Journal of Computer Science

Original Research Paper

Plant Computational Modelling of Green Amaranth Plant for Investment Analyst using FSPM-GroIMP and Fuzzy Logic

[1]Bakti Amirul Jabar and [2]Ditdit Nugeraha Utama

[1]*Computer Science Department, School of Computer Science, Bina Nusantara University, Jakarta, Indonesia*
[2]*Computer Science Department, BINUS Graduate Program - Master of Computer Science,*
Bina Nusantara University, Jakarta, Indonesia

Article history
Received: 25-10-2021
Revised: 21-06-2022
Accepted: 13-07-2022

Corresponding Author:
Bakti Amirul Jabar
Computer Science Department,
School of Computer Science,
Bina Nusantara University,
Jakarta, Indonesia
Email: bakti.jabar@binus.ac.id

Abstract: Functional-Structural Plant Modelling (FSPM) is plant modeling that considers morphology, physiology, and statistical data. One of the software for FSPM is the Growth-Grammar Interactive Modelling Platform (GroIMP). GroIMP is a Java-based platform using the XL language, which is a language developed from System-L. This study aims to build a virtual plant model of green amaranth (*Amaranthus Sp*.) in a hydroponic planting system for strategic decision-making. In this study, parameter analysis and model development were carried out. The model is divided into two sub-model blocks by operating three methods. There are two sub-models, namely the sub-model virtual plant, and the sub-model fuzzy logic. In the virtual plant model using mathematical modeling and FSPM-GroIMP methods, the results of this model are the growth pattern of green amaranth to harvest, the weight of green amaranth, and visualization of hydroponic green amaranth plants. In comparison, the sub-model fuzzy logic uses the fuzzy logic method to predict the selling price of plants and expenses. The two sub-models are combined to produce hydroponic green amaranth strategic decisions. The output of strategic decisions is a decision that has an impact on investment value. The investment value is measured by the CR Ratio, which is the investment value by comparing the cost with the revenue from hydroponic green amaranth. Other results showed that the average weight of a single green amaranth plant is 11.85 g and the RC ratio value is 4.5 for 500 plants with good plant quality, a fixed cost of IDR30,000, variable cost is IDR20,000 and the price is IDR57,282 per kilogram. Calculations of model verification and validation were carried out and indicated the built model according to the existing theory had the correct variable values.

Keywords: Plant Modelling, Functional-Structural Plant Modelling, Growth Grammar Interactive Modelling Platform, Decision Support Model, Fuzzy Logic, RC Ratio

Introduction

Plant Computational Modelling (PCM) is a subfield of environmental informatics (eco-informatics) or natural informatics that combines computer science, agriculture, science, botany, and measurement. PCM generates computational demonstrations of plants based on detailed morphological and physiological analysis. The Functional-Structural Plant Model (FSPM) is the most recent PCM technique for comprehending the intricate relationships between plant structure and the physical and biological processes that drive plant development across many geographical and temporal scales. An appropriate FSPM method should integrate both functional and structural modeling methodologies. While the L-system has been shown to reflect plant functionality accurately, it is merely a string for the plant structure. The downside of the L-system is that it does not allow for visual plant modeling. Thus, an effective FSPM technique can be a combination of L-systems extended to network-like systems and an expanded programming language with features that make it simple to represent components of a plant structure.

The Relational Growth Grammar (RGG) concept is the de facto standard for an FSPM modeling technique based on graphs representing plant structures (Kniemeyer *et al*., 2004). The extended L-System (XL) language, which evolved from the L-system and is based on the RGG notion, simplifies developing complex models (Kniemeyer, 2008). The Growth Grammar Interactive Modelling Platform is open-source software that utilizes the XL language and supports the RGG concept (GroIMP). GroIMP is a platform that integrates modeling, visualization, and complicated interactions.

A model built with GroIMP includes numerous parameters that control its growth strategy and it is discovered that these parameters represent genetic information that evolves. Research can generate models by demonstrating the structural components of plant design, internal functional elements, and environmental implications (Renton, 2013). The rice model was tuned for light influence based on leaf development characteristics and leaf angle data from two rice varieties (Utama, 2015). The generated rice plant model is capable of simulating above-ground indigenous rice plants during their vegetative stage.

Differences in functional features between species are critical in explaining the positive diversity-productivity link observed in plant communities. Using wheat (*Triticum aestivum*) and maize (*Zea maycs*) intercropping as examples of mixed vegetation elements, this research indicated that adaptability in plant traits is a critical feature contributing to complementing light capture in a mix of species (Zhu *et al*., 2015). (Streit *et al*., 2016) developed a model for Scottish pine trees using lignum, Pygmalion, and the GroIMP sensitivity analysis tools. Its objective was to determine the extent to which geometrical placement affects sunlight absorption in conifers. Plant modeling using the Xfrog technique and the GroIMP platform generates plant graphics that are similar to those found in nature (Henke *et al*., 2017).

FSPM and GroIMP have been used to determine the development of the Norwegian spruce cypress tree's (*Picea abies Karst*.) canopy structure and to more realistically model biomass production (Fabrika *et al*., 2019). The FSPM approach was utilized to lengthen the vegetative period in the first fruit (Wang *et al*., 2020). Researchers (Long *et al*., 2018) employ FSPM and GroIMP to combine plant computer models created on disparate platforms. In plant simulation systems, there are identical similarities and also color disparities.

Numerous academics have researched FSPM, including one on graphs to simulate virtual plants (Kurth, 2020). Additionally, research has been conducted on modeling five different rice species found in Indonesia (Utama, 2015), as well as the ability of rice plants to absorb sunlight (Utama *et al*., 2014). FSPM and GroIMP have been employed to investigate the water and sugar transport in the stems of apples (Merklein *et al*., 2018). FSPM and GroIMP can be used to understand and model soybean turgor pressure during the plant's life cycle (Coussement *et al*., 2020). The latest, the FSPM and GroIMP can predict the economic investment of hydroponic green amaranth (Jabar *et al*., 2022).

The benefits of PCM are significant to predict the best plant model for agriculture and agronomy. Of course, the opportunity to model various plants is still great, including green amaranth which has high nutrition and is a vegetable commodity in Indonesia. One of the vegetables that have become a commodity in Indonesia is green amaranth. Green amaranth (*Amaranthus* sp.) is included in the superfood because it has a high nutritional content (Assad *et al*., 2017). The delicious taste makes green amaranth one of the most popular vegetables in Indonesia for consumption.

Green amaranth belongs to the *Amaranthaceae* family and is a potential source of antioxidants (Adegbola *et al*., 2020). Green amaranth plants grow at a pH of 6-7 and can be harvested 3-4 weeks after planting. Green amaranth can be grown using the hydroponic system, which best fits urban communities with narrow land. The research was conducted using green amaranth plants due to the short growing time and hydroponically. Another thing is that length measurements can be done every day using a ruler and caliper.

Besides PCM, there is another field that can help to determine strategic decisions for hydroponic planting. That field is Decision Support Model (DSM), a model that can provide problem-solving skills and communication skills for problems with semi-structured and unstructured conditions. (Magdalena and Santoso, 2021) built a decision support system model to encourage vegetable farmers in Pangkal Pinang to choose hydroponics by considering planting media, pests, growth of harvest age, seeds, and fertilizers. This is useful for farmers to maximize yields from planting with hydroponic media.

Based on this background, the research conducted is hydroponic green amaranth modeling using PCM and DSM approaches. This study combines the PCM and DSM methods because no one has combined the two methods before. This research is expected to obtain plant modeling for strategic decision-making by combining the two methods. The research proposed is the development of a hydroponic-based computational model of green amaranth morphology for strategic decision making. The morphological computational model will simulate the growth and development of green amaranth plants in three dimensions in detail, predicting the growth and development of hydroponic-based green amaranth plants based on the method of providing virtual nutrition. The method used for analysis, design, and model building is the Functional-Structural Plant Modeling (FSPM) which is implemented using the Growth-grammar Interactive Modeling Platform (GroIMP). This method combines structural, physiological, and statistical models in building computational plant models (Kurth, 1994). After that, green amaranth plant data was obtained from a virtual plant model built using FSPM-GroIMP.

This data is used as input into the DSM using the fuzzy logic method. The output of DSM will provide strategic decisions based on the investment value measured using the Revenue-Cost ratio (RC ratio). RC ratio is a method to measure the level of efficiency of farming so that strategic decisions related to the best RC ratio results.

Materials and Methods

This research is divided into three stages: Breeding and planting, model analysis and design, and model construction. The research steps are depicted in Fig. 1, together with the methods utilized and the result produced at each level.

Hydroponic systems are used for the breeding and planting stages (seeding and planting crops). At this stage, the plant's data is meticulously documented. Daily recordings are made to ensure a high-quality model. Plant height, stem length and width, leaf length and width, leaf color, leaf number, weather conditions, fertilizer type, fertilizer solubility, water pH, and water temperature must be noted. The stems and leaves' growth angles were also recorded for modeling purposes. The following tools were utilized to collect the data: Rulers, bows, screw micrometers, TDS meter devices, pH meters, and internet access for photographs and viewing conditions of temperature and humidity.

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 plant models (Kurth, 1994). The XL programming language was used for plant simulation of the GroIMP modeling platform.

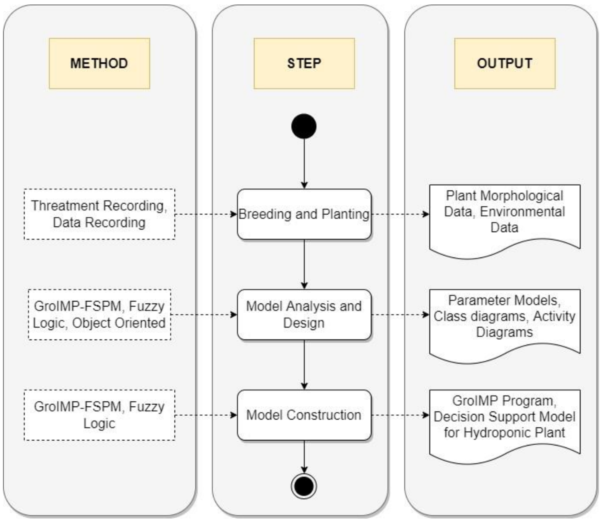

Fig. 1: Research stages

Other methods that must be studied are the object-oriented method and fuzzy logic. The object-oriented method is a design and model development method using an object approach. Some of the object-oriented method tools are class diagrams, activity diagrams, and use case diagrams. Class diagrams help describe each entity involved and the relationships between entities. The activity diagram aims to describe the processes that occur in the model. User involvement is described and explained by use case diagrams. The fuzzy logic eliminates bias in the data calculation so that the model results increase accuracy.

The model construction stage is the stage of building a model with the data obtained and then verifying and validating the model results. The method used to build the model is fuzzy logic and FSPM-GroIMP. The model built at this stage is the entire model from the design stage to implementation.

Results and Discussion

Variable Analysis

An influence diagram is a technique for graphically representing a decision model. The resulting graphic form is useful to help model the design, development, and understanding of a system. To build the model, the author uses influence diagrams to represent the graphical form of the model, as shown in Fig. 2.

Influence diagram in Fig. 2, the hexagonal symbol shows the output of the research, namely determining the investment value of hydroponic green amaranth plants. The output is the expected result of solving existing problems (decision indicators) in the model. The method used in developing the decision-making model is a combination of 3 methods, namely mathematical modeling, FSPM GroIMP, and fuzzy logic.

Model Configuration

The developed model's configuration according to the proposed hydroponic green amaranth decision support is shown in Fig. 3. Hydroponic-based green amaranth is converted into a 3D virtual plant computational model with a mathematical model and FSPM-GroIMP methods and then it will produce various types of important data and information in the form of plant morphology data and plant weight. Morphological data combined with cost and selling per product data is generated from the fuzzy logic method. The results of cost and revenue analysis will produce investment value. Furthermore, the investment value results will produce strategic decisions on hydroponic green amaranth plants.

Model Entity

In Fig. 4, the model to be developed is divided into two clusters, namely the Virtual Plant sub-model and the decision support sub-model. There are five classes in the virtual plant sub-model, namely amaranth plant, stem, internode, petiole, and leaf. While for the decision support sub-model, there are four classes, namely fuzzy, membership function, fuzzy rule base, and Investment.

In the Amaranth Plant class, there is a get Weight() function to get the weight of the plant and get Nutrition() to calculate the nutrients contained in spinach. The grow() function in the stem, internode, petiole and leaf classes is useful for adding length, width, and diameter to each according to the rules created.

The investment value obtained is based on many values in the Fuzzy Logic class. Also, the Fuzzy Logic class is generated based on multiple Membership Function and Fuzzy Rule Base. The resulting investments include calculating the price of spinach and calculating the total expenditure and the RC ratio.

Model Activity

The process flow of the model to be developed can be seen in Fig. 5. The activity diagram starts with activity reading data which will later be divided into two parallel activities. The first is the virtual plant model process; namely, the process defines the age of green amaranth plants ready to be harvested, which is 25 days, then the model will run the grow function up to 25 times. The model will calculate plant weight, total leaf area, and total nutrient content. The second activity is a fuzzy logic model activity. Several parameters from the existing data are fuzzified into fuzzy values. Then evaluate the fuzzy rules to produce the output of each rule. The final output of the fuzzy process is to produce predictions of total cost and selling price from the defuzzification results. After the virtual plant model and fuzzy logic, model activity is carried out in parallel, and the data from the Plant Model and Fuzzy Model results are processed using the CR ratio. The final output of the CR ratio is to get the investment value which will determine strategic decision-making to get the optimal investment value.

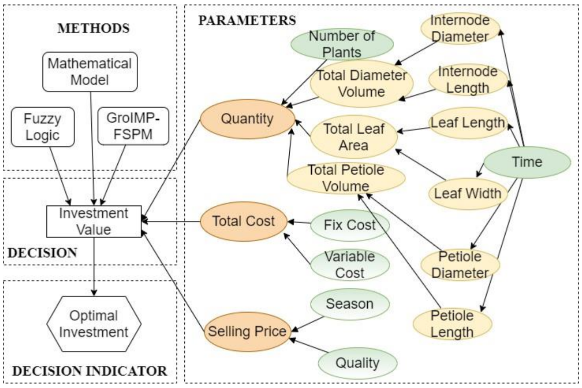

Fig. 2: Influence diagram of the model

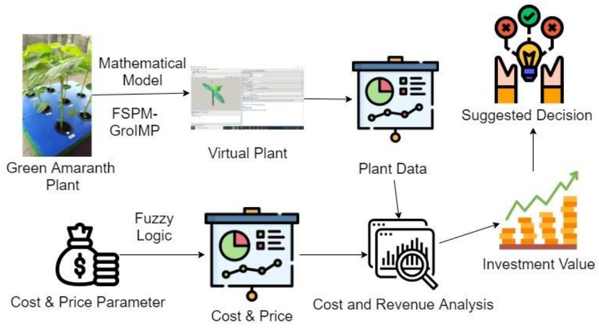

Fig. 3: Model configuration

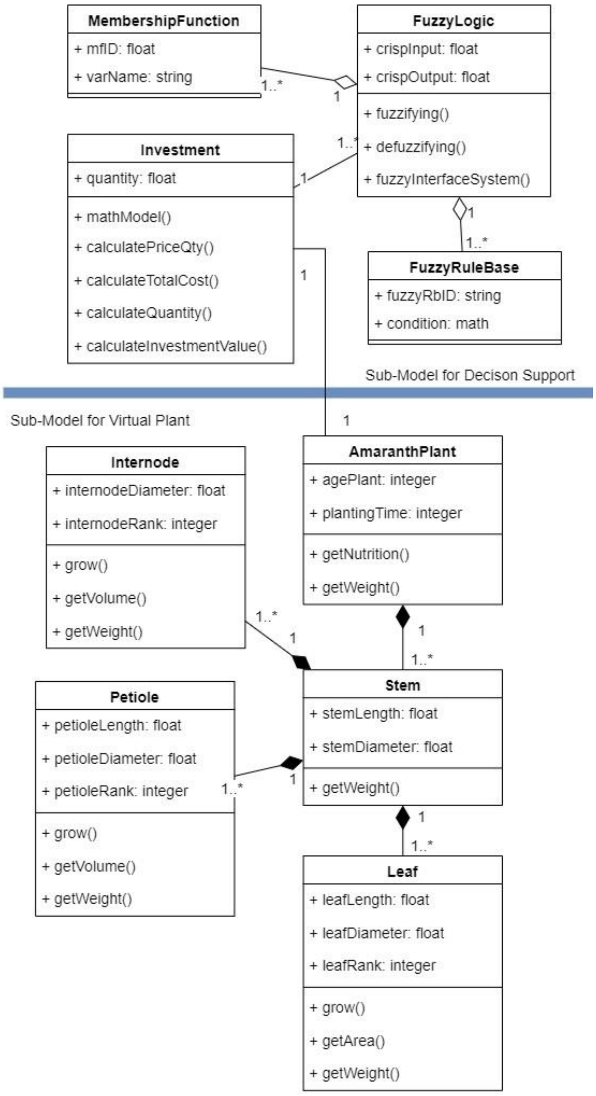

Fig. 4: Class diagram of the model

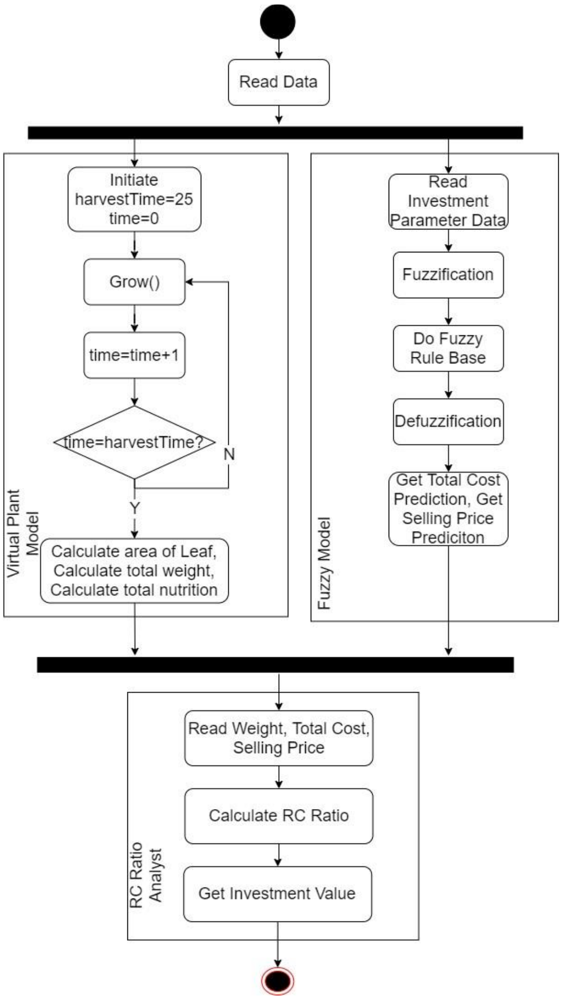

Fig. 5: Flow process of model

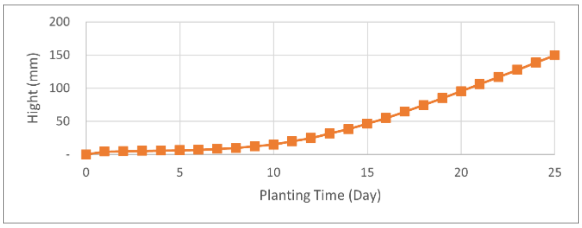

Fig. 6: Height growth

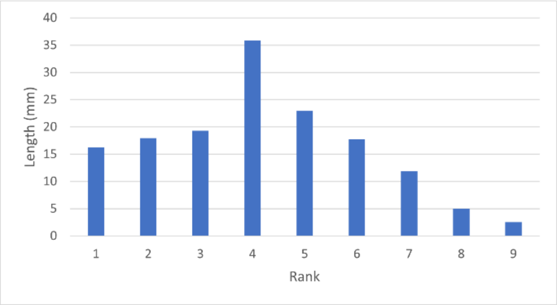

Fig. 7: Height of internode rank

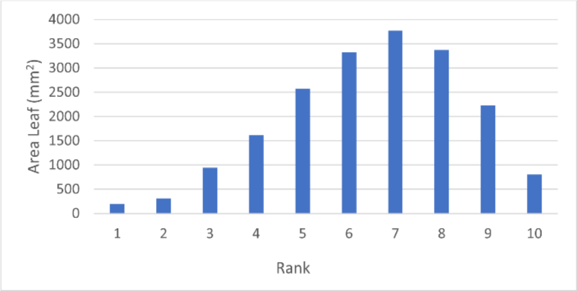

Fig. 8: Area leaf rank

Model Virtual Plant

Figure 6 is a graph of the average plant height growth from day 1 to day 25. The comparison of internode length is shown in Fig. 7, which shows that the longest internode is an internode at rank 4. The leaves with the most significant area are leaves with rank 7. The comparison of leaf area at each rank can be seen in Fig. 8.

Based on the experimental results, the average weight of one green amaranth plant is 11.85 g, with a maximum weight of 12.66 g and a minimum weight of 10.87 g. Figure 4. 15 shows the weight development of 100 plants from planting day to harvest day. The weight of the plants produced on the day of harvest was 1185.6 g. The leaf area development of 100 plants can be seen in Fig. 9, which shows the total leaf area in m^2. The graphs in Fig. 10 and 11 show that the plant will exponentially increase in weight and leaf area.

Model Fuzzy

In this chapter, the fuzzy logic model is explained to predict the total cost and selling price. Each parameter that is determined in making fuzzy logic is a parameter that affects the value to be predicted. The making of the fuzzy logic model begins with determining the membership function for each parameter in the fuzzy logic model, then continues with the creation of a rule base, and finally the defuzzification process. In this study, there are two fuzzy logic models to determine the total cost and the selling price of green amaranth.

Cost Parameter Fuzzy

The model consists of two inputs and one output. Two input parameters are variable cost and fixed cost, which is represented by variable and fixed expenses (in rupiah). While the output parameter is the total cost which is represented in the total expenditure issued (in rupiah).

The parameter value of the cost variable has three types of linguistic variables, namely Low, Moderate and High, with the limit values in sequence being

(0,5000, 25000), (5000, 25000, 45000), and (25000, 45000, 50000, 50000). The fixed cost parameter value has three types of linguistic variables, namely Low, Moderate and High, with the limit values in sequence being (0,0,15000,5000), (15000, 50000, 90000), and (5000, 90000, 100000, 100000). Meanwhile, the total cost parameter has three types of linguistic variables, namely Low, Moderate and High, with the limit values in sequence being (0, 0, 15000, 800000), (15000, 80000, 140000), and (80000, 140000, 150000, 150000).

Furthermore, from three types of linguistic variables for cost variable parameters and three types of linguistic variables for fixed cost parameters, nine types of fuzzy rule bases were made. The fuzzy rule base is a combination of two existing linguistic input parameter variables and produces three possible Total Cost output values (Low, Moderate, High). The nine types of rule bases can be seen in Table 1.

The next stage is the defuzzification process, which is to interpret the fuzzy membership value into certain decisions or real numbers. Graphics of fuzzy logic implementation for cost determination can be seen in Fig. 12. From the results of the defuzzification of the cost parameter model, it can be seen that if the variable cost is IDR30,000 and the fixed cost is IDR20,000, then the total cost is IDR48,930. From the model, it is proven that the larger the variable cost and fixed cost, the higher the total cost.

Price Parameter Fuzzy Logic

The model consists of two inputs and one output. Two input parameters are season which is represented by monthly rainfall and green amaranth quality, which is represented by the value of green amaranth product quality. In comparison, the output parameter is the price of green amaranth per kilogram represented by the price.

The monthly rainfall parameter value has four types of linguistic variables, namely low, moderate, high, and very high, with the limit values sequentially being (0, 0, 50, 150), (75, 200, 325), (250, 400, 500) and (450, 500, 800, 800). For the quality value, there are three types of linguistic variables, namely low, moderate and high, with the limit values sequentially being (30, 30, 40, 50), (40, 60, 80), and (70, 90, 100, 100). Meanwhile, the price parameter value has three types of linguistic variables, namely low, moderate and high, with the limit values in sequence being (10000, 10000, 20000, 300000), (25000, 35000, 500000), and (40000, 50000, 70000, 70000).

Furthermore, from four types of linguistic variables for the monthly rainfall parameter and three types of linguistic variables for the quality parameter, twelve types of fuzzy rule bases were made. The fuzzy rule base combines two linguistic variables of existing input parameters and produces three possible output price values (low, moderate, high). Twelve types of rule bases can be seen in Table 2.

From the results of the defuzzification of the price parameter model and fuzzy rule base in Table 2, the price of the plant is IDR57,282 per kilogram if the monthly rainfall is 200 mm and the quality is 90%. Graphics of fuzzy logic implementation for cost determination can be seen in Fig. 13.

Decision Supporting Model for Hydroponic Green Amaranth

The decision support model for hydroponic green amaranth made is by combining a virtual plant model and a fuzzy model to determine the RC value and looking at the RC that is more than 1 means that investment in hydroponic green amaranth is profitable. Figure 13 is a graph that combines several quality values and the number of plants, with a variable cost value of IDR20,000, a fixed cost of IDR30,000, a planting time of 25 days, and a monthly rainfall of 200 mm. From Fig. 14, the value of the RC ratio is less than 1 if the number of plants is less than 100. And the highest RC ratio is obtained if the quality is the largest and the number is the largest.

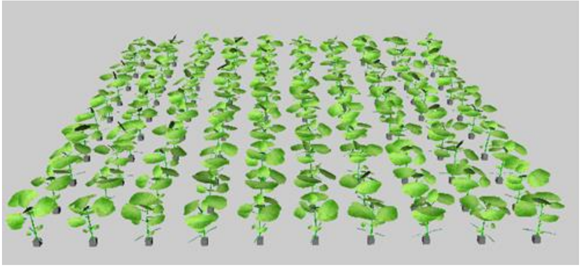

Fig. 9: Multiplan model of 100 plants

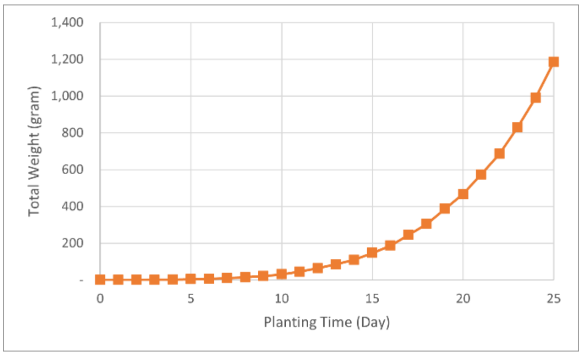

Fig. 10: Weight growth

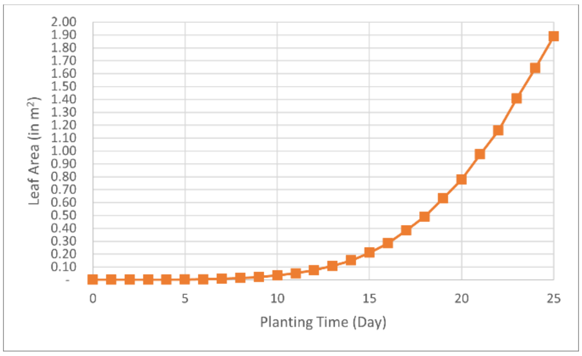

Fig. 11: Area leaf growth

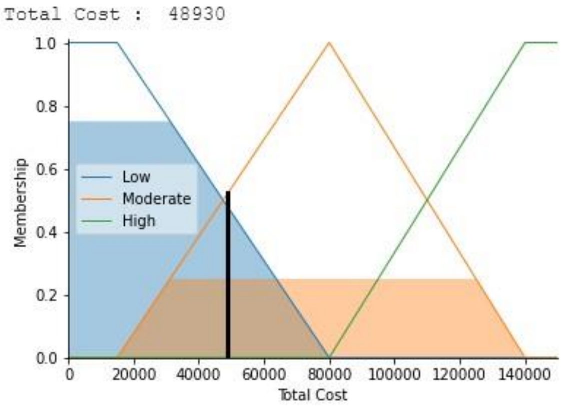

Fig. 12: Variable cost IDR30,000 and the fixed cost IDR20,000

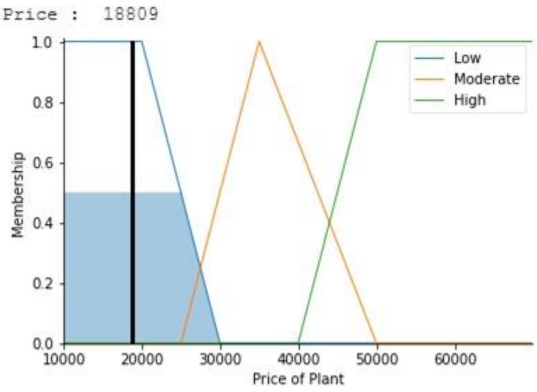

Fig. 13: Price of Plant if Monthly Rainfall 200 mm and The Quality 90%

Fig. 14: RC Graphics with different quality and quantity

Table 1: Fuzzy rule base cost

No	Fuzzy rule base
Rule 1	IF (VCost = Low) AND (FVost = Low) THEN (TCost = Low)
Rule 2	IF (VCost = Low) AND (FVost = Moderate) THEN (TCost = Low)
Rule 3	IF (VCost = Low) AND (FVost = High) THEN (TCost = Moderate)
Rule 4	IF (VCost = Moderate) AND (FVost = Low) THEN (TCost = Low)
Rule 5	IF (VCost = Moderate) AND (FVost = Moderate) THEN (TCost = Moderate)
Rule 6	IF (VCost = Moderate) AND (FVost = High) THEN (TCost = High)
Rule 7	IF (VCost = High) AND (FVost = Low) THEN (TCost = Moderate)
Rule 8	IF (VCost = High) AND (FVost = Moderate) THEN (TCost = Moderate)
Rule 9	IF (VCost = High) AND (FVost = High) THEN (TCost = High)

Table 2: Fuzzy rule base price

No	Fuzzy rule base
Rule 1	IF (Rainfall = Low) AND (Quality = Low) THEN (Price = Low)
Rule 2	IF (Rainfall = Low) AND (Quality = Moderate) THEN (Price = Moderate)
Rule 3	IF (Rainfall = Low) AND (Quality = High) THEN (Price = Moderate)
Rule 4	IF (Rainfall = Moderate) AND (Quality = Low) THEN (Price = Low)
Rule 5	IF (Rainfall = Moderate) AND (Quality = Moderate) THEN (Price = Moderate)
Rule 6	IF (Rainfall = Moderate) AND (Quality = High) THEN (Price = High)
Rule 7	IF (Rainfall = High) AND (Quality = Low) THEN (Price = Low)
Rule 8	IF (Rainfall = High) AND (Quality = Moderate) THEN (Price = Moderate)
Rule 9	IF (Rainfall = High) AND (Quality = High) THEN (Price = High)
Rule 10	IF (Rainfall = Very High) AND (Quality = Low) THEN (Price = Low)
Rule 11	IF (Rainfall = Very High) AND (Quality = Moderate) THEN (Price = Moderate)
Rule 12	IF (Rainfall = Very High) AND (Quality = High) THEN (Price = Moderate)

Conclusion

This research has successfully obtained strategic decisions based on the virtual hydroponic green amaranth plant model by combining PCM and DSM methods. The virtual hydroponic green amaranth plant model built using the FSPM-GroIMP method can produce day-to-day morphological visualization of green amaranth growth and calculate the width and area of green amaranth parts. The final result of the model is a visualization of green amaranth plants with the total weight of the plants harvested through the GroIMP platform and the total vitamin and mineral content in it. This research could aid the farmer in decision-making when growing hydroponic green amaranth plants.

The suggestion for improving the model is to add a development trend to the output of GroIMP. The output of the built model is still in the form of raw data, for that it can be increased by adding graphic output to GroIMP. Adding visualization results to GroIMP by adding pots and also the shape of the hydroponic model created. This will make the GroIMP model more realistic. It was adding parameters to the fuzzy model. The model that has been built still uses simple parameters, so it can be improved by adding fuzzy model parameters such as the type of fertilizer, and the type of hydroponic planting.

Acknowledgment

We appreciate the experts' pertinent and helpful comments to enhance this study. We also thank Bina Nusantara University, which has supported and sponsored our works.

Author’s Contributions

Bakti Amirul Jabar: Collect and analyze date, construct, simulate, and finalizing the model. Also draft and finalize the manuscript.

Ditdit Nugeraha Utama: Wrote and finalized the manuscript.

Ethics

This manuscript substance is the authors’ own original work and has not been previously published somewhere else. Authors already read and approved the manuscript and no potential ethical issues immersed.

References

Adegbola, P. I., Adetutu, A., & Olaniyi, T. D. (2020). Antioxidant activity of *Amaranthus* species from the *Amaranthaceae* family–A review. *South African Journal of Botany*, 133, 111-117. doi.org/10.1016/j.sajb.2020.07.003

Assad, R., Reshi, Z. A., Jan, S., & Rashid, I. (2017). Biology of amaranths. *The Botanical Review*, 83(4), 382-436. https://link.springer.com/article/10.1007/s12229-017-9194-1

Coussement, J. R., De Swaef, T., Lootens, P., & Steppe, K. (2020). Turgor-driven plant growth applied in a soybean functional–structural plant model. *Annals of Botany*, 126(4), 729-744. https://academic.oup.com/aob/article/126/4/729/5821592

Fabrika, M., Scheer, Ľ., Sedmák, R., Kurth, W., & Schön, M. (2019). Crown architecture and structural development of young Norway spruce trees (*Picea abies Karst*.): A basis for more realistic growth modeling. *Bio Resources*, *14*(1), 908-921.

Henke, M., Kniemeyer, O., & Kurth, W. (2017). Realization and extension of the xfrog approach for plant modeling in the graph-grammar-based language XL. *Computing and Informatics*, 36(1), 33-54. http://www.cai2.sk/ojs/index.php/cai/article/view/2017_1_33

Jabar, B. A., Utama, D. N., & Rachmawati, I. D. A. (2022). Plant computational modeling of green amaranth for predicting economic investment. *ICIC Letters Part B: Applications*, 13(5). http://www.icicelb.org/ellb/contents/2022/5/elb-13-05-02.pdf

Kniemeyer, O. (2008). *Design and implementation of a graph grammar-based language for functional-structural plant modeling* (Doctoral dissertation, BTU Cottbus-Senftenberg). https://opus4.kobv.de/opus4-btu/frontdoor/index/index/docId/462

Kniemeyer, O., Buck-Sorlin, G. H., & Kurth, W. (2004). A graph grammar approach to artificial life. *Artificial Life*, 10(4), 413-431. https://ieeexplore.ieee.org/abstract/document/6788871

Kurth, W. (1994). Morphological models of plant growth: Possibilities and ecological relevance. *Ecological Modelling*, *75*, 299-308. doi.org/10.1016/0304-3800(94)90027-2

Kurth, W. (2020, June). Multiscale graph grammars can generate Cayley graphs of groups and monoids. In *International Conference on Graph Transformation* (pp. 307-315). Springer, Cham. https://link.springer.com/chapter/10.1007/978-3-030-51372-6_18

Long, Q., Kurth, W., Pradal, C., Migault, V., & Pallas, B. (2018, March). An architecture for the integration of different functional and structural plant models. In *Proceedings of the 7th International Conference on Informatics, Environment, Energy and Applications* (pp. 107-113). https://dl.acm.org/doi/abs/10.1145/3208854.3208875

Magdalena, H., & Santoso, H. (2021). Decisions support system urban farming di lahan sempit kota pangkalpinang dengan hidroponik menggunakan metode analytical hierarchy process. *Fountain Informatics J*, *6*(1). file:///C:/Users/User/Downloads/4662-12600-1-PB%20(1).pdf

Merklein, J., Poirier-Pocovi, M., Buck-Sorlin, G. H., Kurth, W., & Long, Q. (2018, November). A dynamic model of xylem and phloem flux in an apple branch. In 2018 *6th International Symposium on Plant Growth Modeling, Simulation, Visualization and Applications (PMA)* (pp. 50-55). IEEE. https://ieeexplore.ieee.org/abstract/document/8611561

Renton, M. (2013). Aristotle and adding an evolutionary perspective to models of plant architecture in changing environments. *Frontiers in Plant Science*, 4, 284. https://www.frontiersin.org/articles/10.3389/fpls.2013.00284/full

Streit, K., Henke, M., Bayol, B., Cournède, P. H., Sievänen, R., & Kurth, W. (2016, November). Impact of geometrical traits on a light interception in conifers: Analysis using an FSPM for Scots pine. In *2016 IEEE International Conference on Functional-Structural Plant Growth Modeling, Simulation, Visualization and Applications (FSPMA)* (pp. 194-203). IEEE. https://ieeexplore.ieee.org/abstract/document/7818307

Utama, D. N. (2015). *The Optimization of the 3-d structure of plants, using functional-structural plant models. Case study of Rice (Oryza sativa L.) in Indonesia* (Doctoral dissertation, Göttingen, Georg-August Universität, Diss., 2015).

Utama, D. N., Ong, Y., Streit, K., & Kurth, W. (2014). Determining the influence of plant architecture on light interception of virtual rice plants on the simulation platform GroIMP. *Enhancing Strategic Plant Physiological Research and Technologies for Sustainable Resources*, 92.

Wang, X. J., Kang, M. Z., Fan, X. R., Yang, L. L., Zhang, B. G., Huang, S. W., ... & Wang, F. Y. (2020). What are the differences in yield formation among two cucumbers (*Cucumis sativus L.*) cultivars and their F1 hybrid? *Journal of Integrative Agriculture*, *19*(7), 1789-1801. doi.org/10.1016/S2095-3119(20)63218-X

Zhu, J., van der Werf, W., Anten, N. P., Vos, J., & Evers, J. B. (2015). The contribution of phenotypic plasticity to complementary light capture in plant mixtures. *New Phytologist*, *207*(4), 1213-1222. https://nph.onlinelibrary.wiley.com/doi/full/10.1111/nph.13416