Simulation of bioeconomy system using agent-based model in the case of smart, green, and conventional farming

S Viridi¹, P Premadi², PAditiawati³, E S Maqdir⁴, T Suheri⁵, J Halid⁶, K N Sari⁷, U S Pasaribu⁸, N M Sudaryani⁹, N Latifahⁱ⁰ and S Rahimah¹⁰

¹Department of Physics, Faculty of Mathematics and Natural Sciences, Institut Teknologi Bandung, Bandung, Indonesia
²Department of Astronomy, Faculty of Mathematics and Natural Sciences, Institut Teknologi Bandung, Bandung, Indonesia
³School of Life Sciences and Technology, Institut Teknologi Bandung, Bandung, Indonesia
⁴Swadaya Petani Indonesia, Bandung, Indonesia
⁵Department of Urban and Regional Planning, Universitas Komputer Indonesia, Bandung, Indonesia
⁶Lembaga Pengembangan Pendidikan Masjid Salman, Institut Teknologi Bandung, Bandung, Indonesia
⁷Department of Mathematics, Faculty of Mathematics and Natural Sciences, Institut Teknologi Bandung, Bandung, Indonesia
⁸People (Soft Skill) Development Program, Bogor, Indonesia
⁹Australia Awards in Indonesia, Jakarta Selatan, Indonesia
¹⁰Laboratory of Food Processing Technology, Department of Food Industrial Technology, Faculty of Agro-industrial Technology, Universitas Padjadjaran, Sumedang, Indonesia

Email: dudung@fi.itb.ac.id

Abstract. Using agent-based model (ABM) interaction between agents in the form of weather (temperature and precipitation), soil, and plant for different farming system is simulated. Three farming system: conventional farming (CF), organic farming (OF), smart farming (SF) are chosen, where each has its own characteristics. Age of plant \( \tau_{\text{max}} = 30 \) day and lag time between two successive planting \( \tau_{\text{lag}} = 10 \) day are used for ten years simulation. In each year there are nine replanting process. It is observed that CF and OF are very dependent to the weather, while SF is not. This will make the last farming system very superior, constant and predicted results, compared to the other two based on the proposed model, especially how every system components influence size of the plant as assumed.

1. Introduction

It was already well known that conventional farming will be differ in affecting soil condition compared to green farming on soil erosion [1], soil fertility and biodiversity [2], and soil quality [3]. It is also required higher input labor about 15 % than the other type of farming [4]. Then, come the smart
farming, which is using information and communication technology in advancing farming system, from controlling the plant environment to managing the market of the farming product [5]. In this work the three types of farming: conventional farming (CF), organic farming (OF), smart farming (SF) are represented as agent, which interact with farming land or space (FL) and marketplace (MP), where these are also agents. CF will not be supported continuously by the land due to its unfriendly use of it, while the OF will be. CF and OF do not have up-to-date supply and demand information as SF do, but SF requires more technology investment. There is also competition between CF, OF and SF in the marketplace, which is assumed triggered simply by trend of consumers.

ABM is chosen since it is able to accommodate a holistic approach in economy [6]. Conventionally, agents can have four important characteristics, such as perception of their environment (and also other agents), performance in the form of moving, communicating with other agents and interacting with their environment, memory for their previous actions and states, and policy in the form of a set of rules, heuristics or strategies to overcome their present situation [7].

2. Model

Influence of environment is introduced to the system through temperature and precipitation, which is generated by two agents, which propagate their information, i.e. daily temperature and precipitation, to other agents.

2.1. Temperature and precipitation generator

Probability of occurrence for temperature $p_T$ is assumed to have a form of

$$p_T(T) = \frac{1}{\sigma_T \sqrt{2\pi}} \exp \left[ -\frac{(T - \mu_T)^2}{2\sigma_T^2} \right],$$

and for precipitation $p_I$

$$p_I(I) = \left[ \frac{1}{\ln(I_{\max} - I_{\infty}) - \ln(I_{\min} - I_{\infty})} \right] \frac{1}{I - I_{\infty}},$$

with $I_{\min} \leq I \leq I_{\max}$, where both are deduced from [8]. Illustration for equation (1) and (2) is given in Figure 1.

![Figure 1](image-url)

**Figure 1.** Probability of occurrence for temperature $p_T$ with $\mu_T = 20$, $\sigma_T = 4$, $T_{\min} = 0$, $T_{\max} = 40$, $\Delta T = 1$ (left) and precipitation $p_I$ with $I_{\infty} = -3$, $I_{\min} = 0$, $I_{\max} = 50$, $\Delta I = 1$ (right).

Both equations (1) and (2) meet following criteria

$$\int_{X_{\min}}^{X_{\max}} p_X dX = 1$$

with $X = T, I$ and $p_T$ has $N_T = 40$ values and $p_I$ has $N_I = 50$ values.
2.2. Plant growth
Crop production is globally affected by climate change as observed [9], where temperature effects can be distinguished into the direct effect on germination, the effect on dormancy, and the indirect effect on further development [10], whose responses can be divided into high- and low-temperature responses [11], which unfortunately different to each species, e.g. broccoli and maize [12]. Beside that water use will also affect plant yield [13], where resistance to water stress can be enhanced with growth-promoting bacteria [14].

From reported observation and model how temperature and water use influencing plant growth a function in the form of

\[ G = G(T, H) = G_T(T)G_H(H), \]  

with \( G \) for plant growth, \( T \) for temperature, and \( H \) for water use. One of the forms for influence of temperature to growth response \( G_T \) seems to have three different phases, which are linearly increasing, parabolic-like around optimum, and linearly decreasing, as temperature increases [12], which can be approximated through

\[
G_T(T) = \begin{cases} 
0, & T < T_L, \\
\frac{c_2(T - T_O)^2}{T_L - T} + 1, & T_L \leq T < T_{LO}, \\
\frac{c_2(T - T_O)^2}{T_{HO} - T} + 1, & T_{LO} \leq T \leq T_{HO}, \\
0, & T_{HO} < T < T_H.
\end{cases}
\]

where four parameters \( T_L, T_O, T_H, \) and \( c_2 \) are required. Illustration of \( G_T \) is given in Figure 2 (left). Following equations give value of \( T_{LO} \) and \( T_{HO} \) through

\[ T_{LO} = T_L + \sqrt{(T_O - T_L)^2 + c_2^2}, \]

and

\[ T_{HO} = T_H - \sqrt{(T_H - T_O)^2 + c_2^2}. \]

**Figure 2.** Plant growth as for temperature \( G_T \) with \( T_L = 10, T_H = 38, T_O = 27, c_2 = -0.0084 \) (left) and for water use \( G_H \) with \( H_L = 20, H_H = 40 \) (right).
For water use $G_H$ following function is used

$$G_H(T) = \begin{cases} 0, & H < H_L, \\ (H - H_L)/(H_H - H_L), & H_L \leq H \leq H_H, \\ 1, & H_H < H, \end{cases} \tag{8}$$

which is simplified from reported model [13]. Illustration of this function is given in Figure 2 (right).

Duration of rain in a day, where probability of occurrence is from equation (2), will determine availability of water amount in a day. If water amount is sufficient according to equation (8) then plan will grow with

$$\Delta G = G(T,H)\Delta G_0, \tag{9}$$

where $\Delta G_0$ is its normal growth change, which is simplified from [15] to a derivative sigmoid function

$$\Delta G_0 = S(t)\left[1 - S(t)\right], \tag{10}$$

with the sigmoid function itself it

$$S(t) = \frac{A}{1 + e^{-\Delta G_0}}, \tag{11}$$

where $A$, $b$ and $t_0$ are adjustable parameters.

**Figure 3.** Sigmoid function (left) and its derivative $dS/dt$ or $\Delta G_0$ (right) with $A = 1$, $b = 0.4$, and $t_0 = 15$, where time $t$ is in day.

In the simulation time $t$ will be increased with time steps $\Delta t$, so that at each simulation time the value of $\Delta G$ will depend on temperature $T$ and water amount $H$. There is also another factor $\tau_{SO}$, especially for CF, which controls the soil condition through the relation

$$e^{-\left(t-t_{RP}\right)/\tau_{SO}}, \tag{12}$$

where $t_{RP}$ is replanting time. Each time replanting event occurs, $t_{RP}$ is set to current time $t$. A correction factor $A_{corr}$ must also introduced,

$$\Delta G = G(T,H)\Delta G_0 e^{-\left(t-t_{RP}\right)/\tau_{SO}} / A_{corr}, \tag{13}$$

to normalized the growth to maximum size in the case of SF and $A_{corr} \to \infty$.

### 2.3. Types of farming

There three types of farming (CF, OF, SF) will be considered in this work and how they differ to each other is given in Table 1.
Table 1. Difference of type of farming.

| Farming type | Continue planting time | Control of weather |
|--------------|------------------------|--------------------|
| CF           | no                     | no                 |
| OR           | yes                    | no                 |
| SF           | yes                    | yes                |

Based on these criteria each type of farming will react differently to environment influences, such as temperature, precipitation, and soil recharging mechanism (natural or artificial).

2.4. Schematic of components relation

There are three main components in the simulation, which are environment EV (temperature, precipitation), farming system FS (soil SO, CF, OF, SF), and plantation PL (type A, type B). EV cannot be controlled and it will be generated randomly according to equations (1) and (2). Soil condition in FS will depend on EV and types of FS, i.e. CF, OF, or SF, where CR will allow EV to interact directly to soil (let it becomes very nutrient-poor) and to PL, OR will allow EV to interact directly to PL but it conserves the soil in the state of nutrient-balance, and SF will maintain EV in optimum state for plant growth and provide soil (or other growing medium) with optimum nutrient. These types of FS are illustrated in Figure 4 (left). Nutrient-balance condition is symbolized by green triangle, which represents the organic compound added to the soil.

![Figure 4](image)

Figure 4. Types of farming system: CF, OF, SF (left) and how the components interact (right).

Interaction of each components in the simulation system is shown in figure 4 (right): environment (EV) with precipitation ($p_p$) and temperature ($p_T$), farming system (FS), plantation (PL), and soil (SO). Boxes represented FS and PL are divided into two parts which indicate several types of FS and also PL.

3. Results and Discussion

Simulation parameters are as follow $\mu_T = 20$, $\sigma_T = 4$, $T_{\min} = 0$, $T_{\max} = 40$, $\Delta T = 1$, $N_f = 40$, $I_{\infty} = -3$, $I_{\min} = 0$, $I_{\max} = 50$, $\Delta I = 1$, $T_L = 10$, $T_H = 38$, $T_O = 27$, $c_2 = -0.0084$, $H_L = 20$, $H_H = 40$, $b = 0.4$, $A = 1$, $t_0 = 15$, $\tau_{SO} = 180$, and $A_{corr} = 2.4875$.

![Figure 5](image)

Figure 5. Typical time series of temperature (left) and precipitation (right) for parameters value of $\mu_T = 20$, $\sigma_T = 4$, $T_{\min} = 0$, $T_{\max} = 40$, $\Delta T = 1$ and $I_{\infty} = -3$, $I_{\min} = 0$, $I_{\max} = 50$, $\Delta I = 1$, in a year.
Figure 6. Plant growth for plant max age $\tau_{\text{max}} = 30$ day and lag time between two successive planting $\tau_{\text{lag}} = 10$ day, in the case of CF (top left), OF (top right), SF (middle bottom left), and SF*, a SF without nutrient-balance condition (bottom right).

There are infinity number of sequence of temperature and precipitation which obey equations (1) and (2), typical time series of both environmental parameters are given in Figure 5. Related to those times series plant size in CF, OC, SF, and SF* (SF without nutrient-balance) is shown in Figure 6. It is also assumed that daily duration of rain is only one hour. This duration is important for converting value from $p_I$ in equation (1) to $H$ for $G_{HH}$ in equation (8).

Last chart in figure 6 confirms that the assumption in the case of SF and $A_{\text{corr}} \rightarrow \infty$ is fulfilled with chosen value of $A_{\text{corr}}$. It seems from figure 6 that CF and OF have too small results compared to SF, which can addressed to the form of equation (13) that also depends on the time step. In this work time step $\Delta t = 1$ day. Observation data is required to confirm equation (13) or other more suitable form.

Figure 7. Average size of plant for different FS: CF (○), OF (□), SF (△), and SF* (○).

For ten years with nine times replanting following statistics parameter in the form of average size of plant is obtained as shown in figure 7. The simulation uses $\tau_{\text{max}} = 30$ day and lag time between two successive planting $\tau_{\text{lag}} = 10$ day. It is observed that SF and SF* give controlled results as expected, but
CF and OF seem very depending on the weather condition (temperature and precipitation), which is out of our control.

4. Conclusion
Simulation of three types of farming, i.e. CF, OF, SF, has been conducted using ABM. It has been observed that SF shows most promising result compare to the other two, but requires most investment, especially in the controlling the weather (temperature and precipitation). OF is good in conserving soil condition, even not so promising in the result but it does not require discontinue of planting time as in CF, which is good only in short period of planting time.

Acknowledgments
Authors wish to acknowledge the support from P3MI ITB in presenting this work, UB in arranging this event, and DIPI in providing the field trip to meet the initial problem.

References
[1] Reganold J P, Elliot L F, Unger Y L 1987 Long-term effects of organic and conventional farming on soil erosion Nature 330 370-372.
[2] Mäder P, Fließbach A, Dubois D, Gunst L, Fried P and Niggli U 2002 Soil fertility and biodiversity in organic farming Sci. 296 1694-1697.
[3] Fließbach A, Oberholzer H-R, Gunst L, Mader P 2007 Soil organic matter and biological soil quality indicators after 21 years of organic and conventional farming Agr. Ecosyst. Environ. 118 273-284.
[4] Pimentel D, Hepperly P, Hanson J, Douds D, Seidel R 2005 Environmental, energetic, and economic comparisons of organic and conventional farming systems Biosci. 55 573-582.
[5] Wolfert S, Ge L, Verdoew C, Bogaard M-J 2017 Big data in smart farming – a review Agric. Sys. 153 69-80.
[6] Farmer J D, Foley D 2009 The economy needs agent-based modelling Nature 460 685-686.
[7] Abdou M, Hamill L, Gilbert H 2012 Designing and building an agent-based model in Agent Based Models in Geographical System AJ Heppenstall et al. (Eds). Springer Dordrecht Chapter 8 pp 141–165
[8] Zhang X, Alexander L, Hegerl G C, Jones P, Tank A K, Peterson T C, Trewin B, Zwiers F W 2011 Indices for monitoring changes in extremes based on daily temperature and precipitation data WIREs Clim. Change 2 851-870.
[9] Lobell DB, Schlenker W, Costa-Roberts J 2011 Climate trends and global crop production since 1980 Sci. 333 616-620.
[10] Went F W 1953 The effect of temperature on plant growth Annu. Rev. Plant. Physiol. 4 347
[11] Hughes M A, Dunn M A 1990 The effect of temperature on plant growth and development Biotechnol. Genet. Eng. Rev. 8 161-188.
[12] Hatfield J L, Prueger J H 2015 Temperature extremes: effect on plant growth and development Weather. Clim. Extrem. 10 4-10.
[13] Hanks 1974 Model for predicting plant yield as influenced by water use Agron. J. 66 660
[14] Mayak S, Tiros T, Glick B R 2004 Plant growth-promoting bacteria that confer resistance to water stress in tomatoes and peppers Plant Sci. 166 525-530.
[15] Smith N C, Lee E A 2016 Heterosis and growth in a developing maize plant Maydica 61 1-8.