



PLANT GROWTH MODELING OF ZINNIA ELEGANS JACQ USING FUZZY MAMDANI AND L-SYSTEM APPROACH WITH MATHEMATICA

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ABSTRACT

Modeling of the plant growth can be visualized using the approach of Lindenmayer System (L-System). This L-System models the plants growth by following the production rules, which are the combination of grammar and mathematic formulae. In this paper, we propose the use of fuzzy mamdani, to model the plant growth based on the current environment condition. The varied amount of fertilizer, both organic and inorganic fertilizer, is used as the input to the Fuzzy Mamdani. The output of the Fuzzy Mamdani is used as the input to the zinnia plant growth model. The novelty of this research is the using Fuzzy Mamdani to model the zinnia plant growth with L-System method. In this research, the dynamic plant model of zinnia variant has been developed using Fuzzy Mamdani to model the zinnia plant growth. This model has been simulated on computer software. This model shows the response of the amount of fertilizer towards the zinnia height virtually and this response is then simulated. The best height is when the plant is given 100% organic and 75% inorganic fertilizers.

Keywords: *L-System, Modeling, Fuzzy Mamdani, Plant Growth, Fertilizer*

1. INTRODUCTION

The modeling of plant growth is initialized by Aristid Lindenmayer, when he introduced the theory of anabaena catenula cell growth using the method called rewriting string. Later on, this rewriting string is known as the Lindenmayer System (L-System) [1]. The development of L-System to explain the plant growth based on the environment condition can be seen on [2,3,4,5].

The L-System method has been used for modelling many different kind of plants [6,7]. The basic concepts of axiom and rules are the basis of how the L-System works [8]. Modeling in computer graphic for plant growth and biology cell have rarely been developed in plant growth analyzed. It also has been identified that the environment also effects the plant growth [9].

The L-System method can describe how to model the plant growth using grammar [10]. The L-System model that utilizes the parameter from the measurement has been developed in modeling the morphogenesis of annual plant [11,12]. At the beginning of plant growth, the sprout of plant is initially denoted as axiom. This characteristic rules

are illustrated in the further research of L-System that follows the plant growth naturally.

It is then followed by the growth of stalk, branch, leaf and bloom. The rule of plant growth is represented by the axiom. On the other hand, the value of axiom is generally generated using the probability [13]. To make the growth parameters closer to the real environment condition, we propose the use of fuzzy system.

The aim of this research is to model plant growth using the growth parameters that is given based on the fuzzy system. Design of plant growth used *Mathematica* programming [14,15] on Windows Operating System. The 3D output graphic is reflected on plant growth as a virtual plant growth system.

2. RESEARCH METHOD

This research was carried out at Multimedia and Networking Laboratory, Institute Technology Sepuluh November (ITS). This research used Zinnia Elegane Jacq. Some references on plant growth are also used. Some plant growth is collected based on varying the amount of extra

inorganic fertilizer (Nitrogen(N), Phosphor(P) and Kalium(K)) and also organic fertilizer.

Some tools are used, such as electric scale, leaf area meter, oven, termohigrometer, dan luxmeter. Sample data are taken from the plant after 26 days from transplating (HST). In this research, the amount of fertilizer given varies.

The hardware requirements used to model and visualize the plant growth is a personal computer with the specifications Intel Pentium Dual CPU 2.8 GHZ Processor, RAM 1 Giga Byte, 100GB Hard drive, Graphic Card NVIDIA GeForce 8400GS.

The Mathematica software under windows operating system is used in this research. Figure 1 shows the research methodology for using fuzzy system into an L-System.

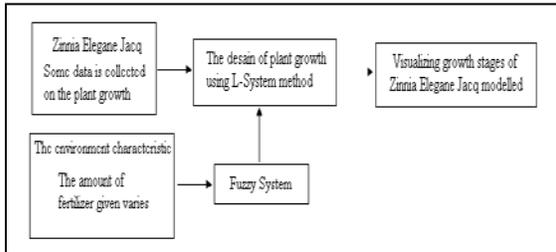


Figure. 1: The research methodology for using fuzzy system into an L-System

In this research, the observations are concentrated on 2 areas, the plant growth itself and the environment. The plant growth observations are carried out by collecting data of the plant based on the height, the stalk diameter, leaf (which includes height, width and area), the bloom diameter. On the other hand, the environment observations include putting different combination of fertilizer, temperature, weather, humidity and light intensity.

3. RESULTS AND DISCUSSION

3.1 The Design of Plant Growth Using L-System Method

Rewriting has proved to be a useful technique for defining complex objects by successively replacing parts of simple initial objects using a set of rewrite rules or productions. Rewriting systems operating on character strings have been successfully used for describing syntactic features of natural languages or for formal definitions of programming languages [16, 17].

D0L-systems (D0 meaning: deterministic with no context) are the simplest type of L-systems. Formally a D0L-system $L=(\Sigma, \alpha, P, T)$, capable of encoding geometrical structures, consists of the following ingredients: a) an alphabet $\Sigma=(\delta_1, \dots, \delta_n)$,

each symbol of which stands for a morphological unit, like a sprout, a stalk, a leaf and a bloom b) a start string α , referred to as the axiom, which is an element of Σ , the set of all finite words over the alphabet Σ , c) $P = (p_1, \dots, p_n)$, a set of productions or rewrite rules, d) a geometrical interpretation T , a 3D semantics, for some of the symbols from Σ , translating a string into a spatial structure, i.e. special symbols represent commands to draw graphic objects like points, lines, polygons etc; this translation is commonly known as turtle geometry interpretation.

Let us consider the following L-system: G

$$\Sigma = \{ a, b, c, d, e \}$$

$$\omega = abc$$

$$P_1 \quad a \rightarrow bc$$

$$P_2 \quad c \rightarrow ae$$

which generates the following sequence of strings:

- Axiom : abc
- Iteration 1 : bcbae
- Iteration 2 : baebbcé
- Iteration 3 : bbccebbaeé
- Iteration 4 in figure 2

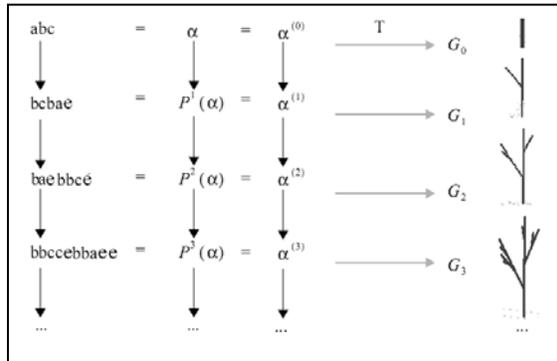


Figure. 2: Rewriting with D0L-systems and geometrical interpretation for an axiom abc and productions $a \rightarrow bc$ and $c \rightarrow ae$.

The D0L-System encodes turtle geometry macros for generating graphical representations of the leaves, blooms and stalks. An each symbol, FO represent commands to move forward the turtle and change the drawing tools orientation by rotation around its longitudinal, lateral, and vertical axes is RL (roll left), RR (roll right), PU (pitch up), PD (pitch down), YL (yaw left) and YR (yaw right) show in table 1 and illustration of turtle graphic on 3D show in figure 3, thus translating a one-dimensional string into a 3D geometrical object resembling a plant (some of these commands do not occur in the example L-system).

Table 1: Turtle Rules for Interpreting 3D

Symbol of string	Description
FO[s]	Advances the turtle by a step size of s in the direction and draws a line depending on the current color and line thickness settings.
PU(α)	The turtle is tilted up around its transverse axis y by an angle of α degree.
PD(α)	The turtle is tilted down around its transverse axis y by an angle of α degree.
RR(α)	The turtle is rotated right (clockwise) around its longitudinal axis x by an angle of α degrees.
RL(α)	The turtle is rotated left (counterclockwise) around its longitudinal axis x by an angle of α degrees.
YR(α)	The turtle is rotated right (clockwise) around its vertical axis Z by an angle of α degree.
YL(α)	The turtle is rotated left (counterclockwise) around its vertical axis Z by an angle of α degree.

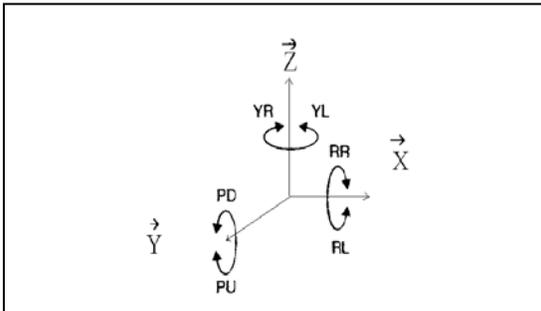


Figure 3: Illustration of Turtle Graphic on 3D

In this research, design of plant growth used kLSystems package in MathEvolvica [19], the kLSystems package contains definitions for the application of parallel rewrite rules of L-Systems with left and right contexts with arbitrary length. Each rule of the form $l < p > r \rightarrow s$ as described above is represented by a *Mathematica* expression of the form

LRule[LEFT[l], PRED[p], RIGHT[r], SUCC[s]].

Accordingly, we define the production set as an LRULES expression

LRULES [LRule[...], LRule[...], ...]

and an L-system is described as follows:

LSystem[_AXIOM, LRULES[__LRule]

With this representation we can easily derive the type of the expressions and sub expressions by only looking at sprout symbols.

In this experiment, some samples of Zinnia Elegane Jacq plant were used. Application kLSystems package in MathEvolvica at plant growth of Zinnia Elegane Jacq can be expressed and visual zinged as virtual plant growth. Figure 4 shows an example of L-system describing growth sequences of sprouts, leaves and blooms of virtual plant, together with its graphical interpretation. The DOL-System encodes turtle geometry macros for generating graphical representations of parameterized DOL-System modeling Zinnia Elegane Jacq stages of plantlike structure in figure 5.

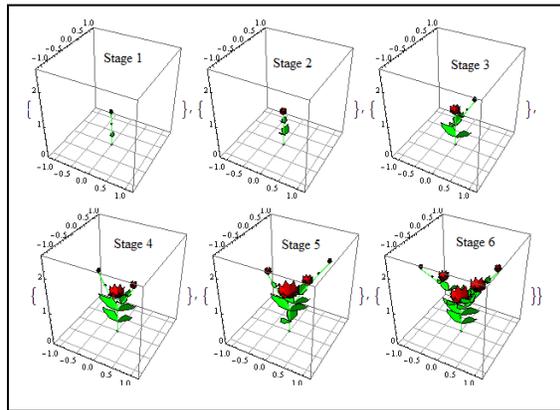


Figure 4: Visualizing growth stages of Zinnia Elegane Jacq plant modeled by the DOL-System

$G_{ZinniaEleganeJacq} = (\Sigma, P = \{p_1 \dots p_5\}, a)$
 $\Sigma = \{FO, PD, PU, RR, sprout, stalk, leaf, bloom\}$
 $a = sprout(4)$

P = sprout developing leaves and flower

$p_1 = sprout(4) \rightarrow FO\ stalk(3)\ [PU(60)\ leaf(1)]\ FO\ stalk(2)\ RR(90)$
 $[PU(60),\ leaf(1)]\ FO\ stalk(2)\ RR[90]\ [PU(60)\ leaf(0)]\ [PU(30)$
 $sprout(2)]\ RR(180)\ [PU(30)\ sprout(2)]\ FO\ stalk(2)\ bloom(0)$

Ripping sprout:

$p_2 = sprout(t < 4) \rightarrow sprout(t+1)$

Stalk elongation:

$p_3 = stalk(t > 0) \rightarrow FO\ stalk(t-1)$

Changing leaf sizes:

$p_4 = leaf(t < 4) \rightarrow leaf(t + 1.5)$

Growing bloom:

$p_5 = bloom(t < 4) \rightarrow bloom(t + 1)$

Figure 5: Example of parameterized DOL-System modeling Zinnia Elegane Jacq of plantlike structure

3.2 Using fuzzy mamdani to model the plant growth

A fuzzy dynamic model has been proposed to represent locally linear input/output relations for nonlinear systems[20]. Role of system fuzzy mamdani for the representation of input/output relationship for system non linear. This relationship is generally the interactions among various elements of a growing structure and the environment. The fuzzy mamdani output is used as values for the growth parameter, such as various elements of a growing structure which are *sprout, stalk, leaf and bloom*.

The observation is conducted to the plant growth of *Zinnia Elegane Jacq*, that is already conditioned with the combination mixture of inorganic and organic fertilizer. The amount of fertilizer that suits the plant growth will generate the growth parameter. Various amount of fertilizer is already given to the plant. It varies from 0% up to 100% concentration. Let 0% to 25% in concentration is indicated as low, 25% to 75% as medium and 75% to 100% as high. In this observation, the measurement of plant growth is divided into two parts: a) 15 data is used as the parameters for the fuzzy system, as in table 2, b). 5 data is used as a comparator to the output of fuzzy mamdani, The modeling of fuzzy mamdani with *Mathematica* software is using 2 parameter inputs which are combination of inorganic fertilizer and organic fertilizer, and one parameter output which is the growth parameter (Stalk Height, Leaves Height, Leaves Width, Bloom Diameter, Length Branch, Number of Branch, Number of Bloom, Plant Height).

A crisp set is described by a characteristic function whose value is always either 0 or 1. A fuzzy set is defined by a membership function that takes values anywhere between 0 and 1. In a fuzzy system, we might represent the sets of low, medium, and height by the fuzzy membership functions[21].

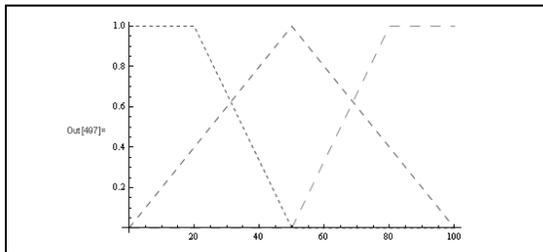


Figure 6: The fuzzy membership functions of organic fertilizer input. The functions take values in the interval [0, 1]

To present the fuzzy membership functions of organic fertilizer input in figure 6, and defineSet function within *Mathematica* is used [22].

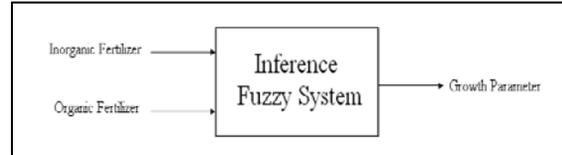


Figure 7: Rule of fuzzy system to identify the growth parameter

Figure 7 shows the Rule of fuzzy system to identify the growth parameter based on the data measurement in research field. With these sets, fuzzy associations are defined. Fuzzy associations could be explained as the relation between various combination of inorganic and organic fertilizers to generate growth parameter (*sprout, stalk, leaf, bloom*).

As an example, if the amount of organic and inorganic fertilizers are *medium* (50%) and *medium* (50%), respectively, then the stalk (the growth parameter) is *medium*. It is then coded as

IF organic MEDIUM AND inorganic MEDIUM THEN stalk MEDIUM

Using the growth parameter from the treatment of various amount of fertilizer given to *Zinnia Elegane Jacq*, Fuzzy Associative Memory (FAM) matrix can be made in table 2.

Table 2: Fuzzy Associative Memory (FAM) Matrix

	Organic Low	Organic Medium	Organic High
Inorganic Low	Stalk Low	Stalk Low	Stalk Medium
Inorganic Medium	Stalk Medium	Stalk Medium	Stalk High
Inorganic High	Stalk Medium	Stalk High	Stalk High

If ϕ denotes the amount of organic fertilizer, where

$$\phi \in \{low, medium, high\}.$$

x denotes the amount of inorganic fertilizer, where

$$x \in \{low, medium, high\}$$

and B denotes the stalk (the growth parameter), where

$$B \in \{low, medium, high\}$$

Then, the following equation can be derived

$$B = \phi \text{ AND } x$$

If there are n number of ϕ , x and B , this equations follows

$$B_0 = \phi_0 \text{ AND } x_0$$

$$B_1 = \phi_1 \text{ AND } x_1$$

⋮

$$B_n = \phi_n \text{ AND } x_n$$

Finally, the combination of all z values can be derived as follows

$$B = B_0 \text{ OR } B_1 \dots \text{ OR } B_n$$

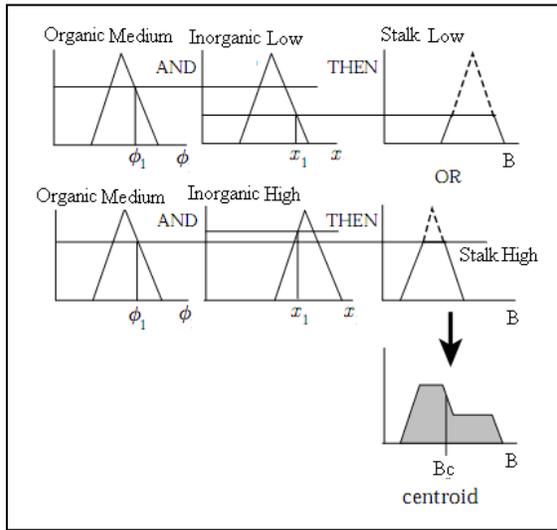


Figure 8: Two rules are combined to produce an output fuzzy set from an input (ϕ_1, x_1) . The numerical output of the system is the centroid B_c of the output set.

In figure 8 to find the actual stalk value, the output fuzzy set is converted into a numerical value for ϕ . This process is called *defuzzification*. There are several possible methods. The centroid method will be used because it is the typical choice for plant growth modelling. The centroid is the “center of mass” of the region under the graph of the membership function:

$$B_c = \frac{\int_{-\infty}^{\infty} Bf(B)db}{\int_{-\infty}^{\infty} BdB} \quad (1)$$

The *defuzzification* process, as in equation (1), is a process to calculate the stalk value at the centroid output fuzzy set, as shown in figure 9. In *Mathematica*, this process is called *fuzzyTheta*.

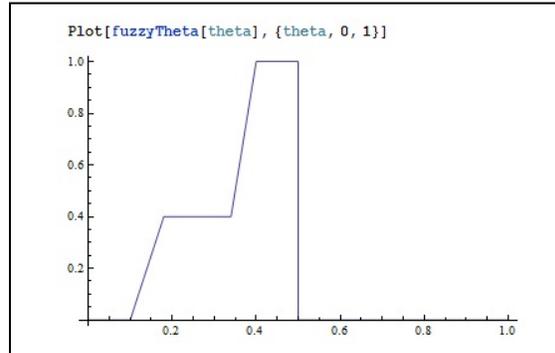


Figure 9: The Defuzzification output of stalk.

The output of the fuzzy mamdani, is then compared to the actual data of plant growth in the field. It can be seen that the difference between fuzzy mamdani output and the actual plant growth is less than 13% on average.

From the inference output of the fuzzy system, it can be derived the growth parameter. It is then implemented to the plant, in such a way that it is possible to get the crop as expected.

Once the stalk growth is found, then the leaf and bloom growth need to be found using the similar fuzzy system method. Those three values are then become the inputs for the L-system in order to visualize the plant, *Zinnia Elegane Jacq*, growth virtually. The simulation output of five treatments, and it was plotted in figure 10.

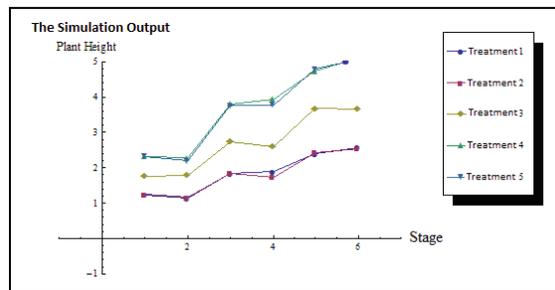


Figure 10: The simulation output of five treatments.

4. CONCLUSION

This research shows that using fuzzy mamdani into a Lindenmayer System based plant modeling environment has been implemented. In this research, it can be demonstrated that the difference between fuzzy mamdani output and the actual plant growth is less than 13% on average. This model has been simulated on computer software. This model shows the response of the amount of fertilizer towards the zinnia height virtually and this response is then simulated. The best height is when the plant is given 100% organic and 75%



inorganic fertilizers. It is concluded from this research that the agriculture of zinnia plant could be develop further with the fuzzy mamdani, which both controlled environment and controlled mixture of fertilizer are used as decision support system.

REFERENCES:

- [1] Lindenmayer P. Prusinkiewicz, The Algorithmic Beauty of Plants, Springer Verlag, New York, 1990, pp. 227.
- [2] Mech R., Prusinkiewicz P., Visual Models of Plants Interacting with Their Environment, *Proceedings of SIGGRAPH 96*, ACM SIGGRAPH, 1996, pp. 397.
- [3] Prusinkiewicz P., Hanan J., Hammel M., Mech R., L-systems: from the Theory to Visual Models of Plants, *Siggraph L-System and Beyond*, California, 2003, pp. 2.1-2.12.
- [4] Suhartono, Mochamad Hariadi, Mauridhi Hery Purnomo, Integration of Fuzzy System into Genetic L-System Programming based plant modeling environment with mathematica, *Australian Journal of Basic and Applied*, Vol. 5(11), 2011 pp. 1760-1765
- [5] Suhartono, Mochamad Hariadi, Mauridhi Hery Purnomo, Integration of Artificial Neural Network into Genetic L-System Programming based plant modeling environment with mathematica, *International Journal of Academic Research*, 2011, Vol. 3. No. 6, I Part
- [6] Prusinkiewicz P., Acta Horti, *ISHS*, 2004, pp. 630
- [7] L.B. Pachepsky, M. Kaul, C. Walthall, J. Lydon, H. Hong, C.S.T Daughtry, *Int. J. Biotronic*, Vol 33, 2004, pp. 31.
- [8] Viruchpintu R., Khiripet N., Real Time 3D Plant Structure Modeling by L-System with Actual Measurement Parameters, *National Electronics and Computer Technology Center*, Bangkok, 2005.
- [9] Prusinkiewicz P., Roland-Lagan A.G., *Plant Biol*, vol 9, 2006, pp. 83.
- [10] Karwowski R., Prusinkiewicz P., The L-System based Plant modeling Environment L-Studio 4.0, *Proceedings of the 4th International Workshop on Functional Structural Plant Models*, 2006, pp. 403.
- [11] Church E.M., Semwal S.K., Simulating Trees using Fractals and L-System, *Department of Computer Science*, University of Colorado, 2007.
- [12] Hosseini Cici S.Z., Adkins S., J. Hanan, *Comput. Electr. Agric.* 2009, vol 69 pp.40.
- [13] Atris Suyantohadi, Alfijan, Mochamad Hariadi, Mauridhi Hery Purnomo, Plant Growth Modelling Using L-System Approach and Its Visualization, *Makara Teknologi*, Vol. 14, NO. 2, November 2010: pp. 92-96
- [14] Jacob C., Illustrating Evolutionary Computation with Mathematica. San Francisco, CA, *Morgan Kaufman*, 2001, pp. 256.
- [15] Heikki Ruskeepaa, *Mathematica Navigator, Elsevier Inc*, 2009
- [16] Backus J.W., The syntax and semantics of the proposed , *Proc. Intl. Conf. on Information Processing*, 1959, pp.125-132.
- [17] Chomsky N., Three models for the description of language, *IRE Transactions on Information Theory*, 1956, pp. 113-124.
- [18] Jacob C., Genetic L-System Programming: Breeding and Evolving Artificial Flowers with Mathematica, *IMS '95*, Computational Mechanics Pub, Southampton, UK, 1995.
- [19] Jacob C., MathEvolvica - Simulierte Evolution von Entwicklungsprogrammen der Natur, PhD dissertation , *Arbeitsberichte des Instituts für mathematische Maschinen und Datenverarbeitung*, Band 28, Nummer 10, Erlangen, 1995. (In Deutch Language).
- [20] Takagi T., Sugeno M., Fuzzy Identification of Systems and Its Applications to Modeling and Control, *IEEE Trans. System, Man, Cyber*, vol. 15, 1985 ,pp. 116-132.
- [21] Purnomo H., Aplikasi Sistem Fuzzy Untuk Optimasi Variabel Lingkungan Kerja, *Proseding Seminar Nasional Aplikasi Sistem Cerdas dalam Rekayasa dan Bisnis*, Universitas Gadjah Mada Press, Yogyakarta, 2000. (In Indonesian Language).
- [22] Freeman J.A., Fuzzy systems for control applications: the truck backer-upper, *The Mathematica Journal* 4, 1994, pp.64-69