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Optimisation of Model-based Fertiliser Formulation for Sustainable Agriculture

Nur Amalina Mohd Nor[a,b], Siti Hajjar Che Man[b], Norfhairna Baharulrazi[b], Nor Alafiza Yunus[a,b,]*

[a]Process Systems Engineering Centre (PROSPECT), Research Institute for Sustainable Environment, Universiti Teknologi Malaysia (UTM), 81310 UTM Johor Bahru, Johor, Malaysia.
[b]Faculty of Chemical and Energy Engineering, Universiti Teknologi Malaysia, UTM Johor Bahru.
alafiza@cheme.utn.my

Agriculture management for better decision making is important due to increased needs for agricultural products and increased pressure on land, water, and other natural resources. Balanced nutrient requirements are essential for increasing tropical crop yield and reducing the risk on the negative environmental impact. Reduce fertiliser consumption and optimise the fertiliser used subjected to waste of fertiliser into the environment are the best way to achieve sustainable agriculture. The nutrient coverage includes macronutrient such as nitrogen (N), phosphorous (P), potassium (K), sulfur (S), magnesium (Mg) and calcium (Ca). In this study, the data and procedures used to set up the model as well as the assumptions made for tropical crops. The main objective of the study is to develop a systematic methodology for fertiliser formulation in fertigation system. The sub-objective of the study is to design fertigation fertiliser formulation by using computer-aided approaches which can minimise the environmental impact by reducing the over-used fertiliser leakage. The methods consist of three steps including data collection, the design of fertiliser formulation and verification of fertiliser formulation. The fertiliser formulation will be formulated by using general optimisation problem as the mixed-integer nonlinear program (MINLP). The results in Stage 1 is expected to be the design formulation of fertiliser sources which gives the minimum cost that is subjected to the plant requirements and the results will further verify in Stage 2. This model-based formulation is the starter for another tropical crop model.

1. Introduction

The expansion in population growth has become a consistent challenge in agriculture sector because of the need of creating more food, both in amount and quality. There is a growing demand for oil palm, paddy, fruits and vegetables. Currently, it is realised that the key in agriculture is the agricultural production because the price of their essential raw materials has suffered a significant increase, and it is expected that the trends continue a next few years. This production will likewise influence the final price of agriculture production. Consequently, an efficient management of fertiliser should be designed in terms of saving money and time that led to more profitable production.

In fertiliser, three key nutrients Nitrogen (N), Phosphorus (P) and potassium (K) are playing the major role in global food production. Nitrogen, for the most part, is for leaf or vegetative development, phosphorus is for root and organic product creation, and potassium is for cool hardiness, disease resistance, and general durability. Little amounts micronutrients are required which are boron, iron, chlorine, manganese, zinc, and nickel. The other three components which are carbon, hydrogen and oxygen originate from water and air. Fertiliser is classified into two types of fertiliser which is granular and liquid fertiliser. Granular fertilisers are solid granules, while liquid fertilisers are made from water-soluble powders or liquid concentrates that mix with water to form a liquid fertiliser solution. Plants quickly take up most water-soluble fertilisers, while granular fertilisers need a while to dissolve or decompose before plants can access their nutrients. However, granular fertiliser can be further characterised into organic or inorganic fertilisers. Organic fertiliser comes from an

organic source such as manure, blood meal, cottonseed meal, feather meal, crab meal, or others, as opposed to synthetic sources. There are also some natural fertilisers that are not organic, which contains potassium, iron, calcium, and other nutrients.
Previous farmers are depending on the traditional method of determining fertiliser formulation which they formulate the fertiliser base on experimental work or previous experience. However, every crop has their own nutrient uptake at the different level of growth stages. The conventional method of determining fertiliser formulation may vary, time-consuming, higher cost, more nutrients excess and may causes the high environmental impact as if compared to the formulation developed by computer-aided software. A major source of agricultural pollution has become increasingly serious throughout the developing countries because of the excessive amount of fertilisers, herbicides and insecticides used in agricultural production (Chen et. al, 2017).
In conjunction with that, there are many computers-aided software in the market to make farmers or other users easier, reflected into saving nutrient needed, fertiliser cost, time and environmental impacts. However, the software available is only applicable for fertiliser source, crop type, and soil type and plant requirement in the country they are built, not in Malaysia. Malaysia tropical crop may be different from other countries depends on the type of soils and climate. Therefore, the efficient method as a simple computer-aided need to be studied. Mathematical models are required for understanding and forecasting the performance of the agriculture system for specific purposes (Jones et al., 2017) especially in fertiliser field. Data are necessary to develop, evaluate and run the models so that the system is studied, interference about the real system can simulated by conducting the model-based case study.
Moreover, the fertigation process is the most common method used to supply water and fertiliser to soil or soilless cultures. Fertigation techniques are used to enhance productivity (Surendran et al., 2014) as it has been proved that fertigation can result in more than 50% saving in production cost (Jayakumar et al., 2017). The purpose of this research is to develop a systematic methodology for fertigation fertiliser formulation by using computer-aided approaches for sustainable agriculture which can minimise the fertiliser cost, a reduced amount of liquid fertiliser consumption and lower environmental impact from over-used fertiliser leakage.

2. Methodology

The systematic methodology for optimal fertigation fertiliser formulation using computer-aided approach is illustrated in Figure 1. This methodology consists of three main steps, which includes data collection and establishment, the design of fertigation formulation and the verification of fertigation formulation. It is expected to design a model based fertiliser formulation to obtain the optimise fertiliser formulation with the minimum cost. The input is the plant requirement, the nutrient content in the medium, the type and cost of the sources. The output is the fertiliser formulation with the total cost of the selected fertiliser sources.

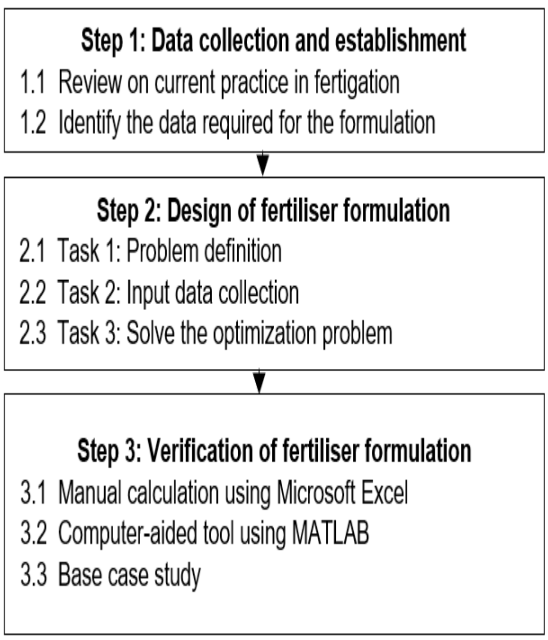

Figure 1: Systematic methodology for optimal fertigation fertiliser formulation

2.1 Data collection and establishment

The data collection is the process of obtaining information about the nutrient requirements of crops, the sources of water, medium, fertiliser and the nutrient contents by each source and their cost. All the data are collected from handbooks, bulletins, experimental data, and journals such as Malaysian Agricultural Research and Development Institute (MARDI) technology bulletin. Furthermore, these collected data are documented in Microsoft Excel and are used in designing model-based fertiliser formulation. Moreover, the review on current practice in fertigation has been done to study the method, algorithm and to identify the possible parameter.

2.2 Design of fertiliser formulation

The fertiliser formulation is formulated by using general optimisation problem as presented in Eqs(1) – (4). The problem is formulated as a mixed integer linear programming (MILP).

Objective function:

$$f_{obj} = \min \sum_{i=1} m_{si} C_i y_i \tag{1}$$

Subject to;

$$m_{nj} = \sum_{i=1} x_{ij} m_{si} y_i \tag{2}$$

$$m_{nj} = M_i V \tag{3}$$

$$x_T = \sum_{i=1} x_{ij} y_i \tag{4}$$

C_i: $C_i \geq 0$, $m_n \geq 0$, $m_s \geq 0$, $M \geq 0$, $V \geq 0$, $0 \leq x_T \leq 1$
where m_s is the mass of fertiliser (kg), m_n is the mass of nutrient (kg), x is the mass percentage of fertiliser (%), x_T is the total mass percentage of fertiliser (%), C is the cost of fertiliser (MYR/kg), M is the concentration of nutrient (ppm), V is the volume of the solution and y_i is the binary variable. The index i indicates the source of fertiliser and j is the nutrient of the fertiliser.

2.2.1 Problem definition

The formulation of fertiliser will be designed subject to the plant requirements which are including macronutrients and micronutrients. The sources of fertiliser are collected including the nutrient contents and the market prices based on the local market. The most optimal formulation will give the minimum cost of fertiliser mixtures with satisfied plant requirements. The formulation will be compared with the conventional fertiliser that is commonly used by local farmers.

2.2.2 Input data collection

This is a critical requirement for keeping the high standard of the journal. The main input needed for this study is the plant requirement. The plant requirements are collected from the literature. Other required inputs are fertiliser and their sources including prices and component fraction, type of planting medium, soil properties and method of planting. The source of fertiliser is divided into two categories, macro and micronutrient. Other than soil-grown, the plant can be grown in the greenhouse on soilless media such as coco peat, rice husk ash, peat moss or a mixture of them. Besides, the method of planting is also very important in determining the nutrient required by a plant. Open field planting may require less nutrient compared than soilless grown greenhouse plant

2.2.3 Solve the optimisation problem

The MILP problem with a linear objective function to minimise the fertiliser cost is solved using mixed integer linear programming solver. The problem cannot be solved by using the simple graphical technique because it consists of more than two variables. The problem can be solved using MILP solver in MATLAB, GAMS or Excel Solver, such as binteg solver in MATLAB.

3. Case study: Design of fertigation fertiliser formulation for eggplant

The case study is about to design the fertigation fertiliser formulation for eggplant. Eggplant is chosen because commercial cultivation of eggplant yields good profits and these vegetables can be marketed easily as there is good demand in Malaysia local markets. Also, eggplants are easy to be planted as it can be grown in greenhouses, playhouses and even in backyards. one of the tropical crops that can achieve maturity for 5 - 6 months. The systematic methodology for optimal fertigation fertiliser formulation of eggplant by using computer-aided approaches is including of the data collection and establishment step. The nutrient requirement by eggplant includes the macro-nutrients and the micronutrients. The eggplant needs the high amount of nitrogen, phosphorus, and calcium for growth.

3.1 Data collection and establishment

The data of sources of fertiliser, medium and water are collected and established in table form. The sources of the medium are the combination of coco peat and paddy husk in the ratio of 7 : 3 of cocopeat: paddy husk. Cocopeat and rice husk were plentifully found in Malaysia (Balasundram et al., 2017) and rice husk is an excellent adsorbent due to its microporous structure these form of carbon (Deiana et al., 2008). The water source use in this study is from tap water. The nutrient requirement and h1the concentration for eggplant is shown in Table 1. The percentage of nutrient for sources of medium is as shown in Table 2. Table 3 illustrate the sources of fertiliser with the nutrient content and the market prices. The prices for fertiliser components are obtained from Seri Lalang Agriculture & Trading Co. Sdn. Bhd. located Kluang, Johor, Malaysia.

Table 1: Nutrient requirement and h1the concentration for eggplant (Mahamud et al., 2009)

Nutrient	Volume (ppm)
N	253.09
P	50.38
K	335.44
Ca	196.61
Mg	48.00
S	74.77
Fe	2.51
Mn	0.54
Zn	0.53
Cu	0.03
B	0.54
Mo	0.05

Table 2: Sources of medium

Nutrient	Percentage weight (wt%)	
	Cocopeat (Havlin et. al, 2005)	Rice husk (Hashim et. al, 1996)
N	3.37	0.00
P	0.41	0.38
K	2.25	1.28
Ca	2.64	0.56
Mg	0.52	0.21
Cu	0.00	0.00
Na	0.00	0.00
Si	0.00	80.26

3.2 Task 1: Problem definition

The objective function is to minimise the cost of fertiliser consumption which is subjected to the nutrient requirements by eggplants and it is expected to minimise the waste of fertiliser to the environment. The fertigation fertiliser formulation by the eggplant is formulated by using MILP based on general optimisation problem as presented in Eqs(1) – (4). The constraints are the mass of fertiliser used for growth, the concentration of the liquid fertilisers and the mass of total nutrient required.

3.3 Task 2: Input data collection

The input required is the eggplant nutrient requirements which are retrieved from the literature. Other than that, the sources of fertiliser with the market prices, nutrient content and the sources of medium and water. The volume of water sources is 10,000 L of the solution but the volume can be adjustable depending on the size of the user’s tank

3.4 Task 3: Solve the optimisation problem

The problem to design the fertiliser formulation for eggplant is formulated as below;

Objective function:

$$f_{obj} = \min \sum_{i=1} m_{si} C_i y_i \qquad \text{for } i = 1...,12 \text{ and } j = 1...,12 \qquad (1)$$

Subject to;

$$m_{nj} = \sum_{i=1} x_{ij} m_{si} y_i \qquad (2)$$

$$m_{nj} = M_i V \qquad (3)$$

$$x_T = \sum_{i=1} x_{ij} y_i \qquad (4)$$

where i represents the sources of fertiliser. From all the sources listed in Table 3, only source 1 to 12 are available in local market. j is the nutrient of fertiliser. Only 12 nutrients are chosen to consist the most important nutrient required which are 6 macronutrients and 6 micronutrients. The constant parameters in Eqs(1) - (4) are V = 10, 000 L, $C_i \geq 0$, $m_n \geq 0$, $m_s \geq 0$, $M \geq 0$, $V \geq 0$, $0 \leq x_T \leq 1$, mn for Sulfur $\geq M_{Sulfur}V$. i are chosen depends on the availability of the fertiliser in the local market. The MILP problem is solved using bintprog solver in MATLAB, which took a total of three seconds to solve the problem. Table 4 shows the results of the fertiliser formulation obtained from this study. The fertiliser formulation is compared with MARDI formulation.

From the results above, the total cost for formulated fertiliser is slightly lower than MARDI formulation by 6 %. This is due to both formulations using different sources of fertiliser for nitrogen. There are two sources of nitrogen, which are potassium nitrate (S4) and ammonium nitrate (S1). The cost for ammonium nitrate is much cheaper than potassium nitrate. The formulated fertilised is optimised to has a lower cost. Thus, the formulation selected ammonium nitrate as the source of nitrogen. Moreover, the optimisation results have fulfilled the nutrients requirement needed for eggplant, which is crucial for plant growth.

Table 3: The market prices and the nutrients content for each of the fertiliser source (Seri Lalang Agriculture & Trading Co. Sdn. Bhd.)

Sources of fertiliser	Price (MYR/kg)	Percentage weight (wt%)											
		N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu	B	Mo
S1	3.00	34.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S2	2.24	15.50	0.00	0.00	18.58	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S3	7.40	0.00	22.69	28.23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S4	5.20	13.50	0.00	38.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S5	5.20	0.00	0.00	41.50	0.00	0.00	18.40	0.00	0.00	0.00	0.00	0.00	0.00
S6	1.60	0.00	0.00	0.00	0.00	9.60	13.00	0.00	0.00	0.00	0.00	0.00	0.00
S7	42.00	0.00	0.00	0.00	0.00	0.00	0.00	13.20	0.00	0.00	0.00	0.00	0.00
S8	42.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	14.00	0.00	0.00	0.00
S9	46.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	13.00	0.00	0.00	0.00	0.00
S10	46.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	14.00	0.00	0.00
S11	40.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	18.70	0.00
S12	370.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	54.00
S13	5.20	0.00	41.50	0.00	0.00	18.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S14	7.80	0.00	0.00	56.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S15	6.80	12.00	22.62	0.00	0.00	0.00	0.00	0.00	35.00	0.00	0.00	0.00	0.00

Where S1 = Ammonium Nitrate NH_4NO_3 (Technical) 34 % N; S2 = Calcium Nitrate (Greenhouse) 15.5 % N, 26 %; S3 = MKP 0 – 52 – 34; S4 = Potassium Nitrate 13 – 0 – 46; S5 = SOP (potassium sulphate); S6 = Magnesium Sulphate; S7 = EDTA Fe 13.2 %; S8 = EDTA Zn 14 %; S9 = EDTA Mn 13 %; S10 = EDTA Cu 14 %; S11 = Hibor 60 (B_2O_3 60 %); S12 = Molybdate (Ammonium) Mo 54 %; S13 = Potassium Sulphate; S14 = Potassium carbonate; S15 = monoammonium phosphate; S16 = diammonium phosphate.

Table 4: Fertiliser formulated in this study and formulation by MARDI

Source of fertiliser	Mass (kg)	
	Formulated fertiliser in this study	MARDI formulation
S1	1.797	0.00
S2	10.581	10.580
S3	2.220	2.220
S4	2.074	6.600
S5	4.665	0.500
S6	5.000	5.000
S7	0.190	0.015
S8	0.038	0.190
S9	0.042	0.002
S10	0.002	0.029
S11	0.029	0.017
S12	0.001	0.001
S13	n/a	n/a
S14	n/a	n/a
S15	n/a	n/a
Total cost (MYR)	101.60	108.13

4. Conclusion

A systematic methodology for the design of fertigation fertiliser formulation has been developed in this study. The methodology was applied to design of fertiliser for eggplant and the result is compared with the fertiliser formulated by MARDI. The fertiliser formulation has fulfilled all the nutrient requirements of the eggplant. The formulated fertiliser is slightly cheaper than the fertiliser formulated by MARDI. The fertiliser formulation, however, needs to be tested for eggplant in order to verify the effectiveness of the newly formulated fertiliser.

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