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Agriculture Management Strategies Using Simple Logistic Growth Model

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Agriculture Management Strategies Using Simple Logistic Growth Model

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Abstract. Farm management involves the development of long-term strategies to increase the profitability and competitiveness of its agricultural business. In recent years, mathematical models have been extended to the agriculture sector as a decision-making tool to ensure continuous and optimum supply. One of the well-known mathematical functions by Pierre François Verhulst, the Logistic function, has been widely used in modelling population growth rates. Many processes in biology, ecology, and other areas follow this S-shaped logistic growth. This paper explores the application of a simple logistic growth model for agriculture management strategies. Two applications illustrated here; vegetative growth response of banana to foliar fertiliser and growth of grey mould disease infection on different drying tomato coating period. The model presented here quantitatively estimates the effectiveness of the procedure used.

1. Logistic Growth Model

A logistic function is a common S-shaped curve with equation

$$f(t) = \frac{L}{1+e^{-k(t-t_0)}} \tag{1}$$

where

t = the t (time) value of the sigmoid's midpoint,
L = the curve's maximum value,
k = the logistic growth rate or steepness of the curve.

This logistic function was introduced by Pierre François Verhulst between 1838 and 1847 and devised as a model of population growth. The S-shaped curve used for modelling the crop response to changes in growth factors.

Plant growth analysis is now a widely used tool in fields such as plant breeding, plant physiology and plant ecology. Changes in a phenotype during the growth period can be modelled via growth curves, such as generalised logistic, logistic or Gompertz growth curves. The behaviour of the growth curves can change according to the living organisms, the phenotype to be studied and the environment to which it is exposed. To be able to evaluate growth data correctly, it is required to select a suitable growth curve, and its parameters should be able to be interpreted biologically [17].

2. Agriculture Management Strategies

2.1 Vegetative Growth Response of Banana to Foliar Fertiliser
Banana is a heavy feeder crop and requires a lot of mineral nutrients, especially nitrogen, phosphorus and potassium to maintain high yields in commercial plantations. Nutrients within banana plantation are lost via bunch removal, leaching and runoff. The depletion of nutrients in soil should be managed to maintain high yield. Nutrient losses can be managed through fertiliser application. Still, the grower must be fully aware of nutrient problems to make the right decision concerning the kind, rates and frequency of fertilisers to be applied.

Conventionally granular fertilisers are used to enrich the crop and maintain soil fertility status. However, the accumulation of inorganic sources in the soil can lead to environmental degradation. Also, applying fertilisers granular fertiliser (non-renewable resources) are costly. The alternative method to overcome this problem is the use of foliar fertiliser through direct absorption by the leaf can be more environmentally friendly and cost-effective. There are many sources of foliar fertiliser in the market. Generally, no standard fertiliser management practices are using foliar fertiliser for a specific variety of banana yet. This study explores the feasibility and potential of foliar fertiliser in banana cultivation. The prediction of plant growth using the logistic growth model was used to predict the response in banana plant growth as a result of the different frequencies of foliar fertiliser application.

2.1.1 Methods
The data for this study was obtained from the experiment was conducted at the post nursery stage in a banana plantation, Bukit Perawas, Ayer Lanas, Jeli, Kelantan [7]. Results show that the solution consists of 1mL L^{-1} gave the best dose of foliar fertiliser application. In this study, two different frequency of application were observed i) single application per month, ii) twice applications per month, and iii) No fertiliser applied (as control). The growth parameters taken in this study were; pseudostem height, pseudostem girth and leaf area.

The logistic growth model in this study has been used in [19]. The equation is

$$y = \frac{K}{1 + Ae^{-rt}} \qquad (2)$$

where the parameter values are described as:
y = pseudostem height (cm), pseudostem girth (cm) and leaf area (cm^2) at time t
t = time (week)
K = carrying capacity i.e. maximum growth (cm)
A = constant
r = growth rate (cm w^{-1})

The model was set up and analysed using curve fitting method through *MyCurveFit*. Data fitting was used to find the values of the coefficients (parameters *K, A* and *r*) in equation (2).

2.1.2 Results and Discussions.
The data fitting simulation (Figure 1) shows that the pseudostem height, pseudostem girth and leaf area follows the logistic equation curve and perfectly fit with the experimental data, with goodness-of-fit R^2, ranging from 0.92 and 0.99. The outcome of the parameterisation from the data fitting process, as shown in Table 1.
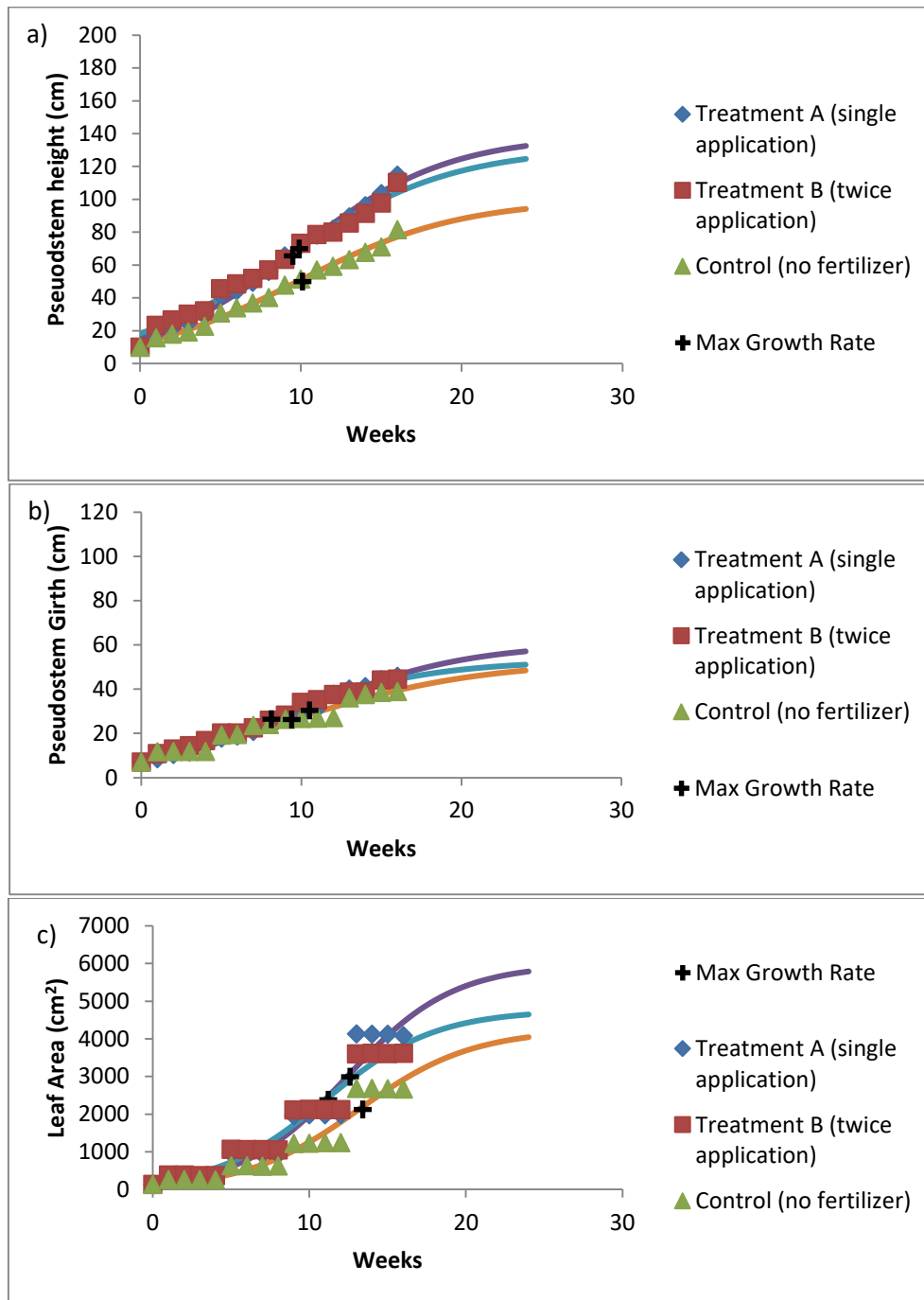
Figure 1. The effect of (a) pseudostem height, (b) pseudostem girth and (c) leaf area of the banana plant on the different frequency of foliar fertiliser application.

For the prediction of the growth, the time of simulation was extended to the 24th week of planting (early reproductive stage). The forecast showed that the banana plant treated by single foliar fertiliser application (Treatment A) better growth improvement compared to twice application in a month. Although as can be seen in Figure 1 that the pseudostem height and pseudostem girth not obvious significantly different from the treatments, however, the leaf area shows the clear significant. A single application had the most leaf area compared to the other treatments. This may be due to leaf age and

cuticle thickness. Increasing age of leaf leads to the increasing cuticle thickness, decreasing cuticle swelling capacity and decreasing nutrient uptake [6]. Several factors can affect the efficacy of foliar fertiliser absorption such as physicochemical properties of the fertiliser formulation, surrounding environment under which foliar fertiliser sprayed and the characteristic of the plant itself [2]. Other than that, at second split application, the leaf has undergone an increase in size through cell expansion. The lamina of banana leaf become more angled as the banana leaf unfolds after emergence. At this stage of leaf growth, the lamina changes from the vertical orientation to the horizontal direction as the lamina moves down the leaf profile [11]. This condition of leaf probably causes foliar fertiliser uptake is less efficient due to drift losses while spraying. With stomata density, mature leaves had reduced stomata density due to these stomata are losses the energy to transport the water. Meanwhile, young leaves photosynthetic exchange and water conductance at maximum level as it has higher stomata density [14]. Reducing in stomata density will reduce foliar uptake.

Table 1. Parameterisation values in equation (2) based on the data fitting.

Growth Parameter	Treatment	A	K	r
Pseudostem Height (cm)	A	8.13	139.09	0.21
	B	6.13	131.39	0.19
	Control	6.85	99.94	0.19
Pseudostem Girth (cm)	A	7.32	60.79	0.19
	B	5.08	52.98	0.20
	Control	4.94	52.60	0.17
Leaf Area (cm^2)	A	38.92	5976.52	0.29
	B	22.98	4763.99	0.28
	Control	37.09	4247.66	0.27

In conclusion, for this particular study, the frequency of a single monthly application is more cost-saving. Banana growers can reduce the cost and time of fertiliser application. Labour cost also can be reduced as the fertiliser should be applied once a month only. This finding can provide the banana growers choices for the frequency of foliar fertiliser which is more affordable to their cost and time availability.

2.2 Growth of Grey Mould Disease Infection on Different Drying Tomato Coating Period
Tomato is known for its climacteric nature where the fruits continue to ripen after harvest. Tomato maturation leads to spoilage and deterioration that attracts fungi such as grey mould, *Botrytis cinerea*. The ripening process increases the fruit's susceptibility towards pathogen [1]. Cuts and bruises on the surface of fruits that happen during mechanical handling will attract *B. cinerea*. This occurrence has been a significant issue on tomatoes that are produced in Cameron Highland, a large local exporter to countries such as Singapore since 2004 [4]. Initially, chemicals are used to treat rising pathogenic infections. The utilisation of fungicides alone is highly effective at 75.12 % when a full dosage is used in treating *B. cinerea* decay in tomatoes [18]. Even though fungicides may be advantageous, its excessive residue is carcinogenic to the other related disease [13]. The growing concern regarding the side effects of synthetic chemicals has led to an increase in research surrounding non-synthetic chemical remedies that can help overcome the early deterioration of fruits and prolong their shelf lives [12].

A large number of studies have been carried out to extend the shelf life of tomatoes by using essential oil [12], ozone treatment [16], hyperbaric pressure treatment [5], active cardboard packaging [3] and UV-C treatment [10]. Nonetheless, most of these methods require high-tech equipment that cares costly and unpractical for commercial, large-scale production. Thus, the edible coating provides a cheap alternative with various studies being actively done to identify their maximum potential in prolonging the shelf life of food products. This study explores the effect of the drying period of edible coating solution (chitosan and cinnamic acid) when the tomatoes were inoculated with *B. cinerea*.

2.2.1 Methods.
Disease management data was validated with an independent set of data from infection occurrence in tomato samples. The model predicted the general trend of population growth. The fruit samples data were divided into control and infected groups taken at a time interval of 30, 60, 90, and 120 minutes. The concentration of the edible coating (chitosan and cinnamic acid) solution used was from the results in [8,9]. *B.cinerea* was inoculated to the tomatoes, and disease progression was observed.

The logistic growth model used in this study was

$$\frac{dy}{dt} = ry(K - y) \tag{3}$$

where;

y = disease progression
t = observation time (days)
K = carrying capacity
r = *Botrytis cinerea* growth rate (days^{-1})

A goodness of fit was performed using a built-in tool in Matlab 'fminsearch'. Fitting the curve means finding parameter that minimised the sum of square errors. Observation of disease incidence and fungal infection on the tomato samples were conducted for 18 days until the fruits were completely infected.

2.2.2 Results and Discussions
Figure 2 shows a noticeable growth of *Botrytis cinerea* in tomato samples with different drying period of 30, 60, 90 and 120 minutes. Tomato samples were observed every three days to record the prevalence of *B. cinerea* as a reflection of the effectiveness of the coating treatment for economic returns.
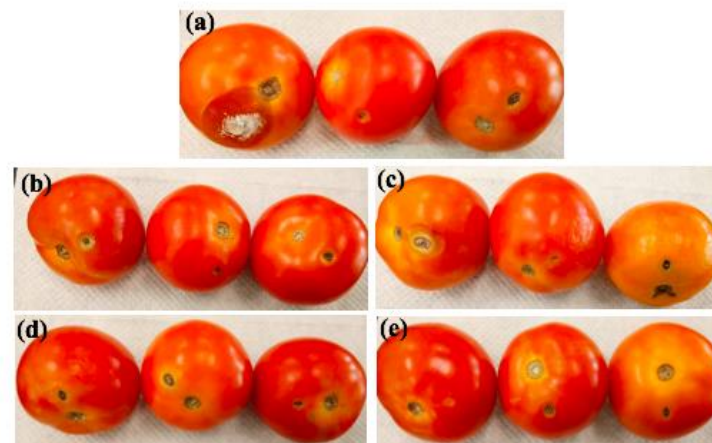

Figure 2. Grazing tomato after 18 days. a) control, b) 30 minutes, c) 60 minutes, d) 90 minutes and e) 120 minutes.

Figure 3 demonstrates the levels of infection in tomatoes against the time. It was inferred that the levels of fruit infection are dependent on days in storage. The outcome graph from a simulation using MATLAB. The model helps to identify the period of infection that demonstrates symptoms of a disease outbreak. The combination of chitosan-cinnamic acid coating delayed the development of disease caused by *B. cinerea* compared to the untreated.

Table 3 shows that the growth of *B. cinerea* was the lowest at 120 minutes drying period. The reduction in disease prevalence effectively prevented coated tomatoes from complete contamination by grey mould up to 15 days in storage. Disease progression occurred at different rates; 0.0057 day^{-1} for untreated tomatoes to 0.0019 day^{-1} at 120 minutes drying period (Figure 3). The later the inoculation time, the lower the growth rate of *B. cinerea*. The results prove that coating influenced disease progression as inoculation at 30 minutes differed only by 0.2 % from untreated tomato after initial infection at $t = 0$. By comparing the results, it can be seen that on day 12th of observation uncoated fruit, day 15th of observation for 30 minutes and 60 minutes coated fruit, and day 27th of observation for 120 minutes all fruits had been infected by *B. cinerea*. This result shows that a more prolonged period of coating before pathogen inoculation will delay the disease progress.
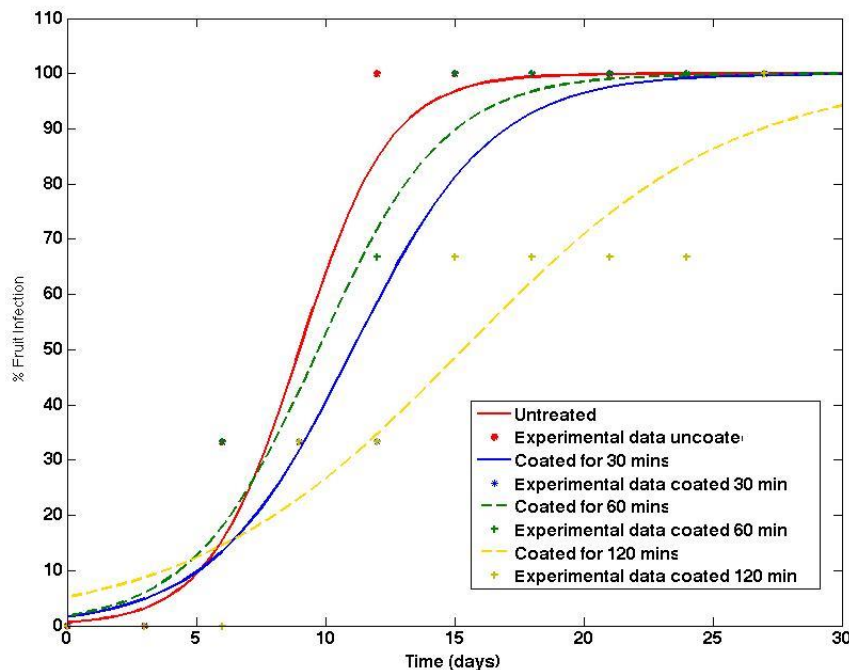

Figure 3. Combined coating chitosan-cinnamic acid efficacy on tomato towards *B. cinerea* infection.

Table 3. Parameterisation of the effect of combined coating chitosan-cinnamic acid on tomatoes samples (Equation 3).

Coefficient	Drying Period (min)			
	Untreated	30	60	120
Growth rate (days^{-1})	0.0057	0.0037	0.0041	0.0019

3. Conclusion

The rising popularity of modelling has observed its application in many areas such as to assist research and farm operation from small to large agriculture holder. The development of a mathematical model act as a predictive system attract farmers to accept this new technology as well as aiding them in the decision-making process in disease management in their farms. Although the logistic growth model is a simple mathematical equation, it does represent the agriculture phenomenon. Complex models often give more precise but not necessary. The complicated models can the modeller into believing that the model is better at the prediction that it is. On the other hand, simple models may be useful for understanding. Economist Arnold Zellner quotes "Keep it sophisticatedly simple" [17].

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