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Fuzzy Decision Support Model based on Virtual Plant for Green-Leaf Vegetable Investment

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Abstract – *Plant computational model (PCM) is a 3 dimension (3d) virtual plant model that configures the whole plant growth system statistically and morphologically. It is a part of the study result of the bigger domain, environmental or ecological informatics. This study constructed the PCM of green-leaf vegetable plant Bok Choy (Brassica chinensis L.). The model was combined with other constructed decision support models (DSM) to give users an investment suggestion. Three kined of method operated here; functional-structural plant model (FSPM) functioned to develop the PCM, fuzzy logic used to develop the investment model, and simple mathematical approach operated to merge both models. The hybrid model can suggest the optimal decision in investing the green-leaf vegetables economically and environmentally. 2,696 Bok Choy plants are a break-event-point the farmer can plant that give a profit.*

Keywords — *plan computation model, decision support model, functional-structural plant model, Bok Choy, fuzzy logic, investment, green-leaf vegetable.*

I. INTRODUCTION

Bok Choy is one of the imperative vegetable plants consumed by the people in the world. It consists of multi-vitamins that are needed by the body health. It is easy to plant, even done in a hydroponic environment. By using a little treatment, the Bok Choy can grow well and give some benefits. The research of the plant is still growing, specifically for seeing the potency economically and environmentally.

A plant computational model (PCM) is an interesting research domain. It is a part of the study domain of ecological or environmental informatics. It combines several knowledge areas like statistics, mathematics, informatics, biology, agronomy, botany, and ecology. PCM can simulate detailed information about plant growth in 3 dimensions (3d) environment [1]. The model possibly depicts the plant's growth statistically and morphologically. It is surely beneficial for the researcher and agronomist to see the potential aspect of optimizing the plant's yield.

The research in PCM was broad. For example, the virtual plant Green Amaranth was constructed well by [2]. It is still a preliminary study; however, it has good potential to be deeply researched, as the study talked about a unique Indonesian plant. [3], who conducted a basic study of the graph that is implemented into basic virtual plant modeling. [4] conducted a study on the modeling of young spruce plants. The modeling results enable the growth and development of the evergreen plant to be seen more realistically (rightly so with the original). The basic form of the plant was presented in a more realistic view. And also [5] who is modeling apple plants using GroIMP-FSPM; finally, the GroIMP becomes a modeling platform, and the FSPM is a popular method operated in the PCM research domain.

Furthermore, [6] developed the virtual rice plants model that proposed the best architecture for intercepting the sunlight. The best one was hypothetically able to give the best yield. It was a part of [1] big work in developing the optimization model of the 3-d structure of the plant. In more detail, the model can simulate all sunlight behavior for all areas in the world. It is practically beneficial for a model to simulate the sunlight intercepted by the plant in various areas.

Also, several years ago, many researchers conducted researches in this area, where FSPM operated as the main method. FSPM also explicitly reflects structural aspects of plant architecture, internal functional aspects, and environmental impacts [7]. All it allows the growth of people and individuals and the level of the plant stand itself. One of the pioneering researchers was de Reffye and colleagues in 1988. The study others [8] combine qualitative botanical analysis and quantitative statistical analysis to create a 3-d tree architectural simulation model with agroforestry applications, using data categorized into processes growth, branching processes, and geometric aspects. [9] designed a LIGNUM model that depicts a 3-d tree canopy (segments, branching points, and shoots) and defines deep growth. It has to do with carbon metabolism that occurs in units corresponding to the organs tree.

Lindenmayer and Prusinkiewicz use the L-system, a system of rewriting strings parallel, to represent the architectural development of plants [10]. This formal language theory approach simulates ontogenesis in dependence on the light regime in plant crops such as maize [11] and wheat [13]. In forest ecology, [14] developed the FSPM to calculate the annual photosynthetic gain in beech saplings (Fagus Crenata). The calculation of the annual photosynthetic gain was used to find out the effect of leaf phenology and shoot slope on the carbon economy. Similarly, [15] uses FSPM as a virtual laboratory for evaluating the effect of alternative local plant architectures on the performance of the entire canopy. He obtained results about the functional significance of foliage parameters for understanding the architectural development of plants and their foliage. Likewise, [16] used FSPM to investigate the effect of geometric properties (internode length, area leaves, angle of branching, and shoot diameter) on the efficiency of tree light interception Apple.

Here, the research in the PCM domain was conducted, with Bok Choy planted in the hydroponic system as an object of the research, associated with the decision support model (DSM), suggesting the objective decision based on environmental features. Indeed, it is a part of a big research project of a PCM development for the Bok Choy plant. Bok Choy itself is a vegetable plant with many vitamin ingredients; it consists of more than 50% vitamin C and is similar to Orange [17]. It is usually used to consume. It is categorized as a short-age vegetable plant; it is habitually harvested at age 40 ± 5 days after seedling. The introduction part of the paper will be continued by other parts respectively; research methodology, result and discussion, and conclusion and further works.

II. RESEARCH METHODOLOGY

The study's three main stages are mentioned in Fig 1: plant seeding and planting, data collecting, and model developing. Vegetable plant Bok Choy was seeded and planted in a hydroponic system. It was seeded in rock-wool with size 2.5 X 25 X 15 cm, where size 2.5 x.2.5 x 2.5 cm practically operated for one plant. Thus, there are 60 Bok Choy seeds in one rock-wool area (see Fig 2), they started to appear on the second day after seeding (DAS). And, when they had approximately three or four real leaves, they were ready to be moved into each 7 cm height-size net-pot and putted in system hydroponic (see Fig 2).

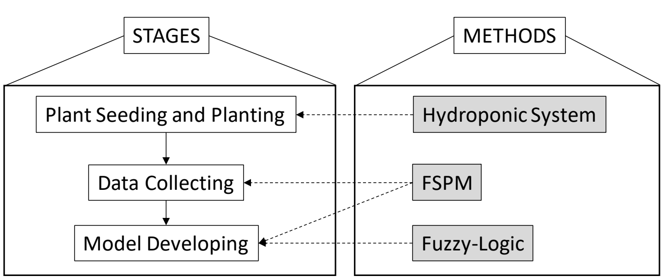

Fig1: Research Stages and Methods

Furthermore, data collecting was performed. It was done day by day to observe above-ground plant Bok Choy's growth morphologically. The growth of Bok Choy's main stem, petioles, and leaves were precisely watched and examined. It was performed on 10%-20% of planted plants randomly.

Moreover, the virtual plant model was developed. The data collected will be delivered in a mathematical model and then coded in the GroIMP modeling platform. FSPM and Fuzzy-logic methods (ever operated in [18]) were operated to construct it, and respectively they functioned in making virtual plant models and decision support models (DSM).

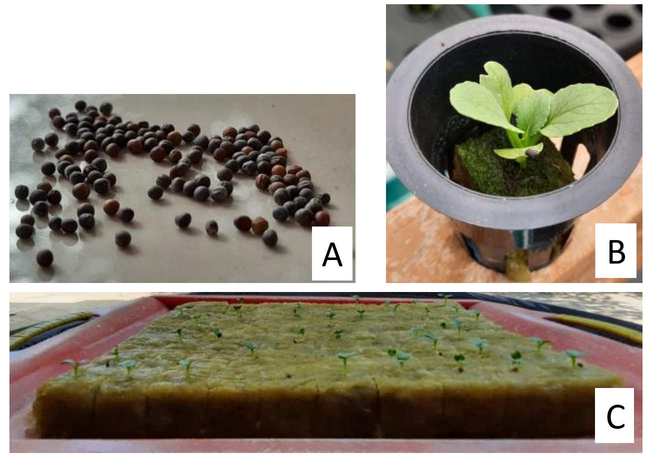

Fig 2: (A) Bok Choy Seeds (B) Net-pot with Four Real-Leaves Bok Choy (C) Rock-wool with Sixty Bok Choy Seeds

II. RESULT AND DISCUSSION

A. The Whole Part of the Constructed Model

The constructed virtual Bok Choy plant model is novel. Several researchers ever talked about virtual plat of apple, rice, pine, etc. the virtual Bok Choy plant has a unique characteristic. It has a soft stem, and it could be eaten. It has a stack stem and continuously grows until 25 peaches of the stem.

The constructed model consists of two big parts; actually plant and decision model. The class diagram in Fig 3 can configure it. The plant model (virtual model) describes plant growth and generates several important information, such as plant form, plat's weight, length and width, growth pattern, nutrition composition, and other biological information. Additionally, the decision model calculates decision-makers can take the possibility of investing value to make a profit. Those all parts of the model can be shown in Fig 3.

Moreover, the model's process flow can be illustrated well in Fig 4 using an activity diagram. In the diagram, all processes are done by the model until the model proposes the decision. Here, all information and data are generated technically from plant growth.

B. Plant's Growth Model

Morphologically, the above-ground plant Bok Choy with 20 day-age is presented via toy picture without texture in Fig 5 and toy picture with texture in Fig 6. It consists of main-stem, petiole, preliminary leaves (red, blue, yellow, and grey), and preliminary leaves (the green ones). Abnormally, the second real leaf has worse performance than the first real leaf. However, for the third real leaf until nth real leaf indicate that the next leaf has better performance.

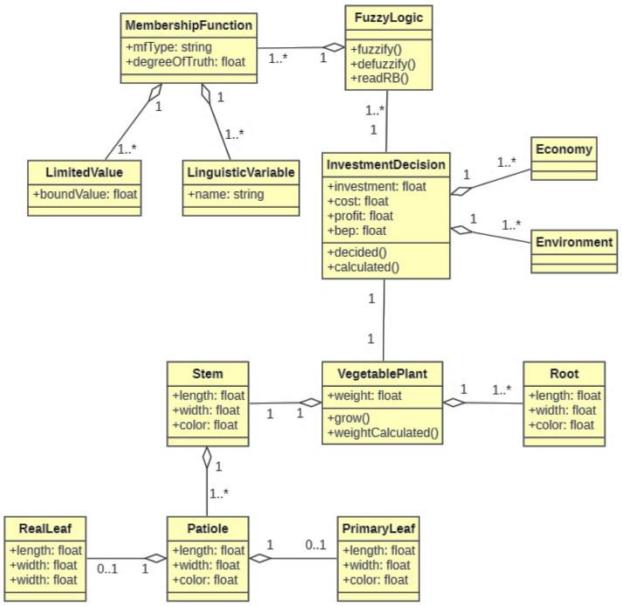

Fig 3: Class Diagram of Constructed Model

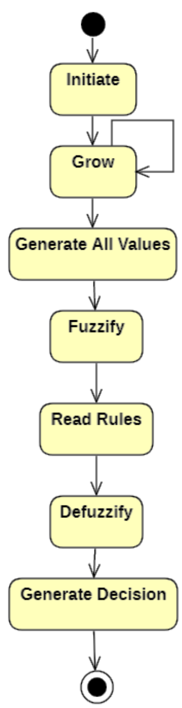

Fig 4: Activity Diagram of Constructed Model

The mathematical model for illustrating the real leaf length (RLL), real leaf width (RLW), real leaf petiole length (PL), and real leaf petiole diameter (PW) are respectively presented in equations (1) – (4); where ln is a leaf number (3 until n); lpn symbolizes a leaf petiole number (3 until n), A denotes a plant age, SD represents a starting day for growing, and ED signifies an ending day to grow. Each leaf and its petioles grow at around 12 days, starting to grow every 3 days.

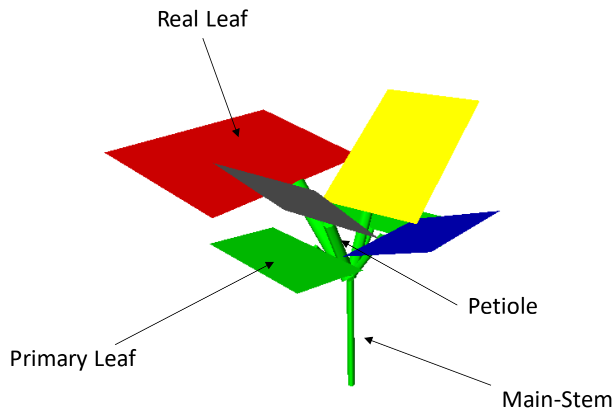

Fig5: Toy Model of above-ground Plant Bok Choy

Fig6: Toy with Texture Model of above-ground Plant Bok Choy

The variable $dayAppear$ means the $i-1$th day from stem, petiole, or leaf starting to grow. The specific condition is operated to model the increment of diameter or width of stem and petiole, where the increment value is 0.025cm $\pm$random(0.00cm, 0.025cm) in one particular condition. For example, the mainstream's diameter increased 0.0063cm on the 8th day.

The trend graph of RLL (the blue line) and RLW (the orange one) in 12 days (in average value from ten types of the real leaf) could be presented in Fig 7. Both trends grow linearly. Furthermore, the trend-line of RLL and RLW respectively are configured in equations (5) and (6), where x is a day. On the other hand, the trend graph of PL (the blue line) and PW (the orange one) is displayed clearly in Fig 8. Those trends expand slight-exponentially. They are formulated in equations (7) and (8) correspondingly.

$$RLL_{ln} = \sum_{i=SD}^{ED} ln \times \Big[(-0.0014 \times (A - i) + 0.1284) \pm rand\Big(\big(0, (-0.0013 \times (A - i) + 0.0588)\big)\Big)\Big] \quad (1)$$

$$RLW_{ln} = \sum_{i=SD}^{ED} ln \times \Big[(-0.0013 \times (A - i) + 0.0766) \pm rand\Big(\big(0, (-0.0008 \times (A - i) + 0.0355)\big)\Big)\Big] \quad (2)$$

$$PL_{lpn} = \sum_{i=SD}^{ED} lpn \times \Big[(0.006 \times (A - i) + 0.0337) \pm rand\Big(\big(0, (0.0028 \times (A - i) + 0.0194)\big)\Big)\Big] \quad (3)$$

$$PW_{lpn} = \sum_{i=SD}^{ED} lpn \times \Big[(0.002 \times (A - i) + 0.0021) \pm rand\Big(\big(0, (0.0011 \times (A - i) - 0.0002)\big)\Big)\Big] \quad (4)$$

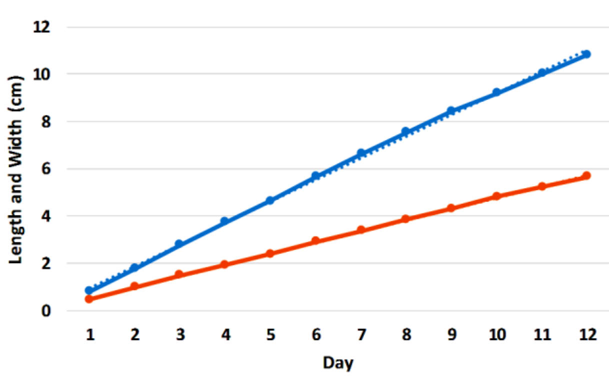

Fig7: Average RLL and RLW in Twelve Days

$$f(x) = 0.9159x + 0.035 \quad (5)$$

$$f(x) = 0.4723x + 0.0411 \quad (6)$$

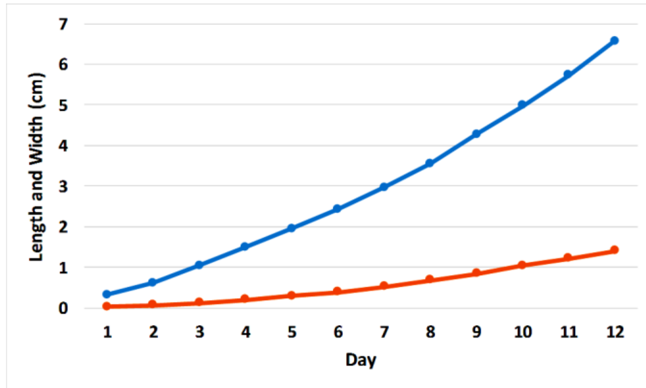

Fig8: Average PL and PW in Twelve Days

$$f(x) = 0.4341e^{0.2493x} \quad (7)$$

$$f(x) = 0.0434e^{0.322x} \quad (8)$$

Fig 9 shows horizontally (also vertical, shown in Fig 10) the artificial model of above-ground 25 Bok Choy plants planted in one hydroponic area with a planting distance of 4.0cm. The model was constructed via the real stem, petiole, and leaf lamina of the twenty-day-age Bok Choy plant. They mostly consist of two preliminary and five real leaves.

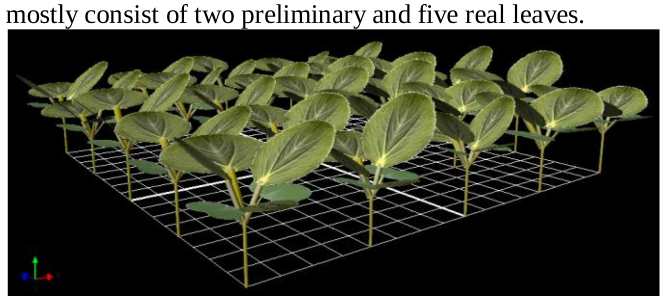

Fig9: Artificial Plants of Above-Ground Twenty-Day-Age Bok Choy in Horizontal View

C. Investment Decision Model

The construction of the membership function for four parameters (plant number, profit, cost, and sale) are configured in Fig 11 until 14. They were developed by the combination of two types of membership functions (trapezoidal and triangular types). All membership functions are constructed based on data collected, especially for parameters profit, cost of production, and sale amount. In real, profit is in the range IDR 0.00 until more than IDR 1M; cost of production is in the range IDR 0.00 until more than

IDR 40.00M, and sale amount is in the range IDR 0.00 until more than IDR 50.00M.

One decision that could be proposed from the model is investing decision. For assumption for operational investment presented in TABLEI, the investors can profit when they harvested the plants in the second period when they planted around 2,696 plants. The simulation result of the profit in the second period of harvest is shown in TABLE II. Then, the graph of cost (blue line), sale (orange line), and profit (grey line) for the second period of harvest are displayed in Fig15, where the type of plat planted number is taken from a column of plant planted number in TABLE II. Fig15 shows the type 6 starting to indicate that the investment is going to give a profit.

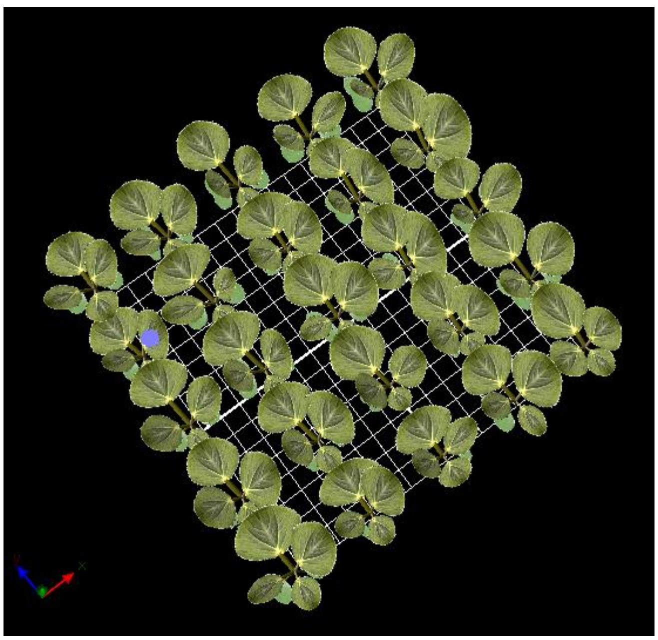

Fig10: Artificial Plants of Above-Ground Twenty-Day-Age Bok Choy in Vertical View

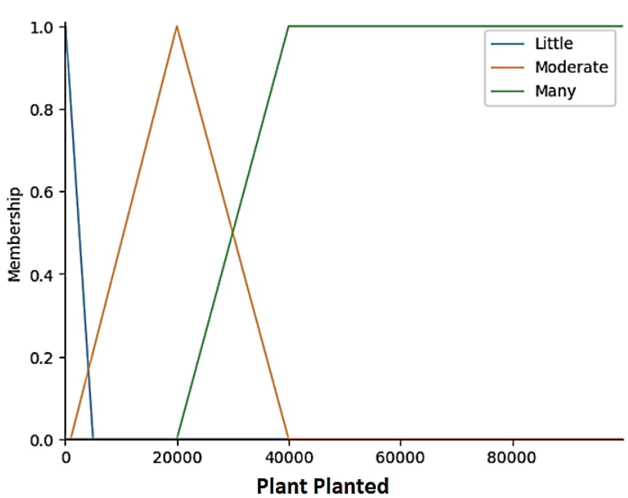

Fig 11: Planted Plant Number

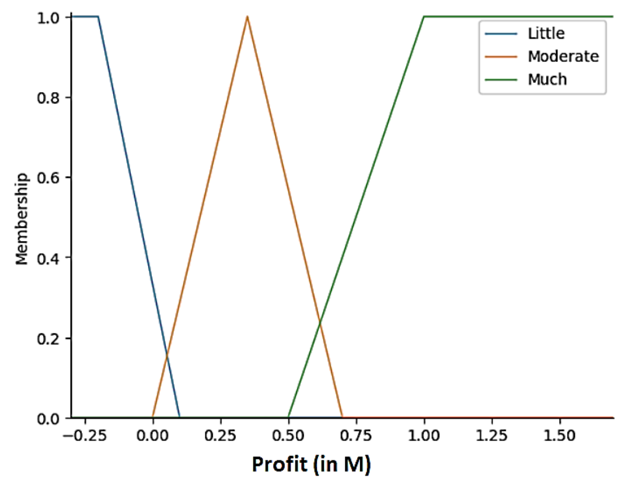

Fig 12: Profit of Production

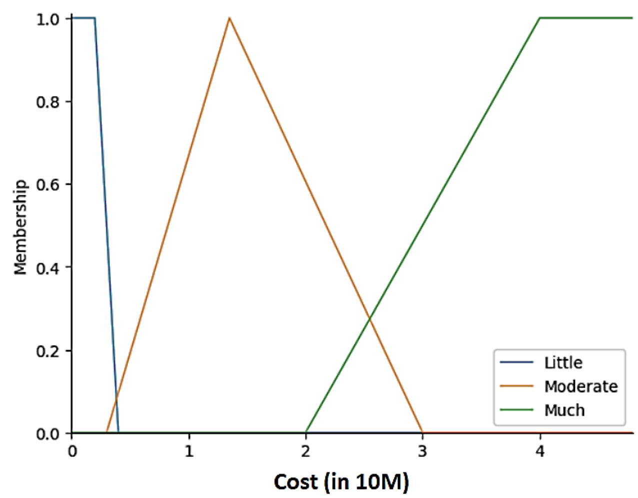

Fig 13: Cost of Production

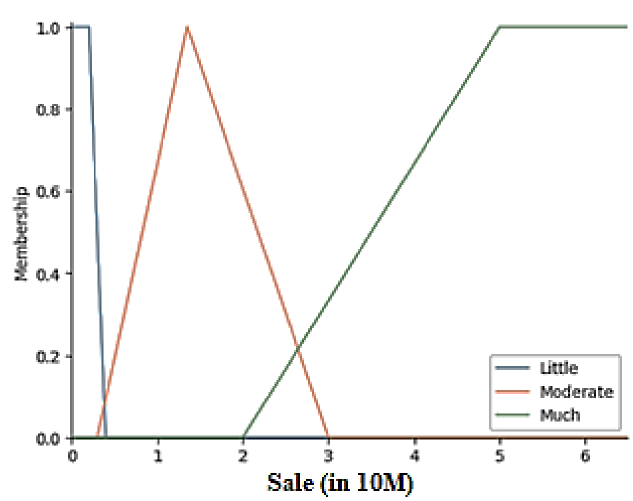

Fig 14: Sale Amount

TABLE I
Assumption of Operational Investment Percentage

No.	Operational Investment	Percentage
1	Rockwool	0.08
2	net pot	0.34
3	Seeds	0.04
4	Water place	0.27
5	Styrofoam	0.27

TABLE II
Simulation Result of Investment

No.	Planted Plant Number	Sale (IDR)	Profit (IDR)
1	1	1,555,555.56	-1,600,000.00
2	10	1,555,555.56	-1,600,000.00
3	100	1,555,555.56	-1,600,000.00
4	1,000	1,626,722.48	-1,522,208.88
5	2,000	7,639,713.55	-651,074.33
6	**2,696**	**10,323,230.74**	**254.15**
7	5,000	16,196,594.43	3,500,000.00
8	10,000	15,862,976.41	3,500,000.00
9	30,000	35,801,227.96	9,029,585.55
10	50,000	48,744,583.19	12,139,839.33

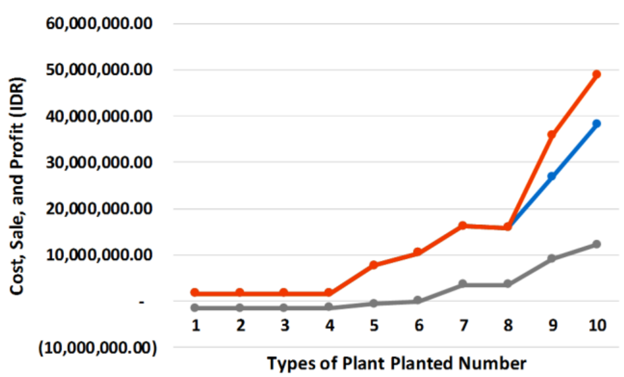

Fig15: Cost, Sale, and Profit Comparison

D. Discussion

The virtual plant model combined with the decision support model for making a strategical decision in hydroponic investment was successfully constructed. Moreover, the mathematical process to suggest the decision is done by implementing the fuzzy logic method. Several researchers conducted the PCM research. However, they did not practically combine the result with the decision aspect and operate the fuzzy logic concept. Here, the model can show the simulation in the 3D environment of plant growth in detail. The model can give any information insight concerning plant growth, vitamin ingredient per plant, and also can model the investment that investment can take.

III. CONCLUSION AND FURTHER WORKS

The virtual plant model has been successfully constructed. It can simulate step by step Bok Choy plant growth and development. It can practically be operated to see various elements mathematically and statistically in a 3d agronomical-based view. Plant growth was simulated well, and it can also function for any agronomy research domain. Furthermore, the virtual plant model joined with other constructed models (DSM) to simulate the investment strategy for green-leaf vegetable investment. The model can suggest to the investor that the investor has to plant at least 2,696 Bok Choy plants in the hydroponic system to get the profit.

Other research fields have opportunities to benefit the constructed model to do other studies. The optimization field is open to doing, particularly to optimize plant growth in several factors; weather, land condition, and vitamin. Thus, the decision-maker can take the right decision to select the best way to plant. Also, the field of decision support models is still open to study. The model should be developed to benefit a large number of stakeholders; government, agronomist, researchers, and farmers.

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