Improving Rice Productivity and Farmers Income in Cambodia:

An Econometric Estimation Using Data from APSIM Simulator

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1. Introduction

Cambodia is located in Southeast Asia. It shares borders with Vietnam, Laos and Thailand. The size of this country is 181,035km^2. Geographically, its shape is almost like a symmetric polygon. The length from north to south is 440km and east to west is 560km. 5/6 of the border is inland border which shares with Vietnam, Laos and Thailand and 1/6 is coastal area. Land of Cambodia is categorised into four types namely coastal area, mountainous area, plateau area, and central low land area. The mountainous area is located from the west to southwest region. The plateau is located from the northwest, north to the east region. The lowland area is located around Tonle Sap Lake and the area along lower Mekong River (From Phnom Penh to Vietnam's border). Lowland proportion to total land is 1/3 (Oumsameng, Pakhu, & Malin, 2007). The advantage of this area is agriculture (rice production, subsidiary and industrial crops) and fisheries. Cambodia has two distinct seasons namely rainy season and dry season. The rainy season is from May to November and dry season is from December to April.

The size of Gross Domestic Product (GDP) Purchase Power Parity (PPP) in 2011 is USD 29.8 billion dollars (UNDP, 2013). Agricultural sector is the second biggest sector (36% of output share in GDP) just after service sector (40.7% of output share) in the economy (Asian Development Bank, 2013). Agricultural sector employs 72.2% of labour forces (Asian Development Bank, 2013). It is projected that by 2040 this sector will keep playing its vital role in Cambodia's economy by sharing 17.1% of economic outputs (the second highest sharing proportion comparing with other Southeast Asian countries, just after Laos) and employing 61.1% of labour forces (Asian Development Bank, 2013).

In agricultural sector, there are four main sub-sectors namely crop, livestock, forestry, and fisheries. Crop is a dominant sub-sector. Rice production has highest proportion in cultivation area and

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production. It is also known as the only staple crop and primary income sources for almost all population in rural area (Ministry of Agriculture, Forestry and Fisheries, 2013). More than three quarters of daily energy intake of average Cambodian is from rice (MAFF and MOWRAM, 2008). It is also the strategic crop in agricultural sector. Royal Government of Cambodia aims to increase rice surplus more than four million matrix tons and white rice for export at least one million matrix tons by 2015 (Ministry of Agriculture, Forestry and Fisheries, 2013).

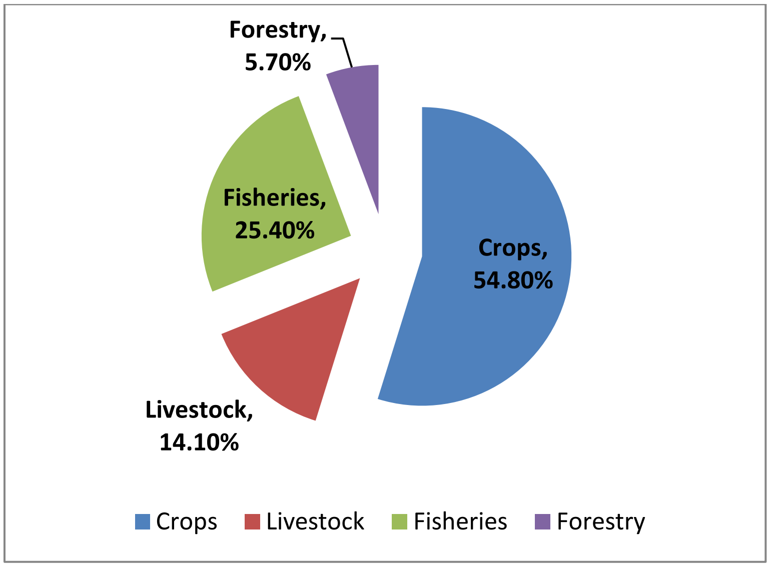

Figure 1 Sub-sectors of Agricultural Sector in 2012
Source: Ministry of Agriculture, Forestry and Fisheries, 2013

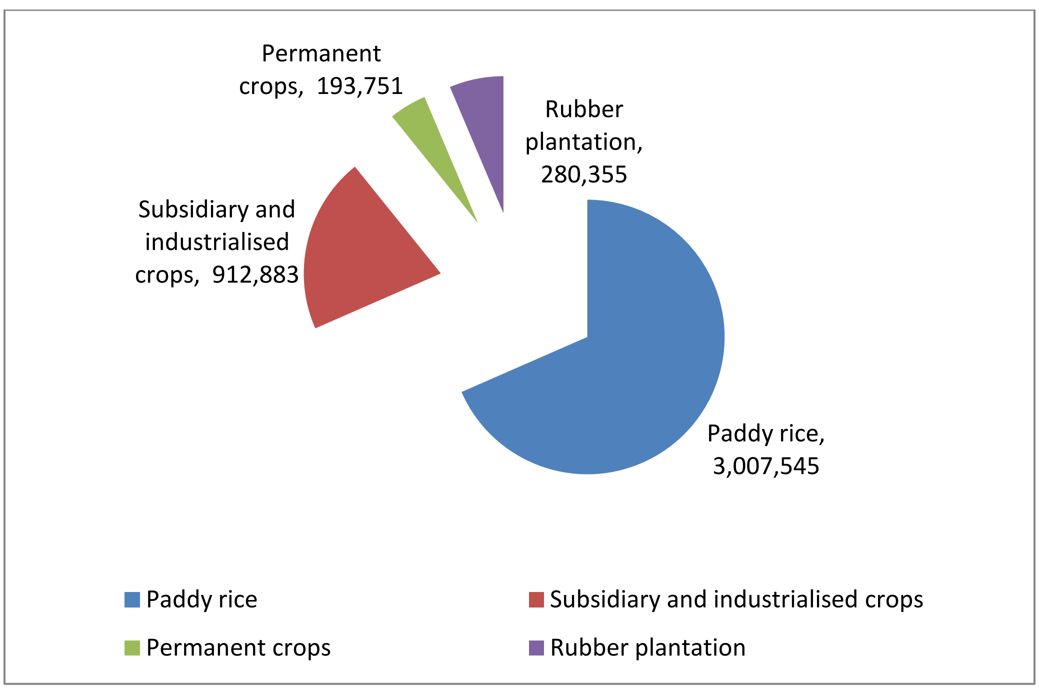

Figure 2 Cultivating areas for all crops 2012 (ha)
Source: Ministry of Agriculture, Forestry and Fisheries, 2013

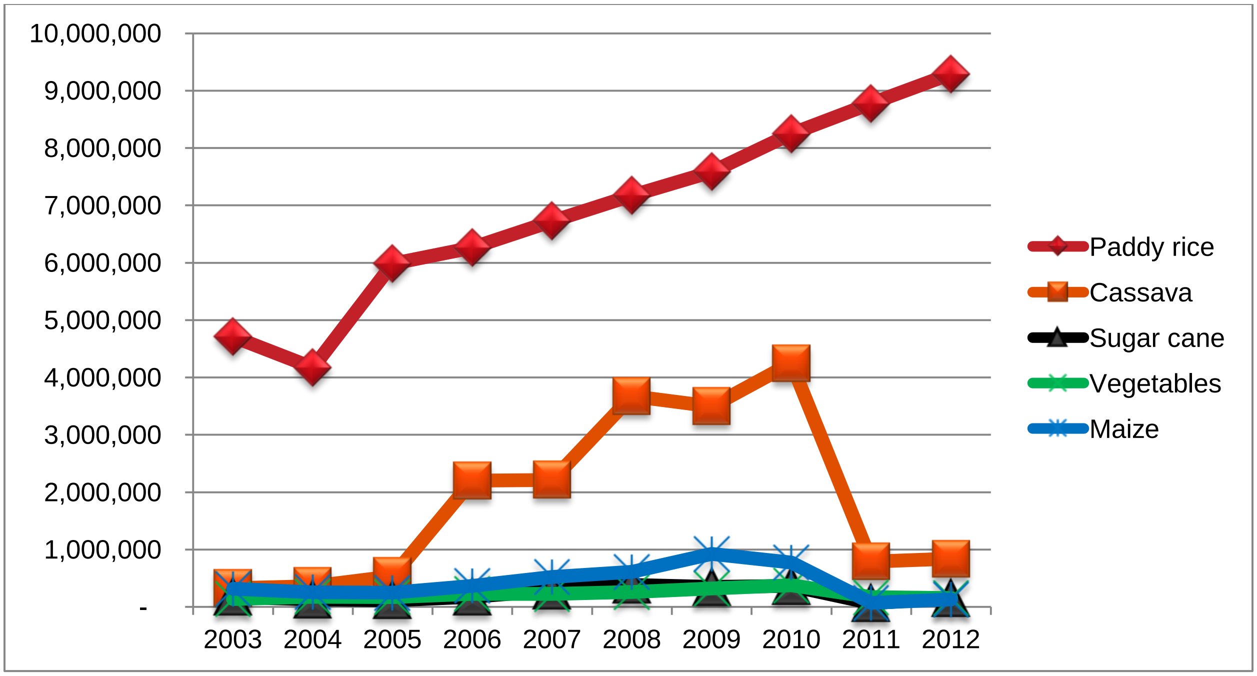

Figure 3 Trends of rice, and major subsidiary and industrial crops (Unit: MT)
Source: Ministry of Agriculture, Forestry and Fisheries, 2011 and 2013

Even though rice is the main diet and source of income, the productivity is low due to the facts that farming is still in subsistence stage and traditional way. Majority of rice farming areas rely on rainfall and its uncertainty significantly affect the production. Based on MAFF and MOWRAM (2008), Cambodia has only 19% of irrigated agricultural areas. Soil infertility is also main constraint. Most soils in rain-fed areas have poor fertility and this affect growth and productivity of plant (White, Oberthur, & Sovuthy, 1997). The report of MAFF and MOWRAM (2008) and the study of Yu and Diao (2011) revealed that farmers apply low quantity of fertiliser and this is due to their financial constraint.

Farmer income is not determined by rice productivity alone. Size of farmland is another constraint to it. Based on FAOSTAT population time series data (FAO, n.d.), in 2011, Cambodia has the ratio of arable land in hectare to agricultural population 0.43. Due to the size of average rural household is 4.6 persons (National Institute of Statistics, 2009), the evarage farming household possess 1.98 hectares of arable land. With given heavy dependence on rice production as main source of income, low productivity, and small arable land, farmers with average size of arable land and below average are barely earn enough income beyond poverty line.

The objective of this study is to investigate how farmers can increase rice productivity and farming income. It uses Agricultural Production Systems Simulator (APSIM) to simulate rice production under four production conditions namely soil types, rainfall uncertainty (i.e., above average rainfall and below average rainfall; this is to be explained in section 2.1.3.2), cultivation methods (direct seeded cultivation and transplanting methods), and fertiliser application (farmer practice quantity and agronomist recommended quantity of fertiliser application). To generate good perspective on the production, the study simulates 21 years of rice production based on meteorology and precipitation data from 1984 to 2004. With the four production conditions, the study generates 32 scenarios of rice cultivation (see in section 2.1.1) and suggests which scenario produces what level of productivity. It uses Ordinary Least Square (OLS) regression to estimate coefficients of the four production conditions that correspond to the variation of rice productivity. Under each production scenario, it finally estimates gross margins based on given yields and variable costs.

This study investigates rice production simulation under rain-fed condition. All selected areas are in arable areas that recommended for rice production. The simulation uses IR72 rice variety, the variety planted in Cambodia and calibrated in APSIM. It is an early variety of rice. This variety is similar to other early mature varieties introduced by the Varietal Recommendation Committee of Cambodia in terms of yields and maturation (Men, et al., 2001). It has yield ranges from 3.5 to six matrix tons per hectares while others have ranges from 3.5 or four tons to six or 6.5 tons per hectares.

2. Methods

2.1. APSIM's Rice Production Simulation

Agricultural Production Systems Simulator (APSIM) is a farming systems computer model that simulates the effects of environmental variables and management interventions on production (CSIRO, 2012). APSIM has proven track records in modelling crop production, environmental dynamics, cropping systems and fallow management (Carberry, Probert, Dimes, Keating, & McCown, 2002; Whitbread, Robertson, Carberry, & Dimes, 2010). APSIM-ORYZA model, the APSIM rice production simulation model, is developed under collaborative research of Wageningen University, International Rice Research Institute (IRRI), and Agricultural Production System Research Unit or APSRU (Zhang, et al., 2004). The model was developed based on ORYZA2000, one of the most intensively tested simulation model (Bouman, et al., 2001; Zhang, et al., 2004). It should be noticed that ORYZA2000 was developed under assumptions that there is no effect of crop diseases, pests, and weeds on yield (Bouman & van Laar, 2006).

Even though Zhang, et al. (2004) found that APSIM-ORYZA model is suitable to dryland soil cultivation, the testing of Zhang, et al. (2007) indicated that with ponding management and water balance, the simulation of the model in low land area is acceptable. Zhang, et al. (2007), through their rice production simulation using the model and field test comparison, also found that APSIM-ORYZA model accurately predicts rice yield in a long-term continuous rice-based production systems. The model is capable to simulate the trends of change of biomass and productivity over multi-year periods (Liu, Wang, Zhu, Tang, & Cao, 2013).

This study uses APSIM-ORYZA model to simulate rice production in Cambodia. It adopts the model assumptions, i.e., rice is well protected from weed, pest and diseases and there is no effect from these factors to yield.

2.1.1. Simulation Scenarios

Under rain-fed condition with the same rice variety, the study examines different cultivation scenarios that bring about different yields and gross marginal income. There are 32 scenarios generated from 16 simulations of APSIM. In these scenarios, rainfall is converted from continuous variable to categorical variable, i.e., above average rainfall and below average rainfall (see detail in section 2.1.3.2).

32 scenarios = 4 soil types x 2 rainfall types (above average rainfall and below average rainfall) x 2 planting methods x 2 fertiliser applications

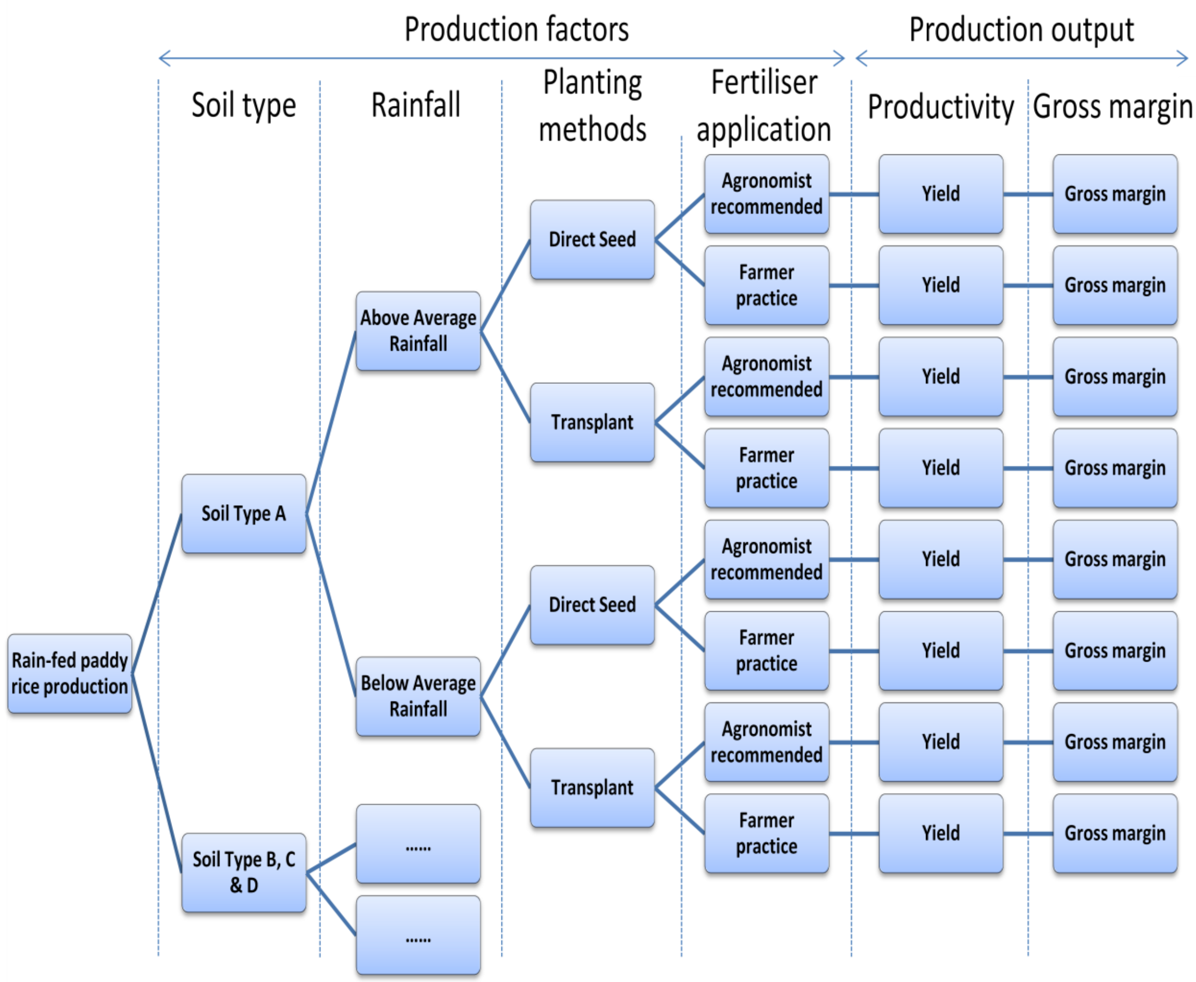

Figure 4 Mapping of Rice Cultivation Scenarios

2.1.2. Data Collections

The simulations in APSIM use mainly secondary data of Cambodia. The primary data sources are soil data of Cambodia (Bell, Seng, Schoknecht, Vance, & Hin, 2007a; Bell, Seng, Schoknecht, Vance, & Hin, 2007b; Bell, Seng, Schoknecht, Hin, & White, n.d.; Bell & Seng, 2004; Hin, Schoknecht, Vance, Bell, &

Seng, n.d.; Seng, et al., 2007) and meteorology data (Mekong River Commission, 2010; NASA Langley Research Center Atmospheric Science Data Center, n.d.).

2.1.3. Data Inputs

The simulation data input is mainly based on major data of Cambodia. A portion of soil data that is not available is replaced by existing soil data in APSIM that have the matching characteristics to soil for rice cultivation in Cambodia. To validate the reliability of simulation outputs, the average of yield from simulation is to compare with actual yield. Average yield from simulation is 2,716kg per hectare comparing to actual average yield of rice wet season cultivation of 2,540kg/ha in 2008 and 2,620kg/ha in 2009 (Ministry of Agriculture, Forestry and Fisheries, 2010), 2,760kg/ha in 2010 (Ministry of Agriculture, Forestry and Fisheries, 2011), 2,920kg/ha in 2011 (Ministry of Agriculture, Forestry and Fisheries, 2012) and 2,872kg/ha in 2012 (Ministry of Agriculture, Forestry and Fisheries, 2013). Due to the facts that data of farmer's fertiliser application is during the year 2008 (Yu & Diao, 2011), the simulation outputs is justifiable.

2.1.3.1. Soil Component:

There are four types of soil selected for the study namely Prey Khmer (World Soil Base Reference [WBR]: Plinthic Alisol), Prateah Lang (WBR: Plinthustalfs), Bakan (WBR: Ulitsol), and Toul Samrong (WBR: Haplic Vertosol) (Bell & Seng, 2004). Toul Samrong Soil is located in Battambang province, western part of Cambodia and the rest are located in Takeo province, north-eastern part of the country. These types of soils cover 62% of rice soils and are among seven major rice soils in Cambodia (Bell & Seng, 2004). Other major three rice soils for rice production namely Krakor, Kbal Po, and Kok Trap cannot be included in the simulation because there is no detailed soil profile data available.

In soil component, there are *Water*, *SoilWater*, *SurfaceOraganicMatter*, *Analysis*, and *Initial Nitrogen* nodes. Data of Cambodia (i.e., from Bell, Seng, Schoknecht, Vance, & Hin, 2007a; Bell, Seng, Schoknecht, Vance, & Hin, 2007b; Bell, Seng, Schoknecht, Hin, & White, n.d.; Bell & Seng, 2004; Hin, Schoknecht, Vance, Bell, & Seng, n.d.; Seng, et al., 2007) is used to complete Initial Nitrogen and Analysis nodes and and a part of SurfaceOraganicMatter node (i.e., total percentage of Organic Carbon). In SurfaceOrganicMatter, data of APSIM-ORYZA model, is used as a proxy data to complete proportion of fresh biomass and inert, carbon-nitrogen (C:N) ratio, root weight and eroson coefficient. Data from APSIM-ORYZA model is also used in SoilWater node except the period and length of winter and summer (it is corrected to actual period and length of seaons in Cambodia), and crop-water data in Water node. Since part of soil organic matter and crop-related water data are not available in Cambodia, APSIM-ORYZA data could be proxy data because proportion of biomass and inert in organic carbon could be similar, and carbon-nitrogen (C:N) ratio and crop-water of rice is common.

Data in Water node, apart from rice crop-water, for each simulating soil types are taken from data of soils in APSIM Soil Module that match the characteristics with the simulating soils. Prey Khmer (Bell, Seng, Schoknecht, Vance, & Hin [2007] refers this soil to Plinthic Alisols) equates to Chromosols (Morand, 2013). This is because it matches soil texture contrast (Morand, 2013, p. 172). Chromosols texture constract in B horizon is >= 5.5 of pH (Morand, 2013) and Prey Khmer has texture constrast of 6.75 in A3 horizon and 5.83 of pH in C1 horizon—no B horizon is report ((Bell R. , Seng, Schoknecht, Vance, & Hin, 2007, p.12). Data of Brown Chromosol (Daymar No.039; AP Soil No.39) is used for Prey Khmer Water node because they are in equivalent soil classifcation and have the same colour, i.e., brown colour. Prateah Lang (Bell & Seng, 2004 refers this soil as Plinthustalfs) is classified in the soil order of Alfisols (United States Department of Agriculture, 1999) that is equivalent to Ferrosols in Australian Soil Classification (Morand, 2013). Ferrosols water data in North Tropilca Coast and Tablelands, Queensland (AP Soil No.649) is used as proxy data of Prateah Lang Water node. Bakan (Bell and Seng [2004] refers this soil as Ultisols) is equivalent to Deomosols (Morand, 2013). Because Bakan has the same soil colour (grey) as Grey Domosol Belah Box (AP Soil No.41), its data of Water node is used as a proxy data in Bakan soil. Toul Samrong, the brown clayic alluvium, is categorised as Haplic Vertisols (Bell, Seng, Schoknecht, Vance, & Hin, 2007b). The water data from medium clay Generic Vertosol (AP Soil No.533 GENERIC) is used as proxy data of Toul Samrong.

Table 1 Prateah Lang properties

Depth (cm)	NO3 (ppm)	NH4 (ppm)	OC (Total%)	EC (1:5 dS/m)	PH (1:5 water)	CEC (cmol+/kg)	Ca (cmol+/kg)	Mg (cmol+/kg)	Na (cmol+/kg)	K (cmol+/kg)	Mn (cmol+/kg)	Al (cmol+/kg)
0-20	1	4	0.43	0.019	6	1.1	0.69	0.27	0.04	0.07	16.38	0.06
20-36	1	1	0.15	0.009	5.4	0.8	0.48	0.17	0.03	0.04	9.27	0.05
36-50	1	2	0.16	0.011	5.7	2.6	1.73	0.74	0.07	0.04	7.55	0.06
50-70	1	1	0.15	0.008	6	4.1	2.38	1.52	0.09	0.05	5.44	0.05
70-80	1	1	0.12	0.008	6.2	3.3	1.81	1.3	0.08	0.04	3.63	0.03

Sources: Soil Survey of the District of Tram Kak, Province of Takeo, The Kingdom of Cambodia, by (Bell, Seng, Schoknecht, Vance, and Hin (2007); Land Capability Classification for Non-Rice Crops in Soils of Banan District, Battambang Province, by Seng et al. (2007); Rainfed Lowland Rice-Growing Soils of Cambodia, Laos, and North-east Thailand, by Bell and Seng (2004)

Table 2 Toul Samrong properties

Depth (cm)	NO3 (ppm)	NH4 (ppm)	OC (Total%)	EC (1:5 dS/m)	PH (1:5 water)	CEC (cmol+/kg)	Ca (cmol+/kg)	Mg (cmol+/kg)	Na (cmol+/kg)	K (cmol+/kg)	Mn (cmol+/kg)	Al (cmol+/kg)
0-10	6	8	1.17	0.032	5.5	12.7	8.8	3.23	0.24	0.34	208	0
10-40	1	2	0.34	0.009	6.3	9.3	5.1	1.48	0.64	0.08	43.4	2.02
40-80	1	4	0.3	0.013	6.6	22.1	10.2	6.87	2.77	0.14	35	2.09
80-100	1	3	0.24	0.047	6.8	26.4	13.7	9.01	3.34	0.19	28.5	0.19

Sources: (Soil Survey of the District of Tram Kak, Province of Takeo, The Kingdom of Cambodia, by Bell, Seng, Schoknecht, Vance, and Hin (2007); Soil and Landscapes of Banan District, Battambang Province, Kindom of Cambodia, by Hin, Schoknecht, Vance, Bell, and Seng (n.d.); Land Capability Classification for Non-Rice Crops in Soils of Banan District, Battambang Province, by Seng, et al. (2007)

Table 3 Bakan properties

Depth (cm)	NO3 (ppm)	NH4 (ppm)	OC (Total%)	EC (1:5 dS/m)	PH (1:5 water)	CEC (cmol+/kg)	Ca (cmol+/kg)	Mg (cmol+/kg)	Na (cmol+/kg)	K (cmol+/kg)	Mn (cmol+/kg)	Al (cmol+/kg)
0-20	1	4	0.4	0.023	5.2	0.9	0.62	0.12	0.09	0.03	9.63	0.08
20-40	1	1	0.16	0.019	6.1	2.7	2.03	0.38	0.18	0.03	13.48	0.03
40-80	1	1	0.12	0.02	6.3	2.5	1.68	0.21	0.35	0.03	5.11	0.21

Sources: Soil Survey of the District of Tram Kak, Province of Takeo, The Kingdom of Cambodia, by (Bell, Seng, Schoknecht, Vance, and Hin (2007); Land Capability Classification for Non-Rice Crops in Soils of Banan District, Battambang Province, by Seng et al. (2007); Rainfed Lowland Rice-Growing Soils of Cambodia, Laos, and North-east Thailand, by Bell and Seng (2004).

Table 4 Prey Khmer Properties

Depth (cm)	NO3 (ppm)	NH4 (ppm)	OC (Total%)	EC (1:5 dS/m)	PH (1:5 water)	CEC (cmol+/kg)	Ca (cmol+/kg)	Mg (cmol+/kg)	Na (cmol+/kg)	K (cmol+/kg)	Mn (cmol+/kg)	Al (cmol+/kg)
0-6	2	3	0.2	0.009	5.3	0.5	0.2	0.07	0.01	0.03	3.46	0.14
6-20.	2	3	0.17	0.009	5.3	0.6	0.2	0.04	0.009	0.02	3.31	0.29
20-60	1	5	0.08	0.011	5.4	0.7	0.2	0.08	0.02	0.03	1.47	0.32
60-85	7	3	0.1	0.012	5.5	5.6	0.25	0.67	1.39	0.05	5.29	3.24
85-100	0.9	2	0.05	0.063	7.5	10.7	0.92	4.44	5.21	0.1	5.36	0

Sources: Soil Survey of the District of Tram Kak, Province of Takeo, The Kingdom of Cambodia, by (Bell, Seng, Schoknecht, Vance, and Hin (2007); Land Capability Classification for Non-Rice Crops in Soils of Banan District, Battambang Province, by Seng et al. (2007); Rainfed Lowland Rice-Growing Soils of Cambodia, Laos, and North-east Thailand, by Bell and Seng (2004)

2.1.3.2. Meteorology Component:

Continuous data of meteorology component is the determinant of maximum simulation periods. Running long term simulation requires consecutive multi-year data. This study aims to run multi-year simulation for generating in-depth perspective on rice production in Cambodia. There are four types of data to be included in meteorology component (minimum requirement) namely solar radiation, minimum air temperature, maximum air temperature and rainfall. These data are daily recorded data and have to be consecutively daily data. Solar radiation data and air temperature both minimum and maximum temperature are retrieved from online data source of NASA Langley Research Center Atmospheric Science Data Center. The usable data for the simulation is from 1984 to 2004. The data are retrieved based on based on latitude and longitude of the location (Battambang is latitude is 13.10N and longitude is 103.20E; Takeo latitude is 10.55N and longitude is 104.47E).

Rainfall data is from Mekong River Commission (Mekong River Commission, 2010). The acquired precipatation data is from Battambang, and Takeo and Kampong Thom. For the long-term simulation, rainfall data for both Takeo and Battambang is problematic. There is no regular records and it is impractical to do a long-term simulation by using this data. For example, Koh Andaet Meteorology

Station in Takeo province has rainfall records from 2001 to 2007. The usable data is only from 2001 to 2004 (usable data means the data that is in the same period as other data specifically solar radiation and air temperature). The other meteorology station, i.e., in Tram Kak district of the province, has only one year record in 2007. Battambang on the other hand, has recorded data from 1984 to 2004 for Battambang Meteorology Station but there are significant missing data with experimenting period—i.e., in 1988, 1992, 1996, 1997, 2000, and 2003. The other two station in Banan district of the province have the records only from 2000 to 2002.

Table 5 Battambang radiation and temperature (1984 – 2004)

Month	Average radiation (MJ/m^2/day)	Average daily maximum air temperature (oC)	Average daily minimum air temperature (oC)
June	18.42	29.05	24.15
July	17.99	28.88	23.88
August	17.52	28.97	23.78
September	17	28.69	23.41
October	16.99	28.39	22.84

Source: Authors calculate based on data of NASA Langley Research Center Atmospheric Science Data Center

Table 6 Takeo radiation and temperature (1984 – 2004)

Month	Average radiation (MJ/m^2/day)	Average daily maximum air temperature (oC)	Average daily minimum air temperature (oC)
June	15.82	29.24	25
July	15.15	28.97	24.67
August	14.27	29.02	24.73
September	15.05	28.8	24.44
October	15.92	28.58	24.14

Source: Authors calculates based on data of NASA Langley Research Center Atmospheric Science Data Center

The simulation uses a proxy rainfall data from Kampong Thom province. It has a good record throughout experimenting period. Kampong Thom province is located in lowland rice growing area (arable area) like Takeo and Battambang and sits in between the two experimenting provinces. The distance between Kampong Thom and Takeo is 223.61km and between Kampong Thom and Battambang is 219.97km (the straight line distance measurement by using *Ruler* tool in Google Earth). With these given geographical condition and distance, it is assumed that there is no significant precipitation variation between Kampong Thom and the two experimenting provinces.

Monthly rainfalls only from May to October (rain-fed cultivating period) within the 21 experimenting years are used to set rainfall benchmark. Average monthly rainfall from May to October of any year below this benchmark is categorised as below average rainfall and above as above average rainfall. The monthly rainfall benchmark during the experimenting years is 303.86 millimetres. There are nine below average-rainfall years and 12 above average-rainfall years.

Table 7 Precipitation of Kampong Thom (1984 – 2004)

Month	Average monthly rainfall (mm)
May	268.13
June	304.21
July	226.31
August	279.59
September	410.69
October	334.22

Source: Authors calculates based on data of Mekong River Commission (Mekong River Commission, 2010)

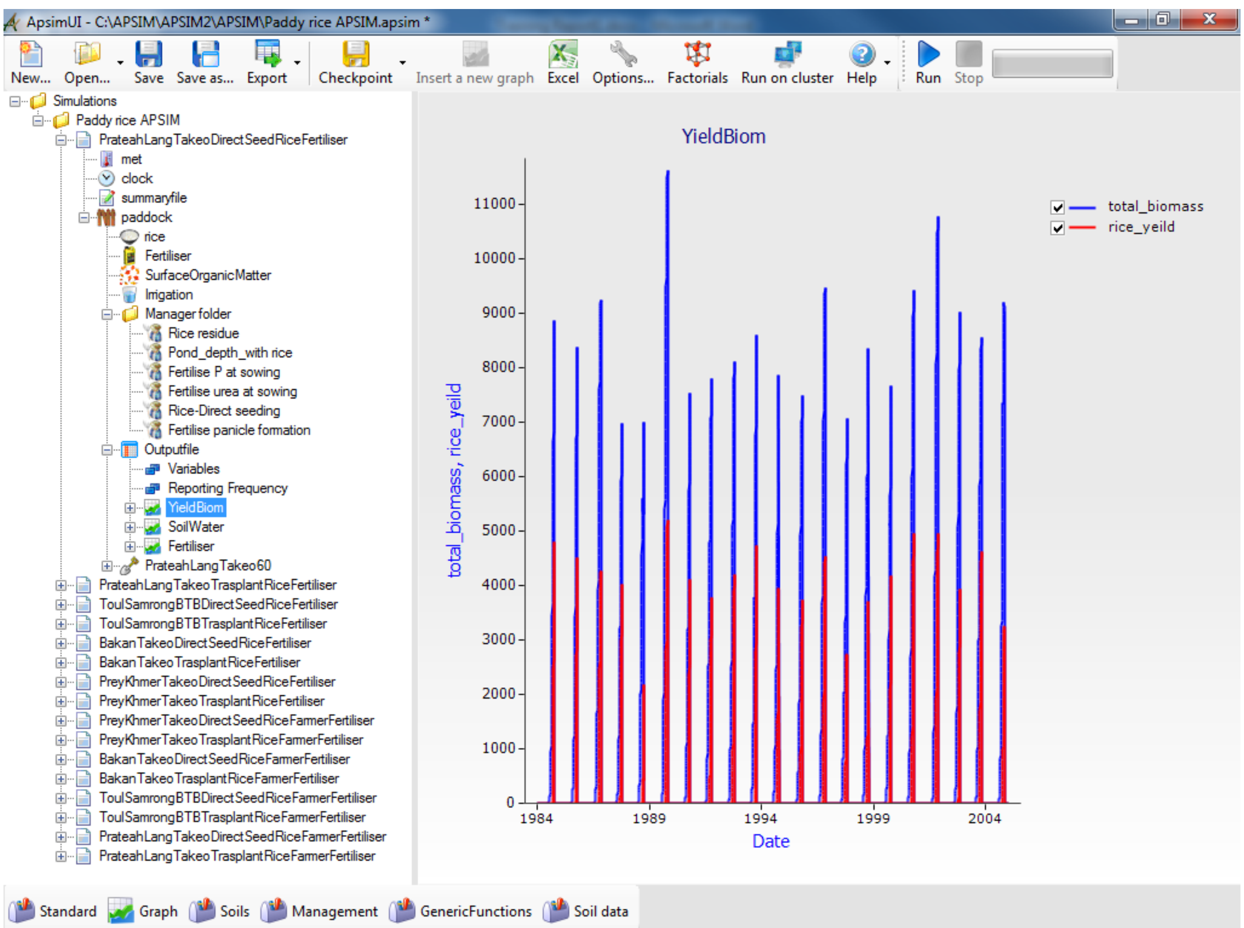

Figure 5 APSIM simulation structure

2.1.3.3. *Management Component and Surface Organic Matter*

Rice cultivation in simulation is designed to closely reflect actual cultivation and recommended farming technique. It accounts for the utilisation of residue of rice stubble, field preparation and tillage, field bund, setting window of cultivation (time of seeding and transplanting) and fertiliser application (period and recommended amount of application), and density of direct seeding and transplanting.

Field bund is applied with its height of 20cm. It sets to be functioned from 01 April so that it can keep water in field from early rainfall schedule. This means that during these periods, rice field has capacity to retain surface water up to 20cm. The exceeding water beyond this storage capacity will be runoff. Due to the simulation is under rain-fed cultivation, the irrigation is set off.

In transplanting simulations, sowing window is from 01 July to 01 August. Sowing date within sowing window is determined by rainfall, i.e., it required 50mm of rainfall within three days to satisfy sowing condition. This is true in the actual practices. Farmers wait for sufficient rainfall prior to their sowing. The simulations set 25 days of seedbed duration. For transplantation, there are three plants per hill and 25 hills per square metre (Seng, 2011).

Sowing of direct seeded cultivation simulation start from 01 July to 01 August. It requires the same rainfall as determined in transplanting simulation to satisfy sowing condition. Direct seeding uses 100kg of rice seed per hectare (Seng, 2011). Based on grain weight, i.e., 2.41 grams per 100 grain (Men, et al., 2001), the average seed per square metre in the simulations is to be 415. Germination rate affects yield of rice direct seeding. Germination rate (minimum rate) of graded seed of the variety in Cambodia is 80% (Men, et al., 2001). Due to the fact that APSIM does not account for germination rate, yield of direct seeded cultivation at post simulation will be adjusted by reducing 20%.

Fertiliser application is categorised into two types, namely, agronomist recommended quantity of fertiliser application and farmer practice of fertiliser application. Yu and Diao (2011) find that farmer practice of fertiliser application from 2000 to 2008 is up to 68kg per hectare. Agronomist recommended fertiliser application differs from one soil type to the other.

Table 8 Agronomist recommended Fertiliser Application

Soil type	Recommended N:P:K (kg/ha)[3]	Fertiliser Application in APSIM Simulation[4]	
		P (kg)	Urea (kg)[5]
Prateah Lang	100:40:80	40	217.39
Toul Samroung	120:40:00	40	260.87
Bakan	120:60:30	60	260.87
Prey Khmer	40:12:60	12	86.96

[3] Source: Paddy Rice in Cambodia], 2007.

[4] APSIM simulation based on APSIM-ORYZA model only account for nitrogen and phosphorous fertiliser. Potassium fertiliser is excluded from the simulation.

[5] Recommended nitrogen application is converted to urea: **Urea (kg) = N (kg) divided by .46** (the percentage of nitrogen in urea fertiliser)

The fertiliser application is in accordance to recommended practice. Men (2007, p. 217) recommended to apply 50% of fertiliser as basal application and other 50% during panicle period for early mature rice variety. All phosphorous fertliser is to apply as basal fertiliser application—apply all prior to direct seeding or transplanting (Men, 2007). It should be noticed that in rice-based systems, nitrogen fertiliser is often in form of urea fertiliser (Gyadon, et al., 2012).

2.2. Ordinary Least Square (OLS) Regression of Rice Yield

OLS regression is used to model the relationship between predictors (i.e., production factors) and rice yield based on data from APSIM simulations. Production factors in simulations are four soil types, fertiliser application, rainfall, planting methods, solar radiation, and air temperature. Some of these factors cannot be included in regression. Solar radiation through scatter plot graph has positive association with yield but once it is included in regression, it has negative coefficient (see **Error! Reference source not found.** and **Error! Reference source not found.**). Inclusion of air temperature variables increases constant of regression from 670 (with its exclusion) to 7,540 without solar radiation variable and 10,252 with the variable (see appendix 2). The constant is statistically significant and represent two control dummy variables, i.e., Prey Khmer soil and direct seeded planting. This is unusual regression output because the two control dummy variables have higher value than maximum value of dependent variable (6,189.1). This spoils the regression model. Solar radiation and air temperature variables are excluded from regression.

It is understandable that although solar radiation and air temperature affect yield, within their reasonable range (average radiation range from 14.27 to 18.43 MJ/M^2/day; air temperature from 22.84 to 29.24 degree Celsius), they are not statistically significant attribute to variation of yield, i.e., dependent variable. The attributes of yield therefore are soil types, planting methods, fertiliser application and rainfall.

$$Y_j = \beta_0 + \beta_1 Bakan + \beta_2 PRateahLang + \beta_3 ToulSamrong + \beta_4 Transplant + \beta_5 Fertiliser_j + \beta_6 RAINfall_j + \mu_j$$

j: observations (1, 2, 3,....n)

Bakan: Dummy variable (Bakan = 1 if the soil type is Bakan, otherwise zero)

PrateahLang: Dummy variable (PrateahLang = 1 if the soil type is Prateah Lang, otherwise zero)

Toul Samrong: Dummy variable (ToulSamrong = 1 if the soil type is Toul Samrong, otherwise zero)

Transplant: Dummy variable (Transplant = 1 if farmers use transplanting cultivation method, and zero if farmers use direct seeded cultivation method)

$Feriliser_j$: Amount of fertiliser applied (kg/ha)

$Rainfall_j$: Average monthly rainfall from May to October (mm)

2.3. Gross Margin Estimation

Overall costs of rice transplanting and direct seeding may vary. For example, transplantation method has higher labour and material costs incurred especially during transplanting period while direct seeded cultivation incurs higher seed costs than transplanting. To make gross margin investigation possible with given data from simulation, the analysis of gross margin is examined separately between direct seeding and transplanting. Following simulation scenarios, seed, labour, and material costs are considered as fixed costs. Only fertiliser cost is variable cost because quantity of fertiliser application varies—farmer's practice of fertiliser application and different quantities of fertiliser application recommended by agronomist based on soil types. These defined cost categories imply to internal comparison in both direct seeding and transplanting cultivation methods. The term gross margin for this study is not a net difference between revenue and all costs, but the different between revenue and variable cost, i.e., fertiliser cost. Fixed costs are not included in analysis.

The gross margin function therefore:

$$I_j = Y_j * P_r - F_j * P_f$$

j: observations (1, 2, 3.......n)
I_j: gross margin ($/ha)
Y_j: Yields of rice (kg/ha)
P_r: Price of rice ($/kg)
F_j: Amount of fertiliser application (kg/ha)
P_f: Price of fertiliser ($/kg)

The study compares gross marginal income among 16 simulation scenarios of direct seeded cultivation and 16 scenarios of transplanting cultivation generated from the 16 APSIM simulations. This provides insightful discussion on which scenario returns highest marginal income and under a given soil condition and rainfall variation, how can farmer obtain their highest gross margin.

3. Results

3.1. Rice Production Simulation Output Summary

Table 9 Summary of Rice Production Simulation Outputs

Description	Bakan	Prateah Lang	Prey Khmer	Toul Samrong	Average Yield
Below Average Rainfall (9 years)	**2,781.47**	**2,441.13**	**1,913.29**	**3,102.01**	**2,559.47**
Direct Seeding	**2,693.36**	**2,381.09**	**1,744.92**	**2,970.11**	**2,447.37**
Farmer Fertiliser Practice	1,747.56	1,741.83	1,598.54	1,955.34	1,760.82
Recommended Fertiliser	3,639.17	3,020.36	1,891.30	3,984.87	3,133.92
Transplanting	**2,869.57**	**2,501.16**	**2,081.65**	**3,233.91**	**2,671.57**
Farmer Fertiliser Practice	2,046.76	1,873.72	1,914.90	2,339.81	2,043.80
Recommended Fertiliser	3,692.38	3,128.60	2,248.40	4,128.00	3,299.34
Above Average Rainfall (12 years)	**2,960.37**	**2,856.61**	**1,923.19**	**3,591.24**	**2,832.85**
Direct Seeding	**2,753.84**	**2,662.47**	**1,766.27**	**3,223.74**	**2,601.58**
Farmer Fertiliser Practice	1,748.38	1,837.21	1,625.77	2,026.41	1,809.44
Recommended Fertiliser	3,759.29	3,487.73	1,906.76	4,421.07	3,393.71
Transplanting	**3,166.91**	**3,050.74**	**2,080.12**	**3,958.74**	**3,064.13**
Farmer Fertiliser Practice	2,061.87	2,167.33	1,932.53	2,594.92	2,189.16
Recommended Fertiliser	4,271.95	3,934.15	2,227.70	5,322.56	3,939.09
Average Yield	**2,883.70**	**2,678.54**	**1,918.95**	**3,381.57**	**2,715.69**

Data source: from 16 simulations of Cambodia's Rice APSIM. Note: Unit of rice productivity is in kg.

Table 9 Summary of Rice Production Simulation Outputs provides average rice yield cultivated in the four soil types, under two categorised rainfall (below average and above average rainfall), cultivation methods and fertiliser applications. The table indicates yield comparison from different point of view. From soil point of view, cultivating on Toul Samrong soil gains highest yield (3,381.57kg per hectare in average) in all categories comparing to cultivation on other soils. Second and third level of productivity is respectively obtained from the cultivation on Bakan and Prateah Lang soils. Prey Khmer obtains lowest yield.

From rainfall point of view, productivity of rice during above average rainfall periods increases more than 400kg for Toul Samrong and Prateah Lang soils, and 179kg for Bakan soil. There is small increase of yield during above average rainfall cultivation periods comparing with yield during below average rainfall periods for Prey Khmer soil. From fertiliser application point of view, when farmer applies agronomist recommended quantity of fertiliser, yield increases by 78% (below average rainfall) and 88% (above average rainfall) for direct seeding cultivation, and 61% (below average rainfall) and 80% (above average rainfall) for transplanting. This table only illustrates yields difference under different production factors. It does not explain which factor contributes what level of productivity.

3.2. OLS Regression Result of Rice Yield

Table 10 Descriptive Statistics

Descriptions	Mean	Std. Deviation	N
Yield	2715.69	1154.80	336
Bakan dummy	.25	.434	336
Prateah Lang dummy	.25	.434	336
Toul Samrong dummy	.25	.434	336
Transplanting dummy	.50	.50	336
Fertiliser (kg/ha)	156.26	107.79	336
Average monthly rainfall May – October (mm)	303.86	68.20	336

Data source: from 16 simulations of Cambodia's Rice APSIM

There are 336 observations obtained from APSIM simulations are used in Ordinary Least Square Regression (OLS). The average rice yield from the simulation is 2,716kg per hectare. There are four types of soil in the analysis. Each soil shares 0.25 of proportion to the total soil. Bakan, Prateah Lang, and Toul Samrong are experiment variables and are indexed as dummy while Prey Khmer soil plays as control variable. In cultivation method, Transplanting dummy variable is experimenting variable with the proportion of .5 and Direct Seeding dummy is control variable with the same proportion to Transplanting dummy. The average fertiliser application is 156kg per hectare, 2.29 times more than level of fertiliser application practised by farmers. Average monthly rainfall from May to October from 1984 to 2004 is 303.86 millimetres.

Regression analysis has significant level at .000 with adjusted R square at .766. This means the regression model is highly significant. The model accounts for 76.6% of the variability in the yield variable. The constant value, Toul Samrong dummy, Transplanting dummy, and Fertiliser is significant at 0.1% and average rainfall from May to October is significant at 1%. Their coefficients are positively associated with dependent variable, i.e., Yield. Bakan dummy and Prateah Lang dummy are not significant. Their coefficients are positively associated with Yield variable.

The value of constant is significant. It represents two control factors namely Prey Khmer soil and Direct Seeding (the dummy variables set to be zero at all cases). The aggregated value is 670. This means Prey Khmer soil and Direct Seeding contribute the net increase of yield by 670kg per hectare.

Table 11 Ordinary Least Square Regression

Model	Unstandardised Coefficients B	Unstandardised Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
Dependent variable: Yield (kg/ha)					
(Constant)	670.059	154.391		4.340	.000 ***
Bakan dummy	16.309	92.857	.006	.176	.861
Prateah Lang dummy	82.468	89.683	.031	.920	.358
Toul Samrong dummy	599.657	91.755	.225	6.535	.000 ***
Transplanting dummy	360.399	60.994	.156	5.909	.000 ***
Fertiliser (kg/ha)	8.548	.310	.798	27.587	.000 ***
Average monthly rainfall May – October (mm)	1.169	.448	.069	2.610	.009 **
F (6,329) = 183.427					
Adjusted R square = .766					
Sign. = .000					

Data source: from 16 simulations of Cambodia's Rice APSIM

Note: "*" significant at 5%, "**" significant at 1%, and "***" significant at 0.1%.

Bakan and Prateah Lang soils increase yield respectively by 16.3 kg/ha and 82.47kg/ha more comparing to Prey Khmer soil but these are not statistically significant. It means there is not statistically significant difference of yield contributed by Bakan, Prateah lang or Prey Khmer soils. Cultivating rice on Toul Samrong soil however significantly increase yield by 600kg per hectare more than Prey Khmer soil.

Fertiliser application is significantly contribute to yield increase. Its coefficient is 8.55. It means that each kilogram of fertiliser application increases rice yield by 8.55kg. With the estimated price of rice (900Riels or 0.225USD per kilogram) and price of fertiliser (3000 Riels or 0.75USD per kilogram), each single kilogram of fertiliser application will raise farmer income by 2.56 times over the cost it incurs.

Rainfall is positively correlated with the increase of rice yield. Its coefficient is 1.17. It means each millimetre of monthly rainfall during May to October increases yield by 1.17kg per hectare. Under rain-fed cultivation, rainfall is crucial to the production and its each millimetre significantly contributes to the yield.

3.3. Gross Margin of Rice

The gross margin is obtained from yields times its price deducts fertiliser cost. The cost of fertiliser recommended by agronomist applied in Bakan soil is 240.65USD and Toul Samrong soil is 225.65USD almost five times higher than cost of fertiliser that farmers generally bear. Cost of recommended fertiliser application for Prateah Lang soil is almost four times while for Prey Khmer is only 50% higher than farmer's usual cost.

Table 12 Fertiliser Cost

Fertiliser application	Fertiliser quantity (kg/ha)	Cost (USD/ha)[6]
Recommended application for Prateah Lang soil	257.39	193.04
Recommended application for Toul Samroung soil	300.87	225.65
Recommended application for Bakan soil	320.87	240.65
Recommended application for Prey Khmer soil	98.96	74.22
Farmer's practice (for all soil types)	68.00	51.00

Table 13 illustrates average gross marginal income of the 32 simulation scenarios. Columns of the table illustrate soil types and rows illustrate rainfall (below average rainfall and above average rainfall), planting methods and fertiliser application.

Table 13 Average Gross Marginal Income of Direct Seeded Cultivation (in US dollar)

Descriptions	Bakan	Prateah Lang	Prey Khmer	Toul Samrong	Average Gross Margin
Below Average Rainfall	**460.18**	**413.72**	**330.00**	**529.95**	**433.46**
Farmer Fertiliser Practice	342.20	340.91	308.67	388.95	345.18
Recommended Fertiliser	578.16	486.54	351.32	670.94	521.74
Above Average Rainfall	**473.79**	**477.03**	**334.80**	**587.01**	**468.16**
Farmer Fertiliser Practice	342.39	362.37	314.80	404.94	356.12
Recommended Fertiliser	605.19	591.70	354.80	769.09	580.19
Average Gross Margin	**467.96**	**449.90**	**332.74**	**562.56**	**453.29**

Data source: from 16 simulations of Cambodia's Rice APSIM
Note: Price of rice is 900 Riels or 0.225USD per kilogram. The gross margin = yield * price of rice – fertiliser * fertiliser cost

For comparison of gross margins across soil types, Toul Samrong soil returns highest gross marginal income in all cases, Bakan soil return second highest except cases that farmer apply fertiliser based on their practices and under above average rainfall (Prateah Lang soil provides higher yield). Prateah Lang soil returns gross margins slightly below gross margin from cultivation on Bakan soil and Prey Khmer soil is the lowest one.

[6] Cost of fertiliser is 3,000 Riels or 0.75USD per kilogram

Table 14 Average Gross Marginal Income of Transplanting Cultivation (in US dollar)

Descriptions	Bakan	Prateah Lang	Prey Khmer	Toul Samrong	Average Gross Margin
Below Average Rainfall	**499.83**	**440.74**	**405.76**	**589.30**	**483.91**
Farmer Fertiliser Practice	409.52	370.59	379.85	475.46	408.85
Recommended Fertiliser	590.13	510.89	431.67	703.15	558.96
Above Average Rainfall	**566.73**	**564.40**	**405.42**	**752.39**	**572.23**
Farmer Fertiliser Practice	412.92	436.65	383.82	532.86	441.56
Recommended Fertiliser	720.54	692.14	427.01	971.92	702.90
Average Gross Margin	**538.06**	**511.40**	**405.56**	**682.50**	**534.38**

Data source: from 16 simulations of Cambodia's Rice APSIM
Note: Price of rice is 900 Riels or 0.225USD per kilogram. The gross margin = yield * price of rice – fertiliser * fertiliser cost

In direct seeded cultivation, by complying agronomist recommended quantity of fertiliser application, gross margin on Toul Samrong soil increases from 388.95USD to 670.94USD (73% of increase) during below average rainfall cultivation periods and 404.94USD to 769.09USD (90% of increase) during above average rainfall periods. Bakan soil increases from 342.20USD to 578.16SUSD (69% of increase) during below average rainfall and from 342.39USD to 605.19USD (77%) during above average rainfall. Prateah Lang gains lower increase during below average rainfall periods—i.e., 340.91USD to 486.54USD—but similar increase during above average rainfall periods. Gross margin from Prey Khmer Soil obtains modest increase—from 308.67USD to 351.32USD (14% of increase) during below average rainfall cultivation periods and 314.80USD to 354.80USD during above average rainfall periods.

In transplanting cultivation, like direct seeded cultivation, gross margin of production followed agronomist recommended quantity of fertiliser application is higher than farmer practices. Gross margin from cultivation on Toul Samrong soil increases from 475.46USD to 703.15USD (48% of increase) during below average rainfall periods and from 532.86USD to 971.92USD (82%) during above average rainfall. Gross margin from Bakan soil increases from 409.52USD to 590.13 (44%) during below average rainfall and from 412.92USD to 720.54USD (74%) during above average rainfall period. Gross margin from Prateah Lang soil is a bit smaller increase than Bakan soil for both above average and below average rainfall cultivation periods. Prey Khmer soil increases gross margin less than 100USD both in above average and below average rainfall cultivation periods and it gains lowest return among the four experimenting soil.

4. Discussion

4.1. Rice Productivity

Recalling the result of OLS regression, regression constant in which represent two control dummy variables namely Prey Khmer soil and direct seeded cultivation significantly contribute to rice yield. It is interesting that Prateah Lang and Bakan soils do not have statistically significant attribute to yield comparing with Prey Khmer although the simulations indicate that cultivation on the two soils produce higher yield than Prey Khmer. In facts, these soils have small variation in nutrients.

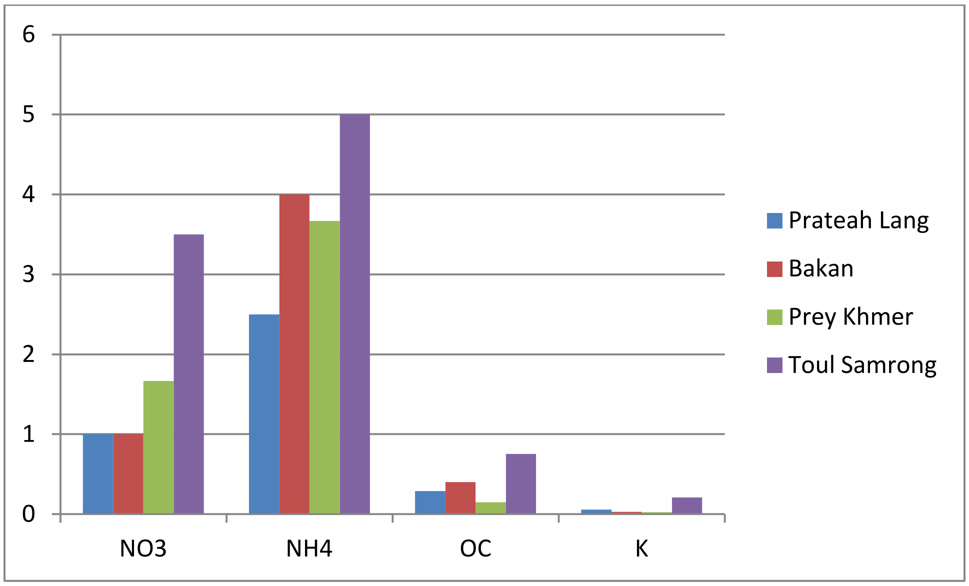

Figure 6: Average Nutrients Comparison in A horizon
Prey Khmer, Prateah Lang, Bakan and Toul Samrong soils

Note: unit of NO3 and NH4 is mg/kg; Organic Carbon (OC) is % in total soil; potassium (K) is cmol+/kg

Toul Samrong soil has high attribute to the increase of yield. Because this soil has highest nutrient balances comparing to other three soil types. By cultivating on this soil in the same condition as Prey Khmer, farmer can get extra yield of 600kg per hectare more than Prey Khmer.

Different level of rice yield attributed by each soil type provides insight about soil contribution to rice productivity. It does not necessarily mean that farmer should move their cultivation to better soil. It is good awareness for farmer to know about fertility of his soil and how it contributes to yield. One of main observable aspects that make productivity in Toul Samrong significantly higher than other soils is availability of nutrient balances for plant. Farmer cultivates on any soil can improve his soil nutrient balances. Managing rice stubble or crop residues and fertiliser application may increase available nutrients in soil in the long term. Residue retention influences the amount of nutrients return to soil and increases organic carbon specifically for slowly decomposing residue (Whitbread, Blair, Konboon, Lefroy, & Naklang, 2003).

Rainfall significantly contributes to yield. Each average millimetre of average monthly rainfall during cultivation period increases 1.169kg of rice yield. Monthly rainfall benchmark determined in APSIM simulation of this study contributes to 355.21kg of rice yield. Although it has a modest contribution to yield, it attributes to survivability of rice. Therefore, when there lacks rainfall, alternative water supplies should be available. Apart from big scale irrigation system that could never be built by farmers per se, constructing pond is part of farm is suggested as alternative water source. This will help farmers to harvest rain in especially early rainy season for irrigating to rice field specifically during short dry period that normally occur in July—just a month or so after rice seeding. Based on experimenting data from 1984 to 2004, the average rainfalls that could be harvested in May and June—just prior to short dry period—are 268.13mm and 304.21mm respectively. If these are well harvested and managed in pond, this water supply could help rice to survive during short dry period in the middle of rainy season.

Shifting from direct seeded cultivation to transplanting significantly increases yield by 360kg per hectare. With this given benefit, farmer can select their cultivation methods, i.e., whether to do direct seeded or transplanting cultivation. With unknown data on costs of seed, labour, materials and inputs except fertiliser, the finding on productivity difference among these cultivation methods does not provide a complete sense whether transplanting is better than direct seeded cultivation.

Fertiliser application is another production factor that is in control of farmer besides planting methods. Each kilogram of fertiliser application increases yield by 8.548kg. Putting this variable into perspective, applying 257.39kg/ha of fertiliser in Prateah Lang soil as recommended by agronomist contributes to rice yield by 2,200.17kg/ha, applying 300.87kg/ha of fertiliser in Toul Samrong soil contributes to yield by 2,571.84kg/ha, applying 320.87kg/ha of fertiliser in Bakan soil contributes to yield by 2,742.80kg/ha, and 98.96kg/ha of fertiliser in Prey Khmer soil contributes to yield by 845.91kg/ha. Farmer's level of fertiliser application (i.e., 68kg/ha) produces yield by 581.26kg/ha. It is a dominated determinant of rice yield.

Comparing with farmer practice of fertiliser application, small incremental increase of fertiliser application results to moderate increase in rice productivity. This infers to small increase of recommended fertiliser application comparing with farmer practice of fertiliser application on Prey Khmer soil. Based on Soil nutrient balances as shown in Figure 6, soil nutrient balances of Prey Khmer, Prateah Lang and Bakan have no big variation. The productivity on the three soils with the same amount of fertiliser application—i.e., farmer's practice on fertiliser application—is also not widely dispersed. In direct seeded cultivation, rice productivity on Prateah Lang soil is 143.29kg/ha higher than productivity on Prey Khmer soil during below average rainfall and 41.18kg/ha lower Prey Khmer's during above average rainfall. Productivity on Bakan soil is 149.01kg/ha and 131.86kg/ha higher than Prey Khmer during below average and above average rainfall respectively. In transplantation, Bakan productivity is around 120kg/ha and Prateah Lang is 235kg/ha more than Prey Khmer. Agronomist recommended quantities of nitrogen fertiliser application make yields from Prey Khmer soil widely lower than Bakan and Prateah lang soils. Agronomist recommends application of nitrogen fertiliser 100kg per hectare for Prateah Lang soil, 120kg per hectare for Bakan soil and 40kg per hectare for Prey Khmer. It is argueable that low nitrogen fertiliser application on Prey Khmer may cause low productivity comparing with Bakan and Prateah Lang.

Interesting discussion in regards to this point is that why does farmer not apply quantity of fertiliser as recommended by agronomist. Based on the Ministry of Agriculture Forestry and Fisheries (MAFF) and Ministry of Water Sources and Meteorology (MOWRAM, 2008; as cited in Yu and Diao [2011]), financial constraints in the main reason of underfertilisation in Cambodian agriculture. With a given cost of fertiliser ranging from 75USD to almost 250USD, subsistence farmers in the country with 45.9% of population in multidimensional poverty and 22.8% of population earn less than 1.25USD a day (UNDP, 2013) are barely acquire it. There must be support from government or institutional arrangement that helps farmers to access to fertiliser. This is to be discussed in section 4.3.

4.2. Gross margin

Increase of estimated gross margins is parallel to increase of productivity within both direct seeded cultivation method and transplanting methods. The main production factor contributes to gross margins in fertiliser application for both direct seeded cultivation and transplanting methods, i.e., applying agronomist recommended fertiliser application returns higher gross margin than farmer practices of fertiliser application.

In farmer practice of fertiliser application simulations, cultivation conditions across all scenarios are the same except the cultivations are on four different soil types. The variation of gross margins from the four soil types is relatively small especially among Prey Khmer, Bakan and Prateah Lang soils which only have small difference in soil nutrient balances. Gross margin variation from the three soils is less than 53USD. In agronomist recommended fertiliser application simulation, because recommended quantities of fertiliser application are widely different across soil types, the gross margins obtaining from each specific soil are widely dispersed. With compliance of agronomist recommended quantity of fertiliser application, gross margins obtaining from cultivation on all soils are increased, but in diverse rate. Gross margin obtaining from yield on Toul Samrong soil increases from 281.99USD to 439.06USD depending on rainfall conditions and cultivation methods. Gross margin obtaining from Bakan soil cultivation increases from 180.61USD to 307.62USD and Prateah Lang soil cultivation increases from 140.30USD to 255.49USD. Gross margin obtaining from Prey Khmer soil cultivation increases only from 40USD to 51.82USD.

Agronomist recommended fertiliser application substantially increases gross margin. With the case of recommendation of fertiliser application on Prey Khmer soil, it is learned that increasing fertiliser application by a small quantity will increase the gross margin moderately.

4.3. How to help farmers improving farm productivity and increasing income?

This study proves that helping farmer able to apply fertiliser as recommended by agronomist will significantly improve rice productivity. As discussed in previous section (section 4.1), poor farmer is hardly to cope with the cost. Generating sufficient income is another issue. Having high productivity and earning high gross marginal income per hectare do not assure farmers generate good income—they must have reasonable size of farm to ensure good return from farm. FAO (2000) indicates that the ratio of agricultural population to actual arable land is 0.5. This implies average farmer own very small plot of cultivating land. Cambodia has potential to increases this ratio up to 1.7 (FAO, 2000). Cambodia therefore utilises only 29.41% of its arable land for agricultural production. With potentially available arable land, government can help farmers to expand culitaving land more than three times.

This study proposes some recommendations to improve farmer productivity and increase agricultural income. To increase productivity by sufficient access to fertiliser, it is suggested to establish and strengthen agricultural institution that promote farmer's self-help innitiatives. For example, creating agricultural cooperative may help farmers to do collective saving so that they can uses it for purchasing fertiliser. Promoting contract farming is another option. Through contractual arrangement that typically involve supplies of agricultural inputs from contractor, farmers could outsource their farming business. Lastly, government should consider a certain level of fertiliser subsidy to especially poor farmers who are barly able to have alternative way in access to fertiliser. Data from Indentification of Poor Households Program, or IDPoor (Ministry of Planning, 2006) will help government identifying who should be eligible for subsidy program. Related to farmer's income, government policy related to farmland expansion of smallholder farmer is vital. Instead of land provision to agro-industrial companies in form of economic land concession that causes many controversal issues in the country, government should consider helping farmers to get more farm land. Having access to more land, farmers can generate good return for their livelihood. There are still window of opportunities for private companies to invest in agricultural sector especially through supporting farmers to plant better produces, and procuring agricultural produces, processing, distributing and marketing them. Through this scenario, everyone wins—farmers produce more, private companies invest better, and government can have more tax. Lastly, it is recommended to extend utilisation of APSIM in Cambodia agricultural production simulation. Using APSIM really provides noticeable perspectives in development of agricultural production systems especially for agrarian country like Cambodia. Utilising APSIM is not just about making simulation models for different crops in different areas, it is also about debating how the models predicting accurately and what does it mean for farmers.

Having productivity and income increased, farmers as net food purchasers except rice can increase their acess to nutritous food and improve their nutrition status.

5. Conclusion

Through 16 APSIM simulations and regression analysis, it is found that agronomist recommended quantity of fertiliser application, rainfall and nutrient balances in soil are significantly associated with increase of rice productivity. Transplanting cultivation method gains higher yield than direct seeded cultivation. Fertiliser is the main attribute to rice productivity. Based on regression analysis, agronomist recommended quantity of fertiliser application alone (no inclusion of other production factors) contributes to yield by 2,571.84kg/ha on Toul Samrong soil, 2,200.17kg/ha on Prateah Lang, 2,742.80kg/ha and 845.91kg/ha to Prey Khmer. Increasing fertiliser application contributes to increasing both productivity and gross margin. In contrary, small addition of recommended fertiliser application will result to moderate increase of yield and gross margin.

The underlying challenge for farmers to increase their productivity and income is limited access to fertiliser due to their financial constraint and small plot of cultivating land. To support farmer access to fertiliser, building and strengthening farmer self-help institution like agricultural cooperative will help farmers coping financial constraint, e.g., through collect saving. Contract farming and government subsidy are other alternative ways in supporting farmer access to fertiliser. Increasing productivity alone does not ensure profitable return to farmers. It is suggested that government should have policy that help smallholder farmers access to more farmland. There is less than one third of arable land used in agricultural production. More than two thirds can be used for the proposed policy.

There is an arguable perspective on recommended quantity of nitrogen fertiliser application for Prey Khmer soil—i.e., the low recommended quantity of fertiliser application on this soil comparing with other three experimenting soils is the cause of low productivity. There should be further investigation on the recommended nitrogen fertiliser application on Prey Khmer soil.

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