 [Accessed 5 June 2015]

[27] MODIS, (2015). Global Land Cover Facility: MODIS Land Cover. [online] Available at: http://glcf.umd.edu/data/lc/ [Accessed 5 Jul. 2015].

[28] FAO. 2013. FAO - Water Development and Management Unit - Information Resources -ETo Calculator. [online] Available at: http://www.fao.org/nr/water/eto.html [Accessed 20 May 2015].

[29] USDA (2015). Soil Water Characteristics: Hydraulic Properties Calculator. [online] Available at: http://hydrolab.arsusda.gov/soilwater/Index.htm [Accessed 27 May 2015].