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Using linear programming to optimize rice yields in Battambang, Cambodia

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សង្ខិត្តន័យ

កសិករកម្ពុជាបានអនុវត្តនូវវិធីសាស្ត្របុរាណក្នុងការជ្រើសរើសទម្រង់ដាំដុះដំណាំស្រូវរាប់ជំនាន់មកហើយ។ ប៉ុន្តែគួរឱ្យស្តាយ ទម្រង់ដាំដុះបែបនេះផ្តល់ទិន្នផលទាប។ ដើម្បីទទួលបានទិន្នផលខ្ពស់បំផុត កសិករត្រូវចេះគ្រប់គ្រងផ្ទៃដីដាំដុះឱ្យបានត្រឹមត្រូវ។ វិធីសាស្ត្រកំណត់តម្លៃបរមាតែងត្រូវបានប្រើប្រាស់នៅពេលដែលមានធនធានស្តួចស្តើងដូចជាផ្ទៃដីដាំដុះ ដើមទុន កម្លាំងពលកម្ម ជី និងគ្រាប់ពូជជាដើម។ ការសិក្សានេះផ្តោតសំខាន់ទៅលើរបៀបបែងចែកផ្ទៃដីដាំដុះដើម្បីទទួលបានផលស្រូវអតិបរមា។ ចំណោទបរមារកទិន្នផលស្រូវត្រូវបានបង្កើតឡើងទាក់ទងនឹងស្រូវបីប្រភេទគឺ សែនក្រអូប ផ្ការំដួល និងស្រូវស IR504។ វិធីសាស្ត្រគណិតវិទ្យា Linear Programming ត្រូវបានប្រើប្រាស់ដើម្បីបង្កើតគំរូនិងរកចម្លើយអតិបរមា។ លទ្ធផលសិក្សាទៅលើផ្ទៃដីដាំដុះក្នុងតំបន់មួយនៃខេត្តបាត់ដំបង ដែលទទួលបានពីគំរូនេះបានបង្ហាញនូវលំនាំនៃការដាំដុះមួយដែលផ្តល់ទិន្នផលខ្ពស់បំផុតចំពោះស្រូវទាំងបីប្រភេទនេះ។ ការវិភាគបម្រែបម្រួលទិន្នផលស្រូវសរុបត្រូវបាន

អនុវត្តដោយធ្វើបម្រែបម្រួលទិន្នផលមធ្យមនៃប្រភេទស្រូវនីមួយៗក្នុងគំរូដាំដុះនោះ។ លទ្ធផលបង្ហាញថា អ្វីៗមានសភាពដូចគ្នា។ មានន័យថា បើទិន្នផលមធ្យមរបស់ស្រូវសែនក្រអូបប្រែប្រួល ±10% នោះទិន្នផលស្រូវសរុបនឹងផ្លាស់ប្តូរប្រហែល ±7.68% ដែរ។ ចំពោះស្រូវផ្ការំដួលក៏ដូចគ្នាដែរ។ បើទិន្នផលមធ្យមនៃស្រូវផ្ការំដួលប្រែប្រួលក្រោម 4101.65 Kg/Ha ទិន្នផលសរុបមិនប្រែប្រួលទេ។ ចំណែកឯទិន្នផលមធ្យមនៃស្រូវពីរប្រភេទទៀតមិនត្រូវបានផ្លាស់ប្តូរ។ ចំពោះស្រូវស IR504 ក៏ដូចគ្នាទាំងអស់ដែរ។ បើទិន្នផលមធ្យមប្រែប្រួលក្នុងកម្រិត ±10% ទិន្នផលមធ្យមនៃស្រូវពីរប្រភេទទៀតប្រែប្រួលក្នុងកម្រិត ±2.24%។ លទ្ធផលនៃការសិក្សានេះនឹងផ្តល់ជំនួយដល់កសិករកម្ពុជាក្នុងការជ្រើសរើសទម្រង់ដាំដុះដែលផ្តល់ទិន្នផលខ្ពស់បំផុត។

Abstract

Cambodian farmers have been applying traditional techniques for selecting cropping patterns of rice production for generations. Unfortunately, current cropping patterns provide low yields. For the producing maximum rice yields, land resources need to be managed efficiently. Optimization techniques are often used for resource management when there is limited availability of land, capital, labor, and inputs; such as fertilizers and seeds. This study considers how to optimize the use of land resources to produce optimal rice yields. This problem was formulated for three varieties of rice: *sen kro ob* (fragrant rice), *phka romdoul* (premium fragrant rice), and *IR504* (white rice). A linear programming method was then used to model and determine an optimal solution. The results from this model demonstrate an ideal cropping pattern for the three varieties of rice aimed at achieving a maximum rice yield in the study area of Battambang. A sensitivity analysis was performed on these results by varying the average rice yield of each type of rice in the model. All things being equal, if the average yield of *sen kro ob* was changed by ±10%, the optimal rice yield varied by ±7.68%. Similarly, all things being equal, if the average rice yield of the *phka romdoul* was at any value below 4101.65 kg/ha, the optimal rice yield would be unchanged. Finally, all things being equal, if the average yield of *IR504* was modified by ±10%, the optimal rice yield would vary by ±2.24%. These findings will assist Cambodian farmers to select cropping patterns that are more likely to achieve a maximum possible rice yield.

Keywords: rice, *sen kro ob*, *phka romdoul*, IR504, optimization, Cambodia

Introduction

Within Southeast Asia, Cambodia's economy is one of the most dependent on agricultural production. Rice is one of the most important crops and contributed roughly 17% of the country's GDP in 2014 (Goletti & Sin, 2016). Rice production and associated markets are estimated to provide jobs for around three million Cambodian citizens (MAFF, 2017). Rice is still a staple food for many in the country and it is a crop that is still highly significant in contributing to food security, political security, as well as national socio-economic development when surplus production is exported. Cambodia has realized a remarkable increase in rice exports over the past decade. For instance the country formally exported 100,000 metric tons of milled rice in 2010; 378,000 metric tons in 2013; 542,144 metric tons in 2016; and in average 600,000 metric tons annually between 2016 and 2018 (CRF, 2020).

As a lower middle income economy, Cambodia previously enjoyed duty-free exports to EU markets under the Everything-But-Arms (EBA) trade scheme, up until 2019. Under this scheme, the around 48% of Cambodia's total rice surplus was exported to the EU 2012 and 2018 (MAFF, 2017). However, these exports fell sharply in 2019, following the imposition of tariffs. Six months after the introduction of these tariffs, rice exports to the EU were reduced by 32%, compared to the same period of the previous year

(93,503 metric tons) (SOWS-REF, 2019). This adversely affected almost 500,000 families in Cambodia, who were highly dependent on rice production for their livelihood (CRF, 2020). In January 2020, rice exports to the EU decreased by a further 15%, or 22% compared to the same period in 2019. This reduced the total revenue from rice exports in January 2020 in Cambodia to only $39 million. The country is predicted to lose about 50 million USD per annum, as a result EU tariffs (CRF, 2020).

The land area that rice was cultivated on in Cambodia was estimated to be 3.052 million hectares in 2016, accounting for 74% of the total land area under cultivation (MAFF, 2017). An average yield of 3.117 tons per hectare means that the country produces a total volume of around 9.29 million tons of rice per annum. While a significant proportion of this is used for to meet domestic needs, there is a surplus of around 4.7 million tons (3 million tons of good rice) per annum that is exported to international markets (MAFF, 2017).

In 2010, the Cambodian government pledged to increase rice production in line with an export target of one million tons per year by 2015. However, this target is yet to be reached, with exports in 2018 amounting to just 626,225 metric tons (OCM, 2019). The failure to achieve this target has been a result of inconsistent paddy quality and poor post-harvest management (CRF, 2020). Many farmers still adopt traditional techniques that have been passed down over generations (Srean et al., 2018). While these techniques may be enhanced with access to high-tech farming practices, investment in research and development for rice production is still limited (CRF, 2020). One challenge that exists for many farmers is not having the capacity to determine optimal cropping patterns to maximize rice yields. Additionally, the quality of rice produced in Cambodia is often not in line with international standards, which results in lower prices being achieved in the market place.

Effective land management practices, including an improved capacity to select optimal cropping patterns for rice production (Shreedhar, 2018), may be a solution to increasing rice yields under these current constraints. To date, there has been no research conducted on the use of linear programming methods to optimize the rice yields in Cambodia. In this study, an optimization model has been developed to determine the most effective cropping patterns for maximizing the combined yield of three specific rice varieties. This problem was formulated previously using linear programming to determine cropping patterns that would produce optimal yields for multiple crops (Shreedhar, 2018).

The study places extra constraints on some resources in this model to determine an optimal pattern for maximizing the net benefits of rice production in Battambang, Cambodia. It builds on the use of linear programming to improve the management of land and water resources in Egypt through the use of optimal cropping patterns (Osama et al., 2017). The model was first tested on a hypothesized area of 1,000 ha using actual data collected from Battambang, which may later be extended to larger areas of Cambodia. Due to time restrictions, the study only focused on three rice varieties: *sen kro ob, phka romdoul*, and *IR504*. The linear programming method was used specifically for: (1) optimizing rice yields in the Battambang with respect to gross income and production inputs; and (2) conducting a sensitivity analysis.

Research Methodology

Battambang, a province in the far northwest of the Cambodia, is the focus of this study. It borders Banteay Meanchey province to the north, Pursat to the south, Siem Reap to the northeast, and Pailin to the west. The Tonle Sap also forms part of northeastern boundary of Battambang between Siem Reap and Pursat. It is the fifth most populous province in Cambodia, accounting for 6.5% of the total population of the country (15,288,489 in 2019). Battambang also comprises the fifth largest land area of all Cambodian provinces (MoP, 2019). Fertile rice fields and an economy based predominantly on agriculture have led to the bestowal of the moniker 'the rice bowl of Cambodia'.

This study assumes a hypothetical land area of 1,000 ha using actual data for three varieties of rice (*sen kro ob, phka romdoul*, and *IR504*) for analysis, provided by Amru Rice Cambodia (SRP, 2018). A linear programming method has been used to determine an optimal cropping pattern for the three varieties in terms of a maximum rice yield. The objective function of the related model is subject to the following constraints: (1) the land area requirement for the crop, (2) fertilizer requirements, (3) seed requirements, (4) labor requirements, and (5) minimum profit. The optimization problem was formulated as follows:

Objective function of the maximum rice yield:

$$\mathrm{Z} = \sum_{\mathrm{i}=0}^{2} \mathrm{RY_i} \times \mathrm{x_i}$$

Where: $\mathrm{RY_i}$ = the rice yield per Ha of i^{th} variety in Kg/Ha, and $\mathrm{x_i}$ is the area of ith variety in the study in Ha (the decision variables).

Constraints on land use:

$$\mathrm{x_0} + \mathrm{x_1} + \mathrm{x_2} \leq ALA, \quad (1)$$

Where $\mathrm{x_i}$ is the area of i^{th} variety in the study in ha, and ALA is the available land area in ha.

Constraints on fertilizer use:

$$\sum_{\mathrm{i=0}}^{2} \mathrm{F_i} \times \mathrm{x_i} \leq \mathrm{AF}, \quad (2)$$

Where $\mathrm{F_i}$ is the amount of fertilizer used per ha of i^{th} variety in kg/ha, and AF is the available amount of fertilizer in kg.

Constraints on seed use:

$$\sum_{\mathrm{i=0}}^{2} \mathrm{S_i} \times \mathrm{x_i} \leq \mathrm{AS}, \quad (3)$$

Where $\mathrm{S_i}$ is the amount of seed used per ha of i^{th} variety in kg/ha, and AS is the available amount of seed in kg.

Constraints on profits:

$$\frac{\sum_{\mathrm{i=0}}^{2} (\mathrm{CI_i} - \mathrm{E_i})\mathrm{x_i}}{\sum_{\mathrm{i=0}}^{2} \mathrm{x_i}} \geq \mathrm{MinPro}, \quad (4)$$

Where $\mathrm{CI_i}$ is the gross income of rice yield per ha of i^{th} variety in USD, $\mathrm{E_i}$ is the total production cost of ith variety per ha in USD, and MinPro is the minimum average profit per ha in USD for cultivation of the three rice varieties.

Constraints on human labor force (HLF)

$$\sum_{I=0}^{2} LF_i \times x_i \leq AT, \tag{5}$$

Where LF_i is the labor force spent per ha of i^{th} variety in day, and AT is the available labor force per ha in day.

Findings and Discussion

Rice yield, gross income and expenditure on inputs

For a solution to be obtained using the linear programing method, the associated parameters in the related model must be realized numerically. The values of the parameters given in Table 1 and Table 2 were used in this case. Each value is an average of the corresponding data collected by Amru Rice in 2018, across Battambang province (SRP, 2018). For instance, the value of 4596.88 kg/ha given in Table 1 is the mean value for the yield of *sen kro ob* rice calculated on the basis of data collected for all rice cultivated in the province in 2018 (SRP, 2018).

Similarly, in Table 2, the value 258.59 kg/ha refers to the average amount of fertilizer used for cultivating *sen kro ob* rice; while the value 247,166 in the last row refers to the total amount of the fertilizer available for cultivation of all three varieties over the entire 1,000 ha. To obtain an optimal cropping pattern for the three varieties, the linear programing model was run using the Python code provided in the Appendix (Pine, 2019). The numerical results from this model are given in Table 3.

Table 1. Rice yield, gross-income (for fresh rice sold to Amru Rice) and input expense data used in the study

Attributes	**Rice Yield (Kg/ha)**	**Cross-Income (USD)**	**Expense (USD)**
Sen Kro Ob	4596.88	1263.9	426
Phka Romdoul	2891.43	888.98	383
IR504	5409.38	1148.4	511

Source: Amru Rice Cambodia, 2018

Table 2. Actual constraint data obtained for 2018

Constraints	Area (Ha)	Fertilizer (kg/ha)	Seed (kg/ha)	Profit (USD/ha)	Labour force (days/ha)
Sen Kro Ob	x_0	258.59	150.84	-37.9	72
Phka Romdoul	x_1	180.57	127.97	294.02	59
IR504	x_2	302.34	298.75	162.6	86
Limitation	1000	247166	192520	800	70000

Source: Amru Rice Cambodia (2018)

Decision variables are displayed in the first column, while optimal values are displayed in the second column. Specifically, the optimal cultivation area for *sen kro ob, phka romdoul*, and *IR504* varieties was calculated to be 751.124 ha, 0 ha, and 175.077 ha, respectively, to obtain a maximum rice yield for the hypothetical 1,000 ha land area. This includes an uncultivated land area of 73.799 ha.

This cropping pattern is estimated to lead to an optimal rice yield of 4,494,592.11 kg. However, as some parameters have a level of uncertainty due to factors such as climate change, insect damage, and water availability; a sensitivity analysis needs to be conducted. The results of varying the land cultivated of each type of rice is presented in the next section.

Table 3. Numerical results generated in Python

Decision	Optimal solution (ha)	Objective coefficients	Lower limit of objective coefficients	Upper limit of objective coefficients
x_0	751.124	4596.88	-1386.94	5089.28
x_1	0	2891.43	-infinity	4101.65
x_2	175.077	5950.32	5374.61	Infinity

Sensitivity analysis of rice yields

A sensitivity analysis was conducted by solving the model for a decreased and increased average yield of *sen kro ob* rice by 10%, with results displayed in the first and third columns of Figure 1, respectively. All other variables were kept constant. The bar chart shows that when the average yield of *sen kro ob* is decreased by 10%, the total optimal rice yield also decreases to 4,149,309.54 kg, a reduction of 7.68%. Conversely, if the yield is increased by 10%, the optimal yield rises 7.78% to 4,833,178.72 kg.

Similarly, all things being equal, the bar chart in Figure 2 displays the results for total maximum rice yield when a 10% decrease and increase is applied to the average rice yield for *phka romdoul*. The optimal rice yield is shown to remain the same in both cases. In fact, the average yield of *phka romdoul* may take any value less than 4101.65 kg and the total yield would still remain constant.

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Figure 1. Optimal rice yield when varying the yield of the *sen kro* ob

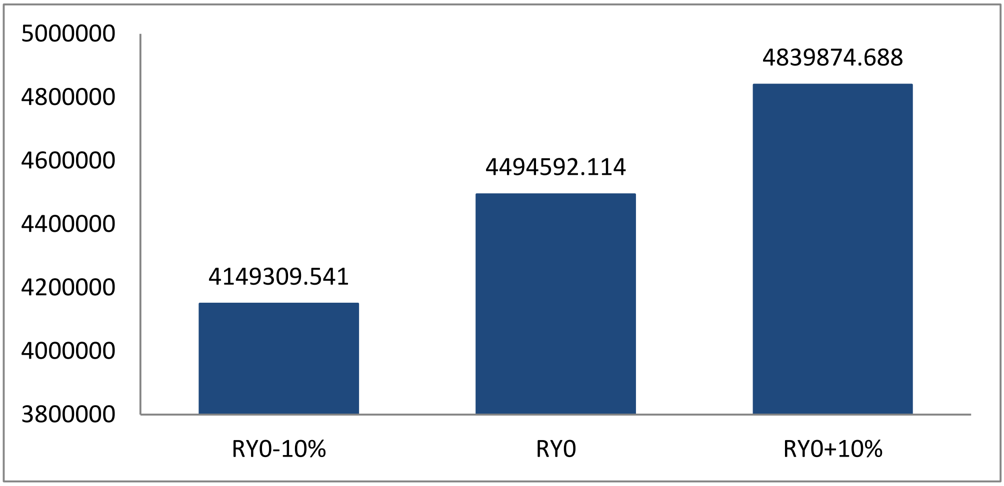
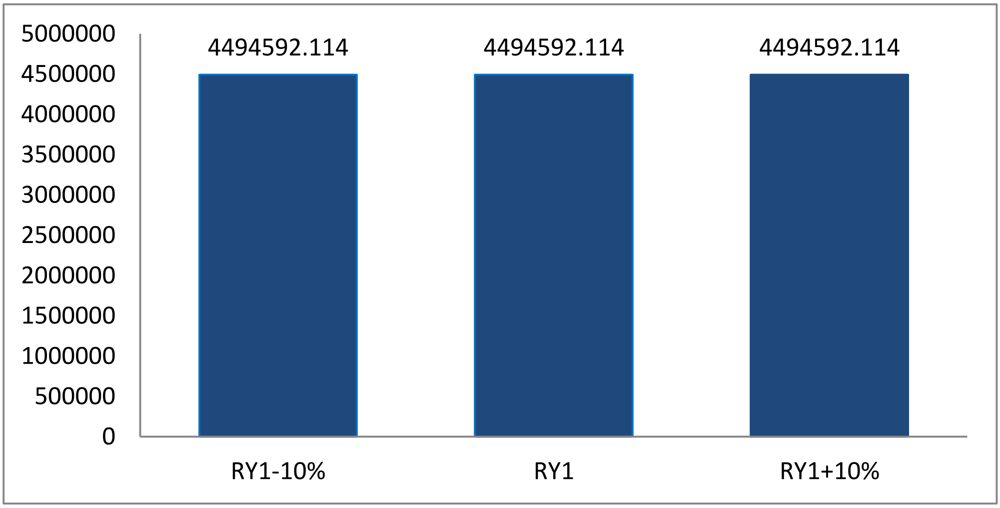
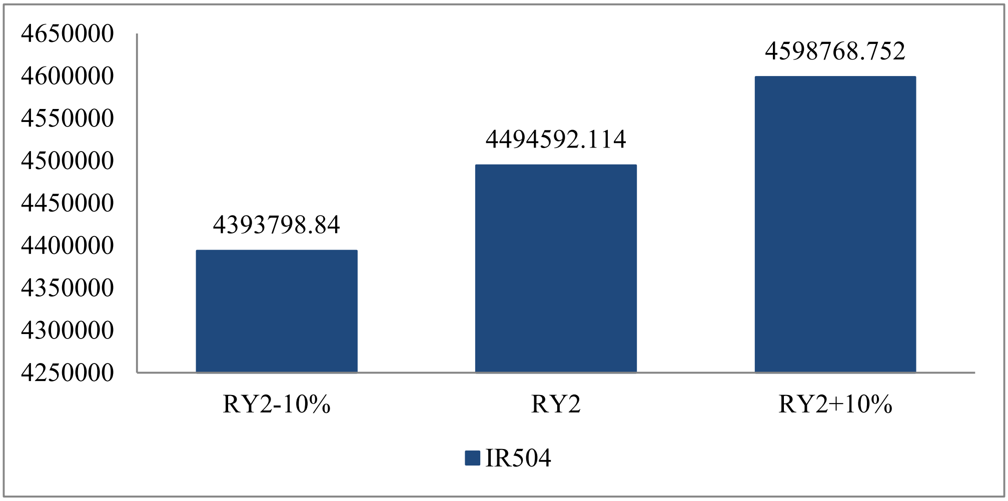


Figure 2. Optimal rice yield when varying the yield of *phka romdoul*



Finally, all things being equal, if the average yield of *IR504* is decreased or increased by 10%, the optimal rice yield will vary according to the results outlined in the bar chart in Figure 3. It shows that when the average yield of *IR504* is decreased by 10%, the optimal rice yield decreases by 2.24%. Conversely, if the amount is increased by 10%, the optimal rice increased by 2.31%.

Figure 3. Optimal rice yield when varying the yield of IR504



Conclusion

In this study, a linear programming method has been used to solve optimization problem and determine an ideal cropping pattern for obtaining a maximum rice yield using a combination of three rice varieties: *sen kro ob, phka romdoul*, and *IR504*. This cropping pattern was determined using actual data collected from Amru Rice, Cambodia in Battambang (SRP, 2018). A hypothetical land area of 1,000 ha was assumed in the model. Different constraints were imposed for the study, including a maximum land area for cultivation, fertilizer use, seed use, the availability of labor, and a minimum profit per ha. The optimal cropping pattern for *sen kro ob, phka romdoul*, and *IR504* rice varieties was determined to be 751.124 ha, 0 Ha and 175.077 ha, respectively. This pattern is predicted to result in an optimal yield of 4,494,592.114 kg.

A sensitivity analysis showed that all things being equal, when the average yield of *sen kro ob* was decreased or increased by 10%, the optimal rice yield would vary by up to 7.68%. The same variation in the average yield of *phka romdoul* resulted in no change to the optimal rice yield. The same outcome would occur for any average rice yield for *phka romdoul* below 4101.65 kg/ha. Finally, the same variation in the average yield of *IR504* results in a variation in the optimal rice yield of 2.24%. The result of this study will be distributed among Cambodian farmers to assist with decisions about cropping patterns to maximize potential rice yields. The methodology used for this study may be extended to crops other than rice, as well to other parts of Cambodia. The decision variables may be also be changed to represent different growing conditions.

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Brief Biography

Dr. VENG Sotheara Veng is a lecturer and researcher in the Graduate School of Science at the Royal University of Phnom Penh (RUPP), where he has been since 2019. He received a Bachelor and Master Degree in Mathematics from the Royal University of Phnom Penh. He also holds an MSc in Applied Mathematics from the University of the Philippines and a PhD in Mathematics from the Pusan National University in South Korea. His research interests is financial mathematics including option pricing and portfolio optimization problems. He published several papers in international journals.

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Appendix. The formulated LP optimization problem is solved using Python code running in Spider 4.0.1

```
from pymprog import *
c = (4596.88 , 2891.43, 5950.318) # coefficient of objective function
A = [(1, 1, 1), (258.59, 180.57, 302.34),(150.84, 127.97, 298.75), (-37.9, 294.02, 162.6)
(72, 59, 86)] # coefficient of 3 variables
b = (1000,247166,192520,0,70000) # value of constraints
begin('basic')
verbose(True)
x = var('x', 3) #create 3 variables
maximize(sum(c[i]*x[i] for i in range(3)))
for i in range(5):
 sum(A[i][j]*x[j] for j in range(3)) <= b[i]
solve() # solve the model
print("###>Objective value: %f"%vobj())
sensitivity() # sensitivity report
end() #the end of the code
```