A DECISION SUPPORT SYSTEM FOR RICE CULTIVATION ON ACID SULFATE SOILS IN MALAYSIA

Totok Suswanto, J. Shamshuddin, S.R. Syed Omar, C.B.S. The, Peli Mat

Department of Land Management, Faculty of Agriculture, Universiti Putra Malaysia,
43400 Serdang, Selangor, Malaysia

ABSTRACT

Ameliorative steps to put acid sulfate soils into productive use can be organized by a decision support system. The model uses microeconomic analysis to get an optimal rate of lime and fertilizer in maximizing profit. A glasshouse experiment was conducted on an acid sulfate soil in Malaysia to get the potential yield. A field trial was conducted for validation purposes. The recommended rate of fertilizer application of 150-200 kg ha^{-1} N, 20-30 kg ha^{-1} P and 150-200 kg ha^{-1} K were applied during the critical stage of the rice growth. Field Adjusting Factor (FAF) of 0.4Q has been found and this was used to analyze the production function. Using TableCurve 3D software, an equation for production function was established. Validation using experimental data showed that the equation has a good capability, shown by the value of $p>0.2$ (t-test) and MEE of 2%. The model, named as RiCASS(Rice Cultivation on Acid Sulfate Soil), was developed and successfully simulated the maximal profit under 4 different scenarios. The recommended rate of lime (GML) was 6.5 t ha^{-1} for maximal profit and 2.5-3.0 t ha^{-1} for the farmers' practice.

Key words: *Acid sulfate soil, decision support system, field adjusting factor, lime, rice*

INTRODUCTION

Acid sulfate soils pose chemical, biological and physical problems for crop production on them. Chemically, acid sulfate soils have the following agronomic problems: 1) direct effect of severe acidity – primarily the increased solubility and toxicity of aluminum and iron (Fe^{3+}); 2) decreased availability of phosphate; 3) low base status and nutrient deficiencies; and 4) salinity problems (Dent, 1986).

Under flooded conditions, acidity is reduced, but new problems occur such as: 1) iron (Fe^{2+}) toxicity; 2) hydrogen sulfide toxicity; and 3) CO_2 and organic acid toxicity. Physical problems that arise mainly through inhibition of root development in the sulfuric layer are: 1) crop suffers water stress; 2) soil ripening is arrested; and 3) field drains may be blocked by iron oxide deposits (Dent, 1986). In a review of the literature on soil chemical properties and their relation to the growth of rice in acid sulfate soils, Satawathanant (1986) reported adverse effects of H^+, toxicities of Fe, Al and sulfite, electrolyte stress, CO_2 and inorganic acids.

Ameliorative steps are needed to put acid sulfate soils into productive use. The several steps of ameliorations are: 1) correct water management to prevent pyrite oxidation by maintaining water table level above the pyrite layers; 2) applying lime and/or organic matter at appropriate rate and time; 3) adequate fertilizer application; and 4) in the case of rice, keeping the soil submerged as long as possible before transplanting.

These procedures can be organized into an integrated decision support system (DSS) whereby using analytical methods and models. DSS are computer technology solutions that can be used to support complex decision-making and problem solving (Shim, 2002). These technologies are software products, which help users in applying analytical and scientific methods to make decision. They work by using models and algorithms from disciplines such as decision analysis, mathematical programming and optimization, stochastic modeling, simulation and logic modeling (Gregoriadesa and Karakostas, 2003).

In order to get maximal profit, microeconomic analysis on production function is required in terms of cultivating rice in acid sulfate soils. Production function is a mathematical relationship describing the way in which the quantity of particular products depends upon the quantities of the particular input used (Bishop and Toussaint, 1958). Once a physical production function has been derived, the amount of revenue, which comes from a particular production process, can be determined by multiplying the quantity of product produced by the price of the products. The optimum production input, which generated the maximum revenue, is at the middle stage of production function. It is the longest distant from the baseline of cost.

The objective of the study was to use experiments and microeconomic analysis in a bundled of DSS that can help decision makers and farmers formulate the best solutions in cultivating rice on acid sulfate soils to produce high yields and the maximal profit. The main users of the system are government agencies, scientists, researchers, farmers and students.

MATERIALS AND METHODS

The first approach in achieving the objectives of this study was the development of a production function. The production function of this study is a response of rice grown on an acid sulfate soil under various ameliorative treatments. The model used this function to simulate yield and using micro economic analysis the maximum profit will be determined.

A field trial was conducted at Kampung Mujur, Bachok, about 25 km south of Kota Bharu, Kelantan, Malaysia. It is located at 06° 00 N and 102° 23 E in the Jelawat Rusa Irrigation Scheme, which is one of the irrigation infrastructures in Kemasin-Semerak Integrated Agricultural Development (IADP) Project. The soils used for a glasshouse experiment were taken from this trial site.

A crop-cutting test (CCT) was conducted before harvest. In this test, samples in the experimental plot were taken from 25 x 25 cm area. The rice was then cleaned and dried to have 14% moisture content. After weighing, the yield was converted to kg ha^{-1}.

Rice Growth Response on Acid Sulfate Soil in Pot Experiment

The rice variety MR 219 was planted in pot with diameter of 27 cm with 6 kg of dry soil in each pot. Three assessment factors were evaluated which included water management, liming rate and fertilizer application.

The water management treatments were designed to determine the effects of surface water. The treatments for this factor included: 1) W0: continuously submerged (control); and 2) W1: drying period once in 50 Day After Seeding (DAS) for about 5-12 days. The treatments for lime (GML) were: 1) no lime (control); 2) liming at the optimal (predicted) rate; and 3) liming at the lime requirement rate. The predicted optimal rate of lime application was 4 t ha^{-1}, while the lime requirement was 13.8 t ha^{-1}. The treatments of fertilizer in this study were: 1) F0: no fertilizer; 2) F1: medium rate fertilizer to achieve 5 t ha^{-1} of yield (45– 60 kg N ha^{-1}; 6–9 kg P ha^{-1}; 45-60 kg K ha^{-1}) and; 3) F2: maximal rate of fertilizer application to achieve 10 t ha^{-1} of yield) (120–160 kg N ha^{-1}; 16–24 kg P ha^{-1}; 120-160 kg K ha^{-1}).

Field Trial for Validation Purposes

A fully controlled environment of glasshouse experiment will maximally support plant growth. The yield can be regarded as the potential yield, which is difficult to achieve under field conditions. In order to get a reasonable model, these glasshouse data must be validated by field trials. A field trial was therefore conducted in Kelantan.

Each plot size was 3 x 3 m area. There were 7 treatments with 5 replications. The treatments included control (no lime), liming using GML at various rates from 2 to 8 t ha^{-1}, combination of lime with organic-based fertilizer (JITU) and additional fertilizer called fused magnesium phosphate (FMP) (Table 1). It was run for 2 seasons.

Model Development

Data from both experiments were analyzed to produce Field Adjusting Factor. Glasshouse data refer to potential yield, while field data refer to the actual yield. From the comparison, field yield achievement percentage can be calculated. After conversion using FAF, a fitting equation was obtained from experimental data using tool TableCurve 3D v4.0 (SYSTAT Software Inc.). This equation refers to production function of rice grown in acid sulfate soil.

Table 1. Treatment in the Field

Symbol	Treatment
T1	Control
T2	2 t GML^{+} ha^{-1}
T3	4 t GML ha^{-1}
T4	6 t GML ha^{-1}
T5	8 t GML ha^{-1}
T6	4 t GML ha^{-1} + JITU*
T7	4 t GML ha^{-1} + FMP$^{\#}$

$^{+}$ GML Ground Magnesium Limestone
* JITU Rice husk-based organic fertilizer (0.25 t ha^{-1})
$^{\#}$ FMP Fused Magnesium Phosphate

To validate the production function, other treatments of experimental plot were used. These included application of lime at the rate of 2, 6 and 8 t ha^{-1} with maximal rate of fertilizer application. These data were compared with the estimated yield from the production function. The validation consisted of two types of tests, which were paired comparison t-test and Mean Estimation Error (MEE).

Simple microeconomic analysis was conducted as an approach of decision model. Increasing ameliorative processes result in a higher production cost. Using the obtained production function, the effects of increasing ameliorative input on farmer's revenue can be calculated. Decision model would then try to find the optimal ameliorative input, which gives maximal revenue. This model would run simulation with different scenarios, which were based on two major types. The first type, it would maximize profit in terms of a pure agribusiness, while the second type would evaluate the maximal profit based on how much the farmers had spent.

RESULTS AND DISCUSSION

Field Adjusting Factor

There were two treatments, which use lime and fertilizer with the same rate from both glasshouse and field experiments. This was L0F2 (no lime, fertilizer at maximal rate) in glasshouse experiment with T1 (control) in field trial. The other treatment was L1F2 (GML at 4 t ha^{-1}, fertilizer at maximal rate) and T3 on field trial. Both data from these treatments were compared.

From the comparison shown in Table 2, general average of the achievement percentage is 40.15 %, which means that of the 10 t ha^{-1} potential yield, only 4 t may be gained in the field, while 6 t is lost. The large amount of loss (60%) was due to poor harvesting technique and/or improper fertilizer distribution, pest and disease damages, flood and poor farmer's management.

Tabel 2. Compilation of Glasshouse Experiment and Field Trial to Produce A Mean Field Adjusting Factor

		Field trial (kg ha^{-1})				
		Experimental plot		Demonstration plot		
		Season 1	Season 2	Season 1	Season 2	
L0F2*	12,201	4,483	5,109	-	-	39.30
L1F2**	14,145	3,512	6,250	5,796	7,641	41.00

* : no lime, fertilizer at maximum rate

** : *GML of 4 t ha^{-1}, fertilizer at maximum rate*

The Production Function

After inputting the FAF converted data into TableCurve 3D software, the surface-fit process generated 345 possible equations of which the r^2 ranged from 0.78 to 0.02. The fittest equation was then chosen based on: 1) significance of overall model; 2) significance of equation parameters; and 3) smallest prediction error. The equation is shown below:

$$\mathbf{Z\,(yield) = 2499.26 + 380.39x - 22.14x^2 + 211.06y}$$

p<0.01 p<0.01 p<0.01 p<0.01 p<0.01

$r^2 = 0.71$

where:

- Z: yield (kg ha^{-1})
- x: lime application (t ha^{-1})
- y: fertilizer index (one index represent fertilizer rate to increase yield 1 t ha^{-1})

Validation of Production Function

Figure 1 shows the result of paired comparison t-test. Statistical t-test analysis showed that for the first season, there were significant differences (P<0.01) between model yields with actual yield, except for the treatment of liming at 2 t ha^{-1}. This is understandable as the first season of field experiment was affected by flood. Flooding might have produced a lower yield so that the yield from the model was significantly higher than these actual ones. However, in the second season, which was under normal conditions, t-test analysis showed that there were no significant differences between predicted model yield and the actual yield. It is proven by the probability of above 20%.

Mean Estimation Error (MEE) analysis showed the same result for the first season, the percentage of error was up to 31% due to flood, while for the second season it was only 2%. This value shows that the estimated yield only varies 2% above or below the actual yield.

From both validation methods, t-test and Mean Estimation Error, the curve was shown to have capability and validity to represent yield for cultivating rice on acid sulfate soil as a response of lime and fertilizers.

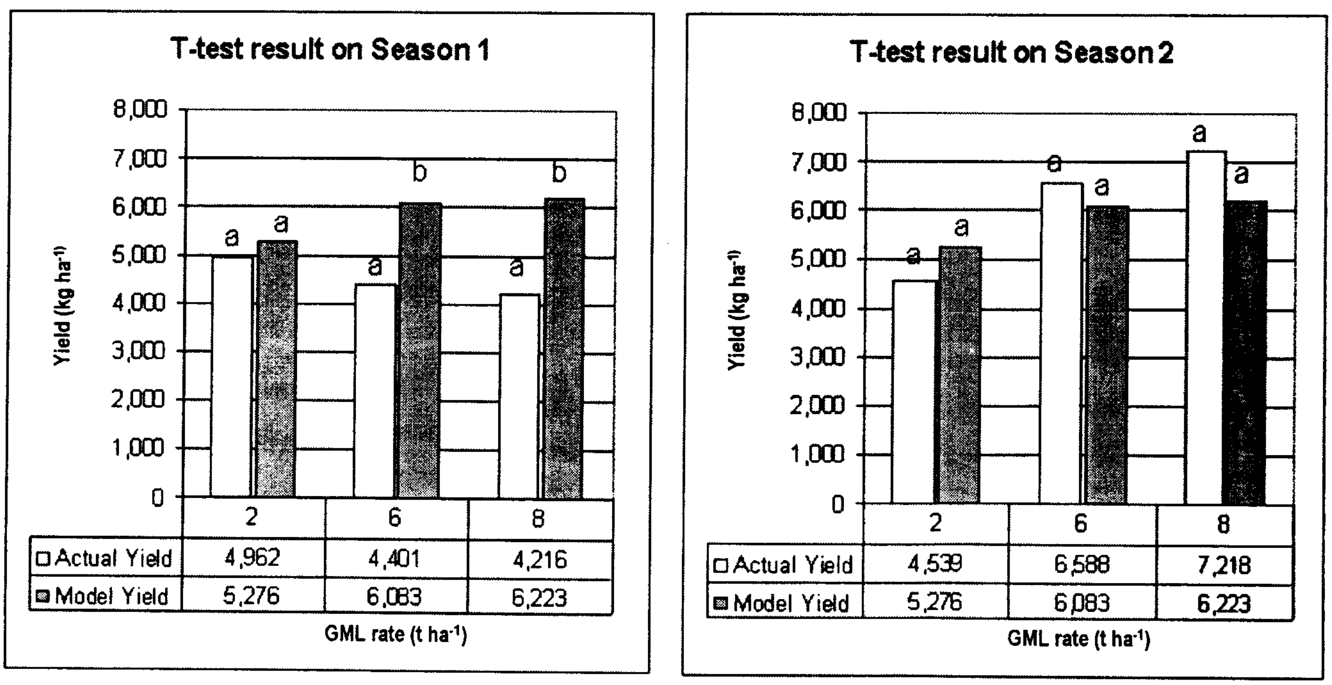

Figure 1. Paired Comparison t-Test for Validation (a, b...P<0.01)

Model Development

The computer software for this particular model was designed to run on Windows-based operating system. The model was developed using C language on PowerBuilder 7.03 (Sybase Inc.) It uses Microsoft Access file database to handle data storage. This software is so named as RiCASS, which stands for "Rice Cultivation on Acid Sulfate Soils". This model consists of two main modules: lime application and fertilizer application modules (Figure 2). These modules were then used to develop integrated relation with economic analysis as a tool in determining the objective of the model, looking for maximal profit.

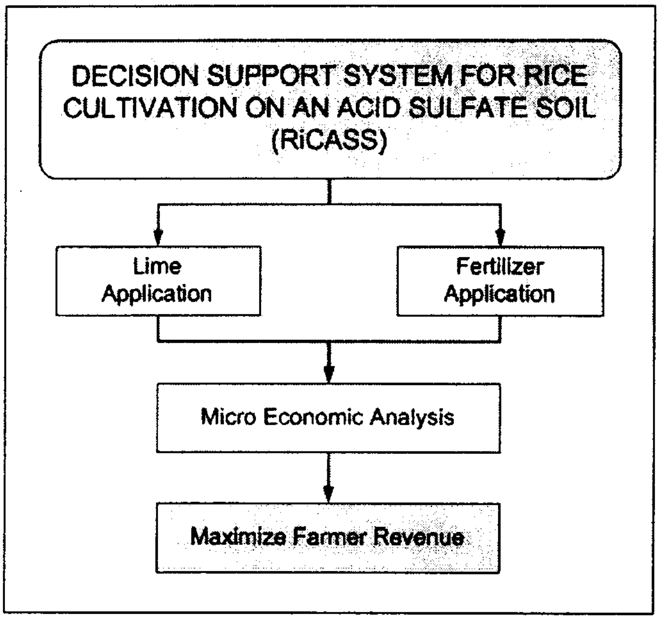

Figure 2. RiCASS Configuration, Consisting of 2 Sub Models

Simulation can be divided into several processes. The first process was determining yield using production function. This process produced output on lime rate, fertilizer rate and predicted yield. That output was then used for the next process, cost evaluation. Cost of each input rate was calculated. User can easily modify the cost accordingly so that the input cost is similar to the actual cost for other specific regions. The last process was calculating the profit margin. Total revenue can be calculated from predicted yield and rice price, while profit was calculated by subtracting total cost from total revenue. All processes in determining profit were repeated for all combination of lime and fertilizer rate. Based on predicted yield, lime rate and fertilizer rate, the highest profit can be found. The complete flowchart of model is shown in Figure 3.

The Maximal Profit

RiCASS simulates the maximum profit in 4 different scenarios which include: 1) general simulation; 2) simulation with cost limitation below RM 1,500; 3) simulation based on farmers' spent; and 4) simulation with combination on cost limitation below RM 1,000 spent by the farmers. Table 3 shows the complete result of the simulation. Cost limitation of RM 1,500 is the default value in RiCASS, but it can be changed.

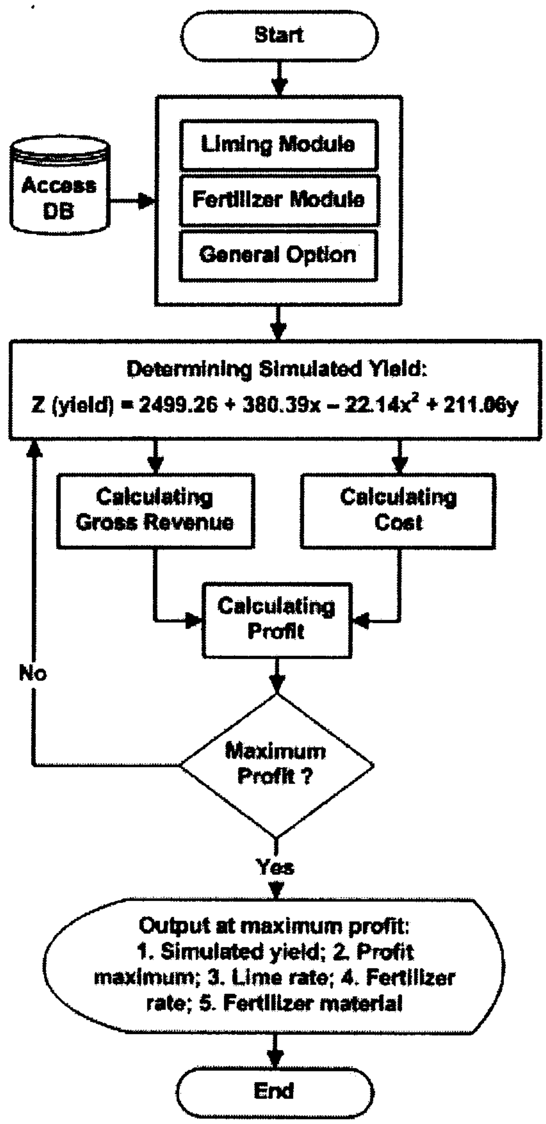

Figure 3. RiCASS Flowchart

Simulation using RiCASS for general scenario predicted the maximal profit of RM 2,847 per ha from lime input of 6.5 t ha^{-1}, using maximal rate of fertilizer. It was delivered from the predicted yield of 6.15 t ha^{-1}. B/C ratio of 1.38 shown for the first scenario indicated that it was profitable. The level of yield was predicted higher than that of the initial yield of 2 t ha^{-1}. Compared to rice grown on good area, this is considered low. Nevertheless, this is good enough even for acid sulfate soil high in Al and Fe.

Using the second scenario, simulation has predicted the maximal profit of RM 2,024 per ha from lime input of at 3 t ha^{-1}, using fertilizer index of 4.60. The total cost of RM 1,497 was in agreement with the minimal total cost below RM 1,500. The predicted yield was 4.41 t ha^{-1}. This scenario was also profitable as shown by B/C ratio of 1.35.

Both the first and second scenario shows a good chance of success for growing rice on an acid sulfate soil.

The third scenario gave the highest profit among all the scenarios. It was a promising result since it was based on farmers' cost. The maximal profit of RM 3,624 was obtained from a predicted yield of 6.15 t ha^{-1} as a result of liming at 6.5 t ha^{-1}, using maximal fertilizer index of 10. Comparing the outputs of RiCASS on this scenario with the initial farmer practices showed that appropriate application of lime and fertilizer increased profit by up to 307.38% (with an assumption that the average initial yield is 2 t ha^{-1} and total cost is RM 417; cost of labor was not included and only used subsidized fertilizer without liming).

Table 3. Result of RiCASS Simulation on Four Scenarios

Result of	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Maximum Profit (RM)	2,847	2,024	3,624	3,263
Simulated Yield (t ha^{-1})	6.15	4.41	6.15	5.34
Gross Revenue (RM)	4,905	3,521	4,905	4,260
Total Cost (RM)	2,058	1,497	1,284	997
B/C ratio	1.38	1.35	2.82	3.27
Lime rate (t ha^{-1})	6.50	3.00	6.50	2.50
Fertilizer index	10.00	4.60	10.00	9.60
Mixed Fertilizer 17:20:10 (kg ha^{-1})	370	170	370	355
Urea 46% (kg ha^{-1})	150	69	150	144
NPK Blue 12:12:17 (kg ha^{-1})	210	97	210	202
Impressa Green 15:15:15 (kg ha^{-1})	140	64	140	134

Scenario: 1) General simulation; 2) Total cost below RM 1,500; 3) Based on farmers spent (without labor cost) and 4) Total cost below RM 1,000 and based on farmers spent

The last scenario also showed a promising result especially for low-income farmers and it may be the best scenario for them. Using total cost of only RM 997, the profit of RM 3,263 can be gained as a result of predicted yield of 5.34 t ha^{-1}. It used GML at rate of 3.27 t ha^{-1} and fertilizer index of 9.60. The B/C ratio of 3.27 was also the highest among the scenarios. With this scenario, the result is expected to help farmers understand how to improve their income when cultivating rice on their acid sulfate soils. This may be preceded by giving information from government agency as decision maker to decide the best option for the farmers.

CONCLUSSION

A Decision Support System, RiCASS, has been developed using a real experimental data. This model is able to predict maximal profit for rice cultivation on an acid sulfate soil. The recommended rate of lime (GML) was 6.5 t ha^{-1} for maximal profit and 2.5-3.0 t ha^{-1} for farmers' practice. The recommended rate of fertilizer application of 150-200 kg ha^{-1} N, 20-30 kg ha^{-1} P, 150-200 kg ha^{-1} K should be applied during critical time of rice plant growth.

ACKNOWLEDGEMENTS

The authors would like to thank the Universiti Putra Malaysia and the Ministry of Science, Technology and Innovation for financial and technical support.

REFERENCES

Dent, D.L. 1986. Acid Sulphate Soils: A Baseline for Research and Development Vol. 39 ILRI Pub. Wageningen, The Netherlands.

Bishop, C.E. and W.D. Toussaint. 1958. Introduction to Agricultural Economic Analysis. Part I: Introduction. John Wiley & Sons, Inc. New York. p. 2-36.

Gregoriadesa, A. and B. Karakostas. 2003. Unifying business objects and system dynamics as a paradigm for developing decision support systems. *J. Decision Support System* 37: 307–311.

Satawathanant, S. 1986. Redox, pH and Ion Chemistry of Acid Sulfate Rice Soils in Thailand. Ph.D. Dissertation. Lousiana State University, Baton Rouge, USA.

Shim, J.P. 2002. Past, Present and Future of Decision Support Technology. Elsevier Science Publishers B. V. Amsterdam, The Netherlands, The Netherlands.