ICIC Express Letters
Part B: Applications
Volume **13**, Number **5**, May **2022**

ICIC International ©2022 ISSN 2185-2766
pp. 455–462

PLANT COMPUTATIONAL MODELLING OF GREEN AMARANTH FOR PREDICTING ECONOMIC INVESTMENT

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Received July 2021; accepted October 2021

Abstract. *Many research teams worldwide have pioneered new plant science methods by developing plant computational modelling in the past decade. This approach uses functional-structural plant model (FSPM) to understand the complex interactions between plant structure and the physical and biological processes that drive plant development on multiple spatial and temporal scales. One of the software used for FSPM is the growth-grammar interactive modelling platform (GroIMP). GroIMP is a Java-based platform using the XL language, which is the language developed from L-system. The FSPM-GroIMP method in plant modelling uses GroIMP software by reviewing morphology, physiology, and statistical data. This research succeeded in modelling the growth of green amaranth (Amaranthus Sp.) on the hydroponic planting system using the FSPM-GroIMP method. The modelling results show the growth pattern and weight of green amaranth until harvest. It also predicts the profit yielded. Other results showed that the optimal distance between plants was 150 mm, the average of a single green amaranth plant weight was 11.85 g, and the profit was IDR 274,808 for 500 plants.*

Keywords: Plant computational modelling, Functional structural plant modelling, Growth-grammar interactive modelling platform, L-system, Green amaranth

1. **Introduction.** Plant computational modelling (PCM) is one of the fields of ecological informatics (eco-informatics) or environmental informatics combined with other fields of science, such as computer science agriculture, biology, botany, and statistics. PCM produces computational modelling of plants with detailed morphological and physiological analysis.

The functional-structural plant model (FSPM) is the latest PCM method to understand the complex interactions between plant structure and the physical and biological processes that drive plant development on multiple spatial and temporal scales. A suitable FSPM method should incorporate proven techniques for both functional and structural modelling. The L-system has been proven to model plant functionality well, but the L-system is only a string/symbol for the plant structure. The disadvantage of the L-system is visual plant modelling. Thus, a good FSPM technique can be an L-system combination, extended to network-like systems, and an extended programming language with features that make it easy to model parts of a plant structure.

The concept of relational growth grammar (RGG) is the standard of an FSPM modelling technique with graphs that can provide data representations capable of describing plant structures [1]. The extended L-system (XL) language developed from the L-system and supported of the RGG concept makes it easier to build complex models [2]. One open-source software that uses the XL language and supports the RGG concept is the growth-

DOI: 10.24507/icicelb.13.05.455

grammar interactive modelling platform (GroIMP). GroIMP is designed as an integrated platform combining modelling, visualization, and complex interactions.

Numerous researchers have carried out research in FSPM, one of which is about implementing graphs to model virtual plants [3]. Other research that has been done is related to modelling five types of rice varieties in Indonesia [4], including the ability of rice plants to absorb sunlight [5]. FSPM and GroIMP have been used to analyze the transfer of water and sugar in the stem of apples (*Malus Domestica (L.) Bartsch.*) [6]. Soybean turgor pressure throughout the plant life cycle can be understood and modeled using FSPM and GroIMP [7].

PCM research is an innovation that provides the best results for agriculture in Indonesia. Because it can produce optimal plants through a computational hydroponic plant morphology model using the FSPM method implemented using GroIMP. Research to create a virtual plant model (PCM) on green leafy vegetables, namely green amaranth (*Amaranthus Sp.*), is an innovation to increase agricultural yields. In Indonesia, there is an increase in the intake of green leafy vegetables because green leafy vegetables are included in a high-quality and nutritious diet. The iron content in green amaranth is relatively higher than other leafy vegetables, which is needed by children and women of reproductive age [8]. Moreover it contains vitamins A, B, C, protein, fat, carbohydrates, potassium, essential minerals such as calcium, phosphorus, iron [9] and is a potential source of antioxidants [10]. The morphological computational model built using FSPM-GroIMP can simulate the growth and development of green amaranth in three dimensions in detail. The growth process will take 25 days. Green amaranth plants grow at a pH of 6-7 and can be harvested 3-4 weeks after planting. A computational model of green amaranth hydroponic morphology was developed to predict plant nutrition, plant weight, and plant selling price.

2. **Previous Works.** A model using GroIMP has several parameters that determine its growth strategy, and it is assumed that these parameters represent genetic information that can change with evolution. The research can create models by showing the structural aspects of plant architecture, internal functional elements, and environmental impacts [11]. The rice model was optimized for light's influence based on leaf growth parameters and leaf angle of two rice varieties [4]. The resulting rice plant model can imitate above-ground native rice plants at their vegetative stage.

The differences between species in functional traits are key in explaining the positive diversity-productivity relationship in plant communities. Taking intercropping of wheat (*Triticum aestivum*) and maize (*Zea mays*) as examples of mixed vegetation elements, this research demonstrated that plasticity in plant characteristics is an important factor contributing to complementary light capture in a mix of species [12]. [13] made a model with LIGNUM for Scottish pine plants with PYGMALION and GroIMP software for sensitivity analysis. It aimed to measure how much influence geometrical location has on sunlight absorption in conifers. Plant modelling based on the Xfrog approach and the GroIMP platform produces plant visuals similar to native plants [14].

FSPM and GroIMP have been used to know the development of the canopy structure of the Norwegian spruce cypress tree (*Picea abies Karst.*) and use it to model biomass production more realistically [15]. FSPM method [16] was used to increase the vegetative phase in the first fruit, and the F1 hybrid yield was higher because it inherited the superiority of its parent (P1, P2). FSPM and GroIMP are used by researchers [17] to combine plant computing models which were developed on different platforms. There are identical similarities and also colours differences in plant simulation platforms. FSPM is also used for light detection and ranging (lidar). With the rapid development of facilities and algorithms, lidar provides powerful new tools for 3D phenotyping analysis [18].

3. **Research Method.** The stages of this research include 1) preliminary study, 2) breeding and planting, 3) model analysis and design, and 4) model construction. Figure 1 describes the stages of the research with the methods used and the output produced at each stage. Preliminary study is conducted to find the comprehensive understanding of selected research object (Amaranth plant). The data are collected in the second stage, and then operated in model analysis and design (the third stage). Finally, the model is constructed by using FSPM-GroIMP.

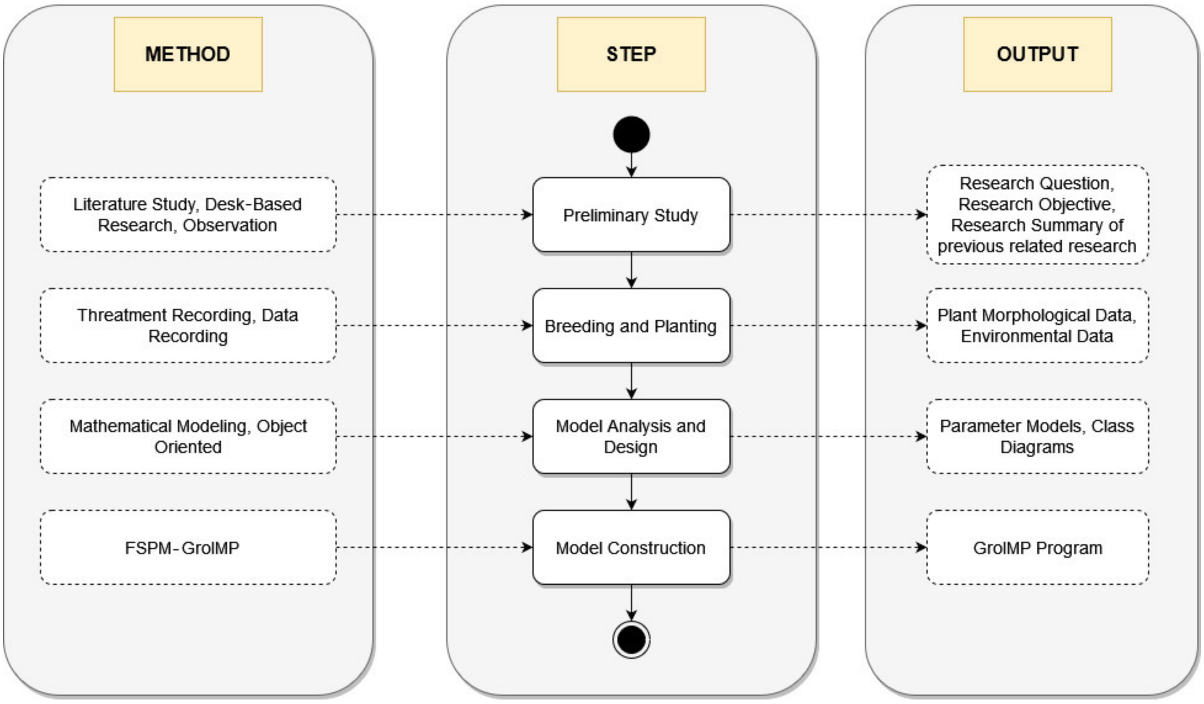

FIGURE 1. Research stages

3.1. **Preliminary study.** The initial stage of this research was a preliminary study consisting of literature studies. The literature study was conducted to determine previous research and explain the theoretical basis and methods used in this study. Study literature is done by searching and reviewing several virtual journals reading sources, both from journals related to computing systems and agriculture such as IEEE, Springer, Frontiers in Computer Science and ACM. Desk-based research was conducted to find the price of green amaranth and the required cost on the Internet. As for the observation see how to plant green amaranth based on hydroponics system by farmers.

3.2. **Breeding and planting.** The breeding and planting stage (seeding and planting crops) is carried out using a hydroponic system. In this stage, the plant data is appropriately recorded in detail. The recording is done every day in order to get a good model. The data that must be recorded are plant height, stem length and width, leaf length and width, leaf colour, leaf number, weather condition, type of fertilizer, fertilizer solubility, water pH, and water temperature. The growing angle of the stems and leaves was also recorded for modelling purposes. The tools used to obtain the data include rulers, bows, screw micrometres, TDS meter devices, pH meters, and Internet access for photos and temperature and humidity viewing conditions.

3.3. **Model analysis and design.** The next stage is the model analysis and design. The method used is FSPM which is implemented using GroIMP. This method combines structural, physiological, and statistical models in building computational models of plants [19]. The XL programming language is used for GroIMP modelling simulations [20]. One of the object-oriented method tools is class diagrams. The class diagram helps describe each entity involved and the relationships between entities.

3.4. **Model construction.** The model construction stage is building a model with the obtained data, then verifying and validating the model's results. The method used to construct the model is FSPM-GroIMP. The model construct built at this stage is the entire model from the design stage to implementation.

4. **Analysis Results.** The configuration of the model to be developed can be seen in Figure 2. Hydroponic-based green amaranth will be converted into a 3D virtual plant computation model. It will then produce various data and information that are important in morphological, physiological, weather data, etc.

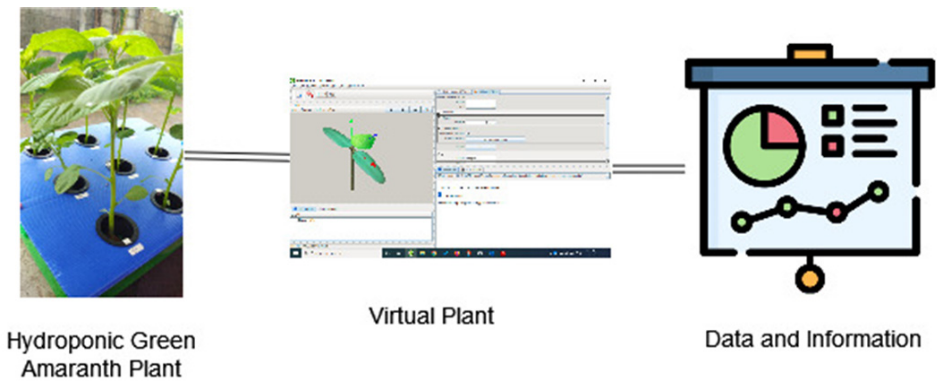

FIGURE 2. Model configuration

The description of the model from this research can be seen in Figure 3 using a class diagram. Class diagrams describe the relationships between entities in the study to be carried out. In Figure 3, the model to be developed is the virtual plant model. In the virtual plant model, there are two main classes, namely AmaranthPlant and WaterNutrition. Each class has attributes that describe the specific properties of that class.

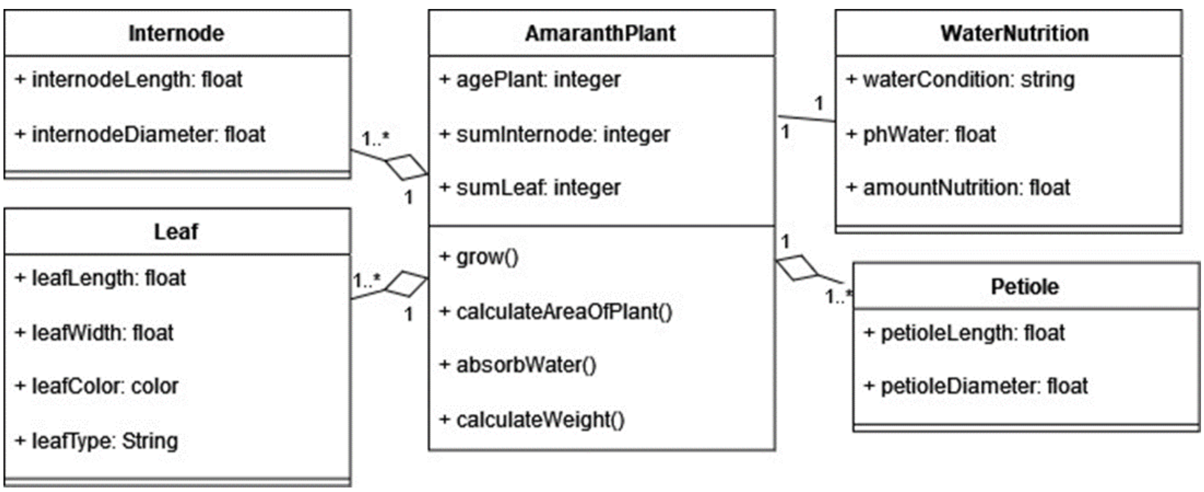

FIGURE 3. Class diagram of model

The process flow of the model developed is depicted clearly in Figure 4. The model process begins by defining the age of the amaranth plants ready to be harvested, which is 25 days. The model runs the Grow function up to 25 times. The model will calculate the plant weight, leaf area, volume of the internode, amount of nutrients produced, and

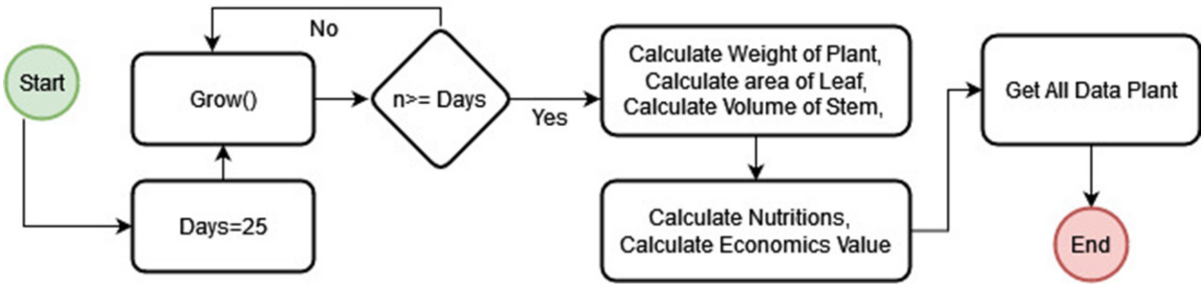

FIGURE 4. Process flow of model

the economic value. The economic value is calculated from the income obtained from the estimated revenue in the market, which is IDR 70,000 per kilogram minus the costs.

It needs a density constant for each part of the plant to obtain the weight of the plant. The parts of the plant that were calculated were leaves, internodes, and petioles. Leaf density is obtained by calculating the weight of the leaf divided by the leaf area. Leaf area calculations are carried out with the assumption that the shape of the leaf is oval. For that, the formula used for calculations was the formula for calculating the area of an oval shape. In contrast to leaf density calculations, internode and petiole density are obtained by calculating weight divided by volume. Internode and petioles are tubular, so to get the volume, the formula used $\pi \times \frac{D^2}{4} \times t$, where D is the diameter and t is the length. Table 1 shows the result of the field calculations. The calculation was carried out with a scale with an accuracy of 0.01 grams (g) and a calliper with an accuracy of 0.01 millimetres (mm).

TABLE 1. Density of leaf, internode and petiole

	Weight	Volume or area	Density
Leaf	2.41 g	17830.41 mm^2	0.000135 g/mm^2
Internode	4.77 g	1411.62 mm^3	0.003379 g/mm^3
Petiole	0.82 g	217.90 mm^3	0.003763 g/mm^3

The green amaranth growth will be modelled in GroIMP with Equation (1), where L_i is the length of the internode on the i-day, and the random function (x, y) will generate a random number with a range of x to y. The value of minimum growth and maximum growth per day is calculated based on the recorded data every day. Each part of the plant has a different pattern of growth.

$$L_i = L_{(i-1)} + Random(Min\ Growth, Max\ Growth) \tag{1}$$

A virtual hydroponic green amaranth plant with its parts was obtained with the growth pattern and rules made by visualizing it in Figure 5. Furthermore, the outputs of the constructed model are total leaf area, total weight, economic value, energy content, protein, fat, carbohydrate, fibre, calcium, phosphorus, iron, vitamin A, vitamin B1, vitamin C and water content. The results of this model were used to experiment with several different plants and spacing. The spacing between plants is calculated by finding the maximum angle, the maximum length of the stalk, and maximum leaf length. It was found that the optimal spacing between plants is 150 mm. This spacing is then used to experiment with several different plants. Figure 6 shows a virtual hydroponic amaranth plant as many as 100 plants with optimal spacing.

Based on the experimental results, the average weight of a single plant is 11.85 g, with a maximum weight of 12.66 g and a minimum weight of 10.87 g. Figure 7 shows the weight development of 100 plants from planting day to harvest day. The weight of the

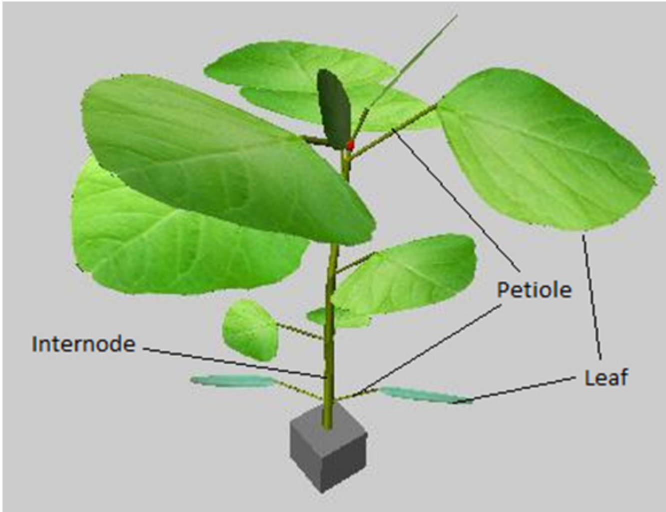

Figure 5. Virtual hydroponic green amaranth plant

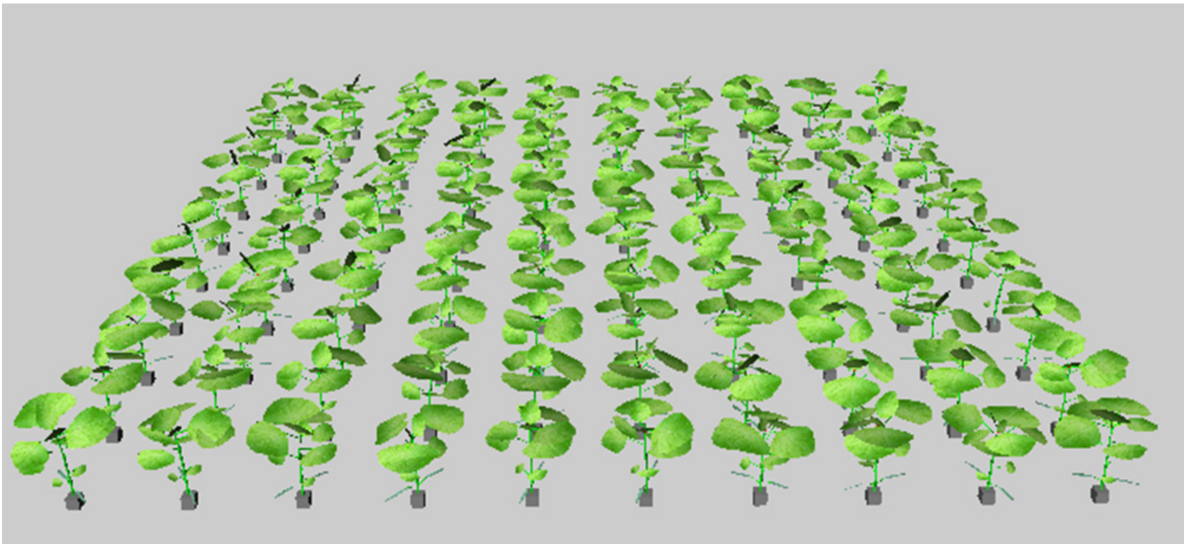

Figure 6. Virtual hydroponic multiplant green amaranth

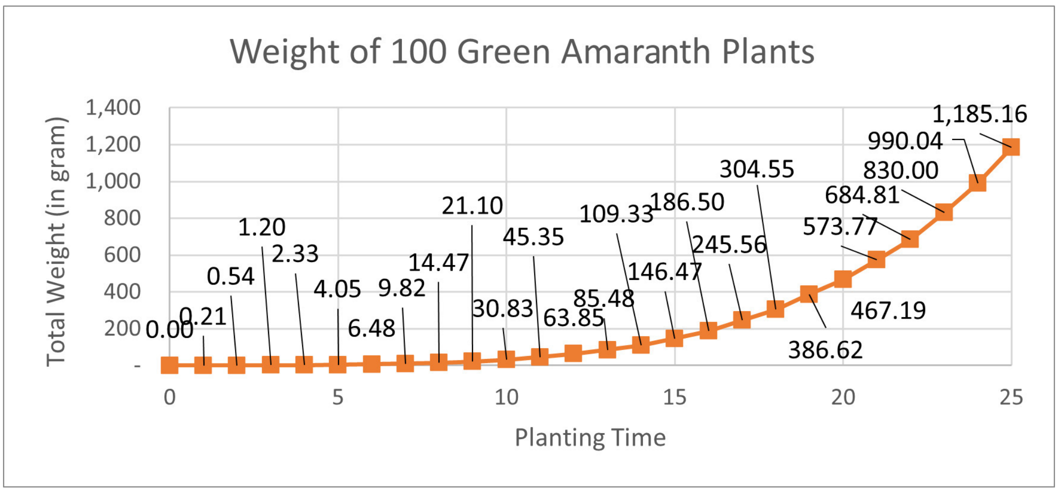

Figure 7. Weight of 100 green amaranth plants

plants produced on the day of harvest was 1185.16 g. The graph shows that the plant will increase in weight exponentially. The seventh leaf and eighth leaf are the widest and appear on the 18th to 21st day.

Figure 8 shows the experimental results for several green amaranths and their predicted profit in one harvest. Experiments were generated with each plant being run ten times and then calculating the average. In this experiment, it can be shown that the more plants planted, the greater the profit.

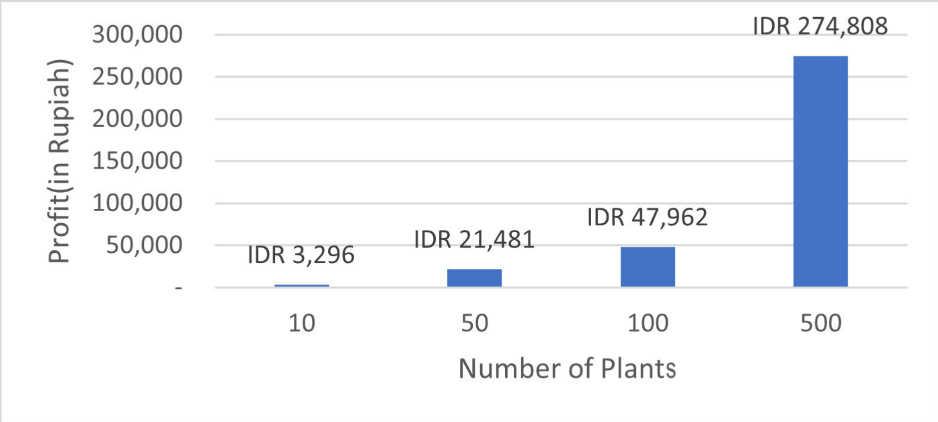

Figure 8. Profit of green amaranth plants

5. **Conclusion.** This research has successfully predicted the economic investment of green amaranth using the FSPM-GroIMP method. The green amaranth plant modelling is built from statistical measurement data and then processed into a mathematical model. This method also allows the researcher to acquire the pattern of plant growth, plant weight, leaves area, and plant density. Plant computational modelling can also calculate the nutritional content of the plant. Future research can examine plant modelling for deciding various strategic decision-making in other fields.

This study has found that the optimal distance between plants was 150 mm. It is important to pay attention to the optimum distance between plants to avoid overlapping growth. A proper arrangement will allow healthy growth that will produce high economic value. In this study, planting was carried out horizontally. For further research, vertical planting can be recommended. To get a better result, future researchers can try giving different treatments such as different fertilizers or different levels of exposure to sunlight.

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