Stochastic model to predict boron concentration with different inflow and interval irrigation in greenhouse

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Abstract. This study presents the development of a stochastic modelling system and a laboratory works on the greenhouse scale for estimating the concentration of boron in controlled irrigated-paddy plants. The model was developed based on Object Oriented Programming (OOP) Python 3.6. The stochastic model is developed to predict boron concentration through different treatments (different inflow and interval irrigation) inside the greenhouse. There were three treatments of the experiment in greenhouse scale: the buckets filled using full of open inflow in bucket one, the buckets filled using a half of open inflow in bucket two, the buckets filled using a quarter of open inflow in bucket three. The study used integration data using Odeint python package, Hargraves model, and chemical kinetics to estimate the boron concentration. The result shows that bucket two and bucket three have higher boron concentration than bucket one based on laboratory experiment. In this study, the simulation approaches show performances which are satisfactory to predict boron concentration up to three second in the buckets.

1. Introduction

Boron (Br) is one of the parameter water quality for irrigation especially for paddy plants in Indonesia, based on Indonesian government regulation No. 82 year 2001 regarding water quality and water pollution control containing water quality criteria based on water quality classes. Boron is an important element and micronutrient for plants especially in growth and productivity. The use of concentration of boron must be controlled in agriculture. Otherwise, the range concentration of boron between plant deficiency and toxicity is narrow. The regulation for boron uses in irrigation for more than 2 mg/L can be harmful for paddy [1]. However, if the amount of boron is high, it gives impact and toxicity especially in water bodies and agricultural areas.

The study about boron concentration prediction is limited. Some important reviews on the study pointed out that pH parameter in soil influenced the increase of concentration of boron [2, 3]. Soil properties (pH, Salinity, sand content, clay content, total organic carbon, total nitrogen, cation exchange capacity) give influence for boron concentration. Otherwise, soil moisture is an important parameter for the boron concentration [4]. The effect for boron concentration < 2 mg/L gives impact to productivity and growth of paddy plant [5]. Boron modelling software was developed with the name of the code program is FITEQL 4.0 [6]. FITEQL 4.0 was one of the computer programs to calculate boron chemical equilibrium constants from experimental data. However, the computation did not include the evaporation rate. Research about boron prediction using stochastic models has been used in materials science, and crop yield production [7, 8, 9].
The objective of the research is to develop a simulation code program based on Object Oriented Programming (OOP) Python 3.6 which has integration between water inflow, irrigation interval, concentration of boron and evapotranspiration rate. The purpose of this study is to predict the concentration of boron in the soil of buckets from water tanks inside the greenhouse. A code program computer consists of Hargraves model as evapotranspiration rate, water inflow, boron concentration of initial condition and boron concentration of last experiment as an input for boron concentration prediction will estimate. Hargraves model (evapotranspiration model) is used because this model is one of simplest and evapotranspiration model estimation based on temperature data.

2. Materials and Method

2.1. Data collection
In this study, the experiment was located in the Research Centre for Limnology, Indonesian Institute of Sciences (LIPI) from June until October in 2019. The experiments were carried out by growing paddy plants inside a research greenhouse. Figure 1 shows that the experiment used nine buckets with one water tank fill synthetic boron divided into three treatments: (i) the buckets were filled of full open inflow in bucket 1 (ii) the buckets were filled of a half of open inflow in bucket 2 (iii) the buckets were filled using a quarter of open inflow in bucket 3.

The evapotranspiration model is used to quantify the water loss for nine buckets. The study used temperature data as an input parameter for Hargraves model (evapotranspiration model). The interval irrigation is related to the evapotranspiration process. This process is one of the important parts as an input to quantify the boron concentration in buckets. Different treatment is used to analyse the concentration of boron with different inflow and different irrigation interval in experiment. Total number of water level in nine buckets for five months (June, July, August, September October 2019) using two times a day measurement data is 312 data. Data Loggers (Elitech RC5 USB and HOBO Data logger MX 2203) were used to record every 15 minutes water temperature of every bucket and air temperature data inside the greenhouse. Soil moisture and pH sensor is used inside the greenhouse. From figure 1, the height of the water tank is 90 cm with a total volume of 500 litre and diameter of water tank is 70 cm. There are 9 buckets with 3 buckets using full open inflow, 3 buckets used ½ inflow, and 3 buckets used ¼ inflow and the size of pipe and tube is ¾.

Figure 2 shows the process of mixing of boron synthetic with water tank as water source for the experiment with refill water tank using 10 ppm (mg/L) for 500 Litre of water tank. Water sample used
to analyse the boron concentration in water tank for irrigation. Water level data recorded using manual measurement and there was a pipe in every bucket to measure the water level in every morning and afternoon.

**Figure 2.** Synthetic boron for experiment and analysis inside greenhouse

### 2.2. Methodology

![Flow chart image](image_url)

**Figure 3.** The flow chart of boron concentration prediction for paddy inside the greenhouse

The first step procedures to develop model simulation is initial condition. Initial condition is an important factor to build up a model using programming based on Object Oriented Programming (OOP). The formulation to quantify water inflow with different inflow and different interval irrigation from water tank to every bucket with contain of soil as below:
\[
\frac{dm}{dt} = m_{in} - m_{out}
\]  
(1)

\[
\frac{dh}{dt} = \frac{C}{\rho_s} \text{%\%open}
\]  
(2)

Where \( \frac{C}{\rho_s} \) (\%open) is the percentage of \% open irrigations using 100\% open of tap for Bucket 1 (bucket 1.1, bucket 1.2, bucket 1.3), 50\% open of tap for Bucket 2 (bucket 2.1, bucket 2.2, bucket 2.3) and 25\% open of tap for bucket 3 (bucket 3.1, bucket 3.2, bucket 3.3). \( m_{in} \) is inflow, \( m_{out} \) is outflow, \( d_h \) is water level in water tank, \( d_t \) is time. At the same time, calculation for evapotranspiration rate is needed. The study used Hargraves model to quantify evapotranspiration rate in the buckets. This approach is a simplest method to quantify evaporation rate and one of the empirical models using temperature data such as maximum temperature, minimum temperature and average temperature. The study used a temperature data sensor inside the greenhouse.

Secondly, the calculation of kinetics constant to estimate the order position was used in this study. The kinetics calculation is an input for chemical reaction using reaction rate in a boron prediction in buckets.

\[
\frac{dC_a}{dt} = -kC_a
\]  
(3)

Where, \( \frac{dC_a}{dt} \) is reaction rate, \( k \) is kinetics, and \( C_a \) is concentration of chemical.

**Table 1.** Boron data sample to analyse kinetics order position.

| Time (days) | [B] mg/L | ln [B]  | 1/[B] |
|------------|----------|---------|-------|
| 0          | 0,001    |         |       |
| 1          | 1,45     | 0,371   | 0,689 |
| 11         | 12,5     | 2,526   | 0,08  |
| 21         | 12,4     | 2,517   | 0,081 |
| 42         | 12,1     | 2,493   | 0,083 |
| 46         | 11,4     | 2,434   | 0,088 |
| 59         | 11,5     | 2,442   | 0,086 |
| 77         | 37,8     | 3,363   | 0,026 |

In the next step, we used boron chemical reaction in below [3]:

\[
\text{SOH}_{\text{\oplus}} + \text{H}^+ \rightleftharpoons \text{SOH}^\text{\oplus}_{\text{\oplus}}
\]

\[
\text{SOH}_{\text{\oplus}} \rightleftharpoons \text{SO}_{\text{\oplus}} + \text{H}^+
\]

\[
\text{SOH}_{\text{\oplus}} + \text{H}_3\text{BO}_{\text{\oplus}} + \text{H}_2\text{O} \rightleftharpoons \text{SH}_3\text{BO}_{\text{\oplus}} + \text{H}^+
\]

where SOH represents reactive surface hydroxyls on oxides and clay minerals in the soil. The soil sample taken from depth of surface (\(+/- 5\text{cm}) of buckets. The next process is using the ODEINT Python package using model, initial conditions and time as an input to ODEINT numerically calculate \( y(t) \).

\[
y = \text{odeint} \text{(model, y0, t)}
\]  
(5)

Where model: function name that returns derivative values at requested \( y \) and \( t \) values as \( dy/dt = \text{model}(y,t) \), \text{y0}: Initial conditions of the differential states, \( t \): Time.
Table 2. Interval irrigation, boron and soil moisture percentage in nine buckets (June-October 2019).

| Date       | Irrigation | Boron (mg/L) | Soil Moisture in Bucketn (%) |
|------------|------------|--------------|------------------------------|
|            |            | 1.1          | 1.2                          | 1.3                          | 2.1                          | 2.2                          | 2.3                          | 3.1                          | 3.2                          | 3.3                          |
| 28/06/2019 | 1          | 10           | 100                          | 100                          | 100                          | 100                          | 100                          | 100                          | 100                          | 100                          |
| 02/08/2019 | 2          | 1.45         | 58.30                        | 46.27                        | 42.85                        | 44.59                        | 41.56                        | 42.04                        | 41.65                        | 42.68                        | 40.55                        |
| 12/08/2019 | 3          | 18.2         | 57.69                        | 46.39                        | 38.84                        | 38.46                        | 40.24                        | 32.72                        | 28.83                        | 31.14                        | 34.35                        |
| 02/09/2020 | 4          | 18.6         | 28.29                        | 26.08                        | 26.38                        | 21.80                        | 21.53                        | 21.13                        | 20.18                        | 19.74                        | 20.84                        |
| 06/09/2020 | 5          | 12.1         | 39.22                        | 34.63                        | 35.86                        | 32.20                        | 35.45                        | 32.41                        | 16.41                        | 26.59                        | 26.49                        |
| 16/09/2020 | 6          | 11.4         | 32.86                        | 28.65                        | 27.32                        | 19.79                        | 24.0                         | 18.04                        | 17.74                        | 24.29                        | 28.35                        |
| 19/09/2020 | 7          | 35.6         | 38.06                        | 27.52                        | 24.63                        | 29.54                        | 25.37                        | 32.22                        | 22.71                        | 23.83                        | 26.46                        |
| 30/09/2020 | 8          | 11.5         | 20.34                        | 17.69                        | 8.888                        | 17.62                        | 12.03                        | 10.26                        | 10.33                        | 15.03                        | 15.59                        |

Table 2 shows irrigation from a water tank filled with synthetics boron using a time interval. There are three treatment for this experiment: bucket 1 (bucket 1.1, bucket 1.2, bucket 1.3) is full open of water tab, bucket 2 (bucket 2.1, bucket 2.2, bucket 2.3) is a half of open of water tab, Bucket 3 (bucket 3.1, Bucket 3.2, bucket 3.3) is a quarter of open of water tab. Soil moisture levels in every treatment have different results because of different inflow and interval irrigation. Bucket 1 has the highest soil moisture than soil moisture level in bucket 2 and bucket 3 because it is full open of inflow water. The experiment started from June until September 2019. The irrigation interval started from August because the experiment needs to calculate the evapotranspiration rate during one month in early experiment.

3. Result and Discussions

Table 3. Boron results experiment inside the greenhouse.

| Date       | Bucket   | Boron Analysis (mg/L) | Test Method       | Analysis          |
|------------|----------|-----------------------|-------------------|-------------------|
| 18/10/2019 | Bucket 1.1 | <5.00                | APHA.3120B-2012   | ALS Laboratories  |
| 18/10/2019 | Bucket 1.2 | <5.00                | APHA.3120B-2012   | ALS Laboratories  |
| 18/10/2019 | Bucket 1.3 | 43.9                 | APHA.3120B-2012   | ALS Laboratories  |
| 18/10/2019 | Bucket 2.1 | 63.3                 | APHA.3120B-2012   | ALS Laboratories  |
| 18/10/2019 | Bucket 2.2 | 49.6                 | APHA.3120B-2012   | ALS Laboratories  |
| 18/10/2019 | Bucket 2.3 | 26.0                 | APHA.3120B-2012   | ALS Laboratories  |
| 18/10/2019 | Bucket 3.1 | 47.2                 | APHA.3120B-2012   | ALS Laboratories  |
| 18/10/2019 | Bucket 3.2 | 42.7                 | APHA.3120B-2012   | ALS Laboratories  |
| 18/10/2019 | Bucket 3.3 | 22.5                 | APHA.3120B-2012   | ALS Laboratories  |

Table 3 shows that there are nine buckets using different inflows with synthetic boron concentration. The result comes from analysis of boron concentration in soils of experiment. Table 3 illustrates that the concentration of boron metal in the soil is higher with decreasing flow rate. On bucket 1.1, bucket 1.2, bucket 1.3, boron metal is detected very low because the inflow rate is fully open. Boron metal washed from the soil because it is easily lost from the soil compared to other important metals [10]. In bucket 1.1 and bucket 1.2, the concentration of boron is under below estimation because of the influence from inflow (water irrigation). It gave impact to high soil moisture levels in the buckets. The boron concentration can be maximally used for growing rice plants in
buckets 2.1, 2.2 and 3.1, 3.2. The level of boron concentrations in bucket 2 is higher than bucket 1 because of fluctuation of dynamic process in soil (boron depends on the soil's humidity) and evapotranspiration process. In conclusion, inflow for buckets gave influence to the boron concentration especially in buckets 2 and buckets 3.

A computer program to model the dynamics of boron concentration was written in the Object Oriented Programming (OOP) python code. The program solves the boron concentration prediction using integration data. In figure 4, the result of kinetics boron concentration signed constant value for orde position is 0 with kinetics = -0.328. the kinetics calculation as an input for chemical reaction for boron concentration.

\[ y = 0.328x + 1.8566 \]
\[ R^2 = 0.654 \]

![Figure 4. Kinetics for boron data experiment inside greenhouse](image)

Figure 5 illustrates prediction for nine buckets about boron concentration. The simulation has an assumption to merge 3 buckets into one bucket simulation. The purpose of assumption is to simplify the computation. Figure 3 explains that the boron concentration of bucket 1 is lower than bucket 2 and bucket 3 because soil moisture gave influence for soil hydrodynamic and water quality. The higher
boron concentration in the end experiment indicates that there was additional boron metal continually through water tank inflow (irrigation). It gave impact to the higher boron concentration than earlier experiments. In the experiment, the accumulation of higher boron synthetic which has been found in the soil of buckets happened because boron was not absorbed by the plant immediately. It gave impact to the higher level of concentration of boron for soil at the end of the experiment.

4. Conclusion
The higher or lower of boron concentration depends on inflow, chemical reaction, and meteorology factor. Boron concentration prediction is an essential topic in water and agriculture management. The benefit of ODEINT python as an input to program code is the method to predict the trend concentration of boron which is useful for boron quantification for agriculture. Overall, the approaches show performances which are satisfactory to predict boron concentration up to three second in the buckets.

Suggestion
This study only simulates using dynamic simulation. In the future, the study will combine with a data driven method to improve the simulation result. The study required a lot of data. Otherwise, it’s critically important to add more boron data experiments for complex analysis data especially in the leaching process.

Declaration
Yuli Sudriani is main contributor and Fajar Sumi Lestari is member contributor for this research publication.

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