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Study of numerical analysis and gravimetric method of soil water contents in relation to growth parameters and yields of onions (*Allium cepa* L.)

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Abstract Results showed that soil water contents were estimated with numerical model and gravimetric method revealed to follow very similar trends. Regression equations for datasets provided some insight into their similarities. Both the numerical model and the gravimetric method showed the two sets of quadratic equations with a mean correlation coefficient of 0.98 and a mean coefficient of determination of 0.99. All equations were very close in nature. Despite high levels of correlation for all simulations, it noted that numerical model was idealized as gravimetric method and the soil domain was assumed to uniform and unsaturated. Analysis of the correlation between the groundwater content of the numerical model and the gravimetric method appeared to be a strong correlation with a correlation coefficient of 0.96. Comparing the results of numerical analysis with the gravimetric method, the similarity level was closed to 80%. Thus, it concluded that the numerical estimation of soil water contents as an alternative method should be considered.

Keywords: Alternative method, Crop watering, Crop development, Correlation

Introduction

Since soil physics properties had begun to study systematically in early of 19th century, scientists have realized the importance of physics for agricultural sciences (Dakshinamurti, 2001). Subsequent developments arrived at the methods used to measure the physics quantities of soil varying. One of them is the numerical method. The numerical model which is the basis of a simulation basically consists of a set of differential equations that can describe the physics of a problem, solved through numerical methods, in a geometrically defined domain (Fabbri *et al*., 2012).

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Mathematical models of physical systems such as soil water diffusivity or transient water flow problems, the movement of soil water content is usually expressed by a system of partial differential equation. The statement of Fuqiang *et al*. (2011) stated that regarding the soil water movement equation states when the soil is homogeneous and isotropic with medium rigid pores, the movement of soil water below the surface line from the source can be simplified as a two-dimensional movement.

Usually, it is not possible to get a closed solution form, but it is possible to get an approximation solution through numerical method (Fabbri *et al*., 2012). In the case of flow in the unsaturated zone described by Richards' equation which is a nonlinear and parabolic differential equation, the solution is more difficult. However, according to Guarracino and Quintana (2004) and Allred *et al.* (2008), the flow in the unsaturated zone for the homogeneous medium can be described by a linear partial differential equation as follows:

$$\frac{\partial\theta}{\partial t} = D\left(\frac{\partial^2\theta}{\partial x^2} + \frac{\partial^2\theta}{\partial z^2}\right), \qquad \forall\,(t,x,z)\, \in (0,t_F)\times(0,L)\times(0,H) \quad (1)$$

Where: θ is the volumetric soil water content, t is time, D is the hydraulic conductivity, x is the spacing horizontally, and z is the soil depth (positive downward).To make D independent with depth and time, it is necessary that the soil profile remains homogenous with respect to all parameters in given time interval (Hillel, 2004). Movement of water within an unsaturated zone is studied in soil physics and hydrology particularly hydrogeology, and is of important to agriculture and contaminant transport (Sharaiyni and Ataie-Ashtiani, 2012) and soil mechanics, the fluid mechanics, and others (Han and Zhou, 2018). Deeper soil layers recharge, which is an important process that refills soil pores generally occurs through the unsaturated zone from precipitation or water applied. The facts show, after heavy rain or after watering, the surface layer of the soil is temporarily saturated. This water is subject to the law of gravity and is therefore gradually infiltrated into the soil through dry layers, and leaving a moist area on its way (Gautam *et al*., 2018).

Measurement of θ can be categorized as direct and indirect measurement. Gravimetric measurement is as conventional method which is categorized a direct method of soil characterization. This method is known very accurate but it is not practice due to time-consuming and expensive (Kazmi *et al*., 2016). However, this method can be used as a calibration for other techniques (Mukhlisin and Saputra, 2013) such as numerical method, while the numerical method is categorized as indirect measurement. In recent decades, the use of computational and numerical models to solve the problems of unsaturated flows grown substantially; subsurface flows are still considered to be one of the most important topics in hydrology and agriculture (Nikzad *et al*., 2016).The numerical simulation methods provide a useful design and analysis tool to agricultural (Fabbri *et al*., 2012).

For centuries the amount of moisture in soil has been of interest in agriculture (Gautam *et al*., 2018) and is an important factor that influences seed yield of onion (Anizuzzaman *et al*., 2009, Roy *et al.*, 2014). It is well recognized by many researchers that soil water content at the field capacity condition is one of the environmental factor of predominant importance affecting on the onion growth, development, and productivity. Therefore, many publications have reported by many researchers. Research reported by Shaibu *et al*. (2015) that maximum yield of onion could be obtained with the achievement of entire crop water requirement. In line with this, Enchalew *et al*. (2016), Metwally (2011) and Shock *et al*. (2010) stated that to maximize of onion yield was required sufficient water. However, the aim of water supply is not to ascertain the amount of water that would result maximal absolute yield or necessarily the amount needed to attain maximal yield per unit volume of water, but the optimal water supplied that can produce the greatest net yield (Hillel, 2004). The optimal water supply is found to be a vital strategy to save water and hence enhance water use efficiency by maintaining satisfactory yield (Temesgen *et al*., 2018).

The numerical solution of ground water content is the ground water content in layers of root depth of onions. The purpose of this study was to analyze the relationship between numerical soil water content and growth and yield of onions and the water content of gravimetric analysis.

Materials and methods

Study area and time of activity

The study was conducted in Usuku, Tomia District of Wakatobi Regency, Indonesia in the hot dry season from September to December 2016. The coordinates are 123^{o}.56.466 'E and 05^{o}.45.906' S, and 107 meters above sea level.

Materials used in the study

The seeds of onions that used in this research were the local onion variety, NPK fertilizer, husks. The tools used were crowbar, hoe, knife, and stationary.

Soil sampling

Soils ampling was used as core sampler at depths of: 0-10, 10-20 and 20-30 cm respectively. The soil chemical-physical properties selected for analysis were pH, texture, N, P, K nutrients, organic matter, organic carbon, and soil water content. The methods used to analysis these parameters were portable pH meter Model 130, Kjeldahl method for N total, Bray method for phosphor and potassium, Walkley and Black method for C-organic (Walkley and Black, 1934) and gravimetric method for estimate soil water contents and pipette method for texture. The soil sampling analysis results were listed in Table 1.

Table 1. Soil physical-chemical properties of experiment site

Chemical properties							Physical properties		
pH	N tot (%)	P (ppm)	K (me.100g^{-1})	BO (%)	CO (%)	θ_0(%)	sand	silt	clay
6.73	0.31	37.74	0.32	1.86	3.81	30.5	13.09	14.24	72.67

Land preparation

Land preparation was done by bouncing, then separated the soil from gravel in such a way that the soil was really in a loose and homogeneous state. Next, four plots were made, each plot 1.5 x 4 m in size with a distance 50 cm between plots. The level of the soil is raised about 20 cm from the ground and planting space of 15 cm x 15 cm. The treatment consisted of 4 different water levels i.e. 0, 4, 8, and 16 liters with a notation A0, A1, A2, and A3, and 4 plots with a notation P1, P2, P3, and P4. Each plot was watered with 0, 4, 8 and 16 liters, respectively. Based on simple random of the plots, it showed4 plot combinations of A3P1, A1P2, A0P3 and A2P4.

Data collection

Data on onion growth and yield were recorded after harvest and expressed as average of population of each plot of treatment. The observations were recorded as plant height, leaf area index, fresh weight and dry weight. Height plant was measured in centimeters unit from ground reference to tip of the stem. The fresh and dry weight was measured in grams using analytical sensitive balance with 0.001 g of accuracy. While the leaf area index (LAI) was calculated from relationship:

$$\mathrm{LAI} = \frac{\text{total leaf area}}{\text{row spacing}} \text{x coeficient of onion at harvest time}$$

The total of leaves area was the average of three leaves of onion multiplied by the number of leaves plant^{-1}. The coefficient of onion at harvest time was 0.85 (Doorenbos *et al*., 1979). Water flow equation was solved numerically with the finite difference using Mat-Lab code.

Data analysis

Analysis of the relationship between the groundwater content of both methods and plant growths and yields as well as correlation analysis between numerical water content and gravimetric water content were all plotted in the Mat-Lab program.

Finite difference method

The finite difference is considered as the most applicable method for numerical solution to many partial differential equations in many disciplines area of science and technology. The method is based on replacing partial derivative by finite difference approximation using expanding Taylor series (Hoffmann, 1989). It is therefore continued to equations(1) for moisture-based can be approximated by using forward difference for the time derivative and central difference for the space derivative which is $[(\Delta t),\ (\Delta x)^2, (\Delta z)^2]$yields, the following discrete equations in time and space for n, x and z sweep:

$$\theta_{i,j}^{n+1} = \theta_{i,j}^{n} + \frac{D\Delta t}{\Delta x^2}\left(\theta_{i,j+1}^{n} - 2\theta_{i,j}^{n} + \theta_{i,j-1}^{n}\right) + \frac{D\Delta t}{\Delta z^2}\left(\theta_{i+1,j}^{n} - 2\theta_{i,j}^{n} + \theta_{i-1,j}^{n}\right) \quad (2)$$

Where: i and j subscripts refer to horizontal and to depth increments, Δx, $\Delta z$are distance apart, n refer to the time increment, andΔt time apart. The ranges of i, j, and n are

$$1 \le i \le I-1, \quad 1 \le j \le J-1, \qquad 0 \le n \le N-1$$

$$x_i = i\Delta x, \qquad \Delta x = \frac{1}{I}, i = 1,2 \ldots, I$$

$$z_j = j\Delta z, \qquad \Delta z = \frac{1}{J}, \qquad j = 1,2,\ldots,J$$

$$t_n = n\Delta t, \qquad \Delta t = \frac{t_F}{N}, \qquad n = 0,1,\ldots,N$$

Define the diffusion numbers

$\lambda_1 = \frac{D\Delta t}{\Delta x^2}$, and $\lambda_2 = \frac{D\Delta t}{\Delta z^2}$,

Then, the stability requirement is express as

$$(\lambda_1 + \lambda_2) \leq \frac{1}{2} \tag{3}$$

(Hoffmann, 1989)

The numerical soil water content was evaluated at all grid points where onions were planted. Soil water content (θ) at certain depth based on the boundary conditions values of soil water content at the upper soil layer for each treatment water levels was estimated. The simulation parameters were total time (T = 3 hours), height (H = 30 cm), initial soil water content ($\theta_i =$ boundary conditions at the top soil level for plot with 0 liter, 4 liters, 8 liters, and 16 liters respectively), soil water at bottom ($\theta_b =$ boundary conditions at bottom), constant hydraulic conductivity (D = 3.99 x 10^{-3}), size of space step ($\Delta x = \Delta z = 3$ cm), and size of time step ($\Delta t =$1/60). The initial soil water contents at the topsoil level were calculated by gravimetric method.

***Soil water measurement**:*

The initial requirements and boundary conditions for the purposes of estimating soil water content in numerical method were needed. In this case it was used the gravimetric method. The required boundary conditions were only at the top soil surface and at a depth of 30 cm onion roots. Field soil samples from each plot of 0 L, 4 L, 8 L and 16 L were taken for about 3 hours after watering at root depths of 5, 10, 20 and 30 cm respectively. Each field sample plot was prepared with standard sampling techniques, and placed in a small plastic bags labeled and then measured using a sensitive analytical balance to obtain the weight of the field (50-100 g), and then placed into an oven at 105 ^{o}C for 24 hours for perfect drying (Sarkar and Hardar, 2005) to obtain the weight of the oven dry soil. Therefore, the soil water content was calculated as a percentage in oven-dry soil weight base according to Survey (2011) as follows:

$$\text{Soil water content (\%)} = \frac{\text{weight of moist soil} - \text{weight of oven dry soil}}{\text{weight of oven dry soil}} \times 100\ \%$$

Boundary conditions can be set up as the usual way. Initial soil water content, θ_i is taken at the top of soil surface based on gravimetric analysis, while the left side, right side, and bottom boundary conditions are set up as a constant value.

Results

The numerical soil water contents in relation to growth parameters and yields of onions

Results of the soil water contents from numerical analysis due to different water levels treatment, and onion growth and yields were illustrated in Table 2. The observed parameters of the onion increased every time the volume of treatment water was added from 0 to 16 liters as well as the numerical soil water content from 6.02 to 35.9 as seen in Table 2. Plotting Table 2, it yielded four functional relationship curves between numerical groundwater content and onion growth and yield parameters as shown in Figure 1. Accordingly, it can be described that with an increase in the numerical soil water content, it will be followed by an increase in the value of each onion parameter until it reached a certain maximum value then reversed towards the coordinates of the turning point, and if the water content of watering is greater or the excess water. It was estimated that the crop yield will decrease. The characteristics of the relationship between numerical soil water content and each parameter of onion were described by their respective quadratic equations, with an average correlation coefficient r of 0.98 and a mean coefficient of determination $R^2$of 0.98 as presented in Table 3.

Table 2. The numerical soil water analysis and the onion parameters

Water treatments (liters)	Numerical soil water content (%)	Plant eight (cm)	Leaf area index	Fresh weight (g)	Dry weight (g)
0	6.02	29.5	1.3	42	34.6
4	12.0	30.6	2.3	45.47	37.7
8	23.7	31.58	2.5	49.02	40.41
16	35.9	32.16	28.53	49.53	42.81

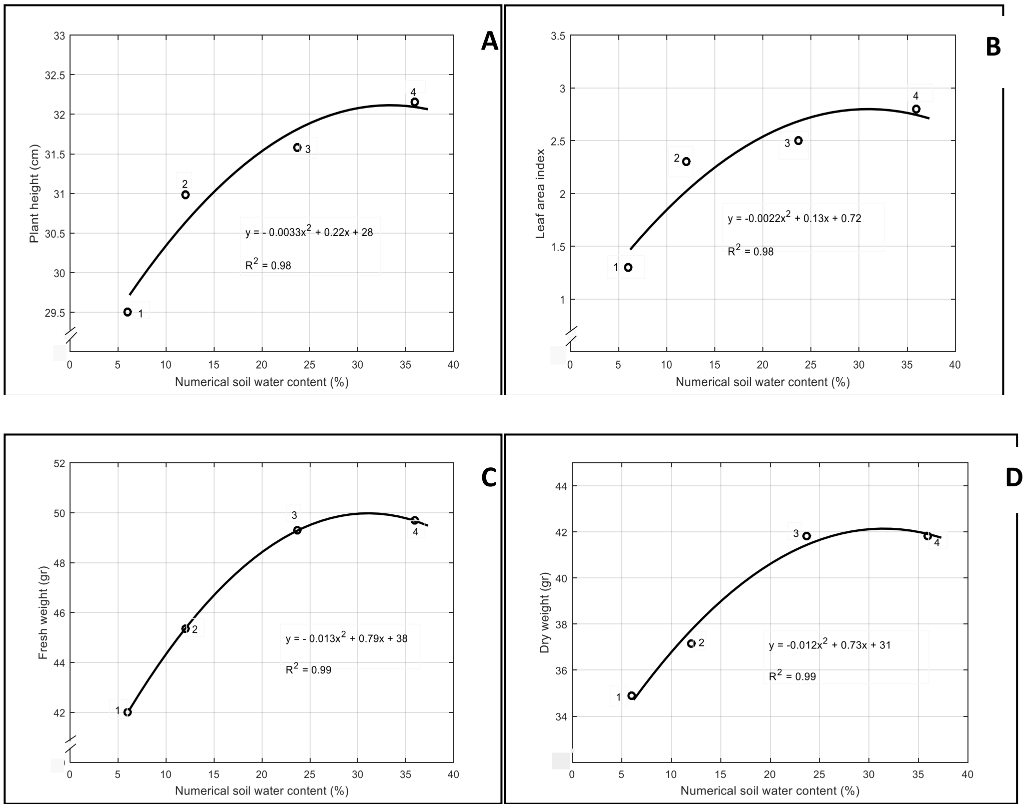

Figure1. The response of onion plants to the soil water contents was estimated using numerical method (A: plant height, B: leave area index, C: fresh weight, D: dry weight)

Table 3. The performance of numerical model of soil water contents

Onion parameters	**Quadratic equations**	**Correlation coefficient (r)**	**Determination coefficient (R^2)**
Plant height	$Y= - 0.0033x^2 + 0.22x + 28$	0.989	0.98
Leaf area index	$Y= - 0.0022x^2 + 0.13x + 0.72$	0.989	0.98
Fresh weight	$Y= - 0.013x^2 + 0.79x + 36$	0.999	0.99
Dry weight	$Y= - 0.012x^2 + 0.73x + 31$	0.999	0.99

The gravimetric soil water contents in relation to growth parameter and yields of onions

Results of the soil water contents from gravimetric method due to different water levels treatment, and onion growth and yields were illustrated in Table 4. The volume of water treatment was increased, the soil water content measured gravimetrically increased to allow plant roots easily uptake soil nutrients which resulted to plant growth and yields increased. The functional of relationships between gravimetric method of soil content and onion growths and yields were illustrated in Figure 2. It can be described that with an increase in the gravimetric soil water content, it followed by an increase in the value of each onion parameter until it reached a certain maximum value, then reversed towards to coordinate the turning point. If the water content of watering is greater or the excess water, it was estimated that the crop yield will decrease. The performance of gravimetric soil water contents with four quadratic equations were presented in Table 5.

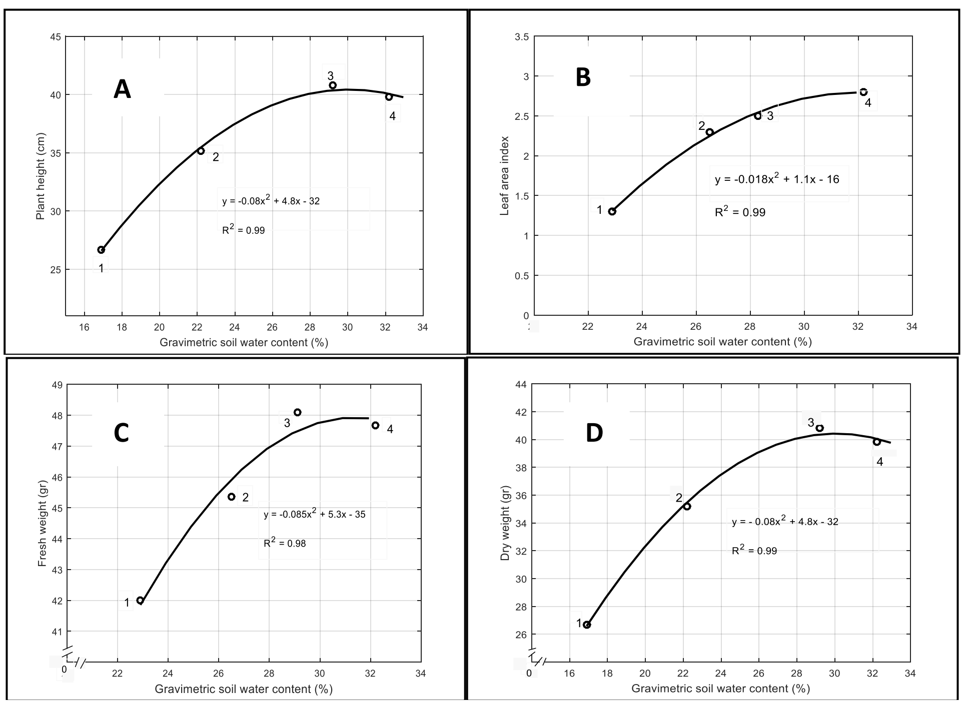

Figure 2. The response of onion to the soil water content was measured using gravimetric method (A: plant height, B: leave area index, C: fresh weight, D: dry weight)

Table 4. The gravimetric soil water contents and the onion growths and yields

Water treatments (liters)	Gravimetric soil water content (%)	Plant eight (cm)	Leaf area index	Fresh weight (g)	Dry weight (g)
0	16.9	29.5	1.3	42	34.6
4	22.2	30.6	2.3	45.47	37.7
8	27.1	31.58	2.5	49.02	40.41
16	31.2	32.16	28.53	49.53	42.81

Table 5. Performance of gravimetric of soil water contents

Onion parameters	Quadratic equations	Correlation coefficient (R)	Determination coefficient (R^2)
Plant height	$Y=-0.08x^2+4.8x-32$	0.989	0.99
Leaf area index	$Y= - 0.018x^2 + 1.1x$ -+16	0.989	0.99
Fresh weight	$Y= - 0.085x^2 + 5.3x - 35$	0.989	0.98
Dry weight	$Y= - 0.018x^2 + 1.1x - 16$	0.999	0.99

Correlation between numerical and gravimetric soil water content

Numerical and gravimetric soil water content data was presented in Table 6. The volume of treatment water tended to higher the groundwater content whether it was estimated numerically or by the gravimetric method as predicted (Table1).In other words, treated water directly affected the addition of groundwater content. In another word, the water treatment directly provided a high degree positive correlation of numerical soil water content was estimated and gravimetric method was r = 0.98 (Figure 3).

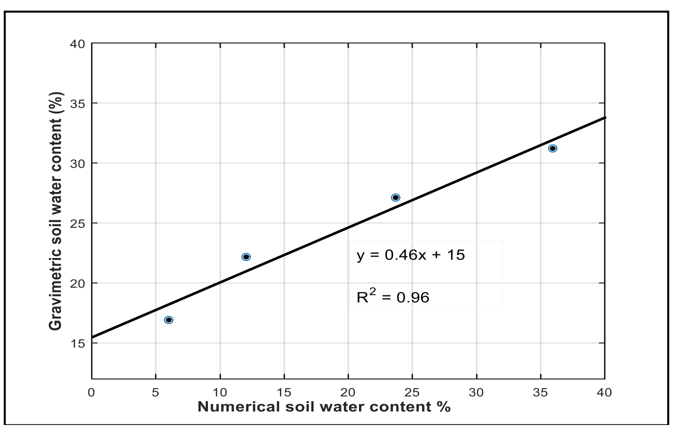

Figure 3. Correlation between numerical and gravimetric soil water contents

Table 6. Soil water was estimated by numerical analysis and was measured by gravimetric method

Numerical soil water (%)	Gravimetric soil water (%)
6.02	16.9
12	22.2
23.7	27.1
35.9	31.2

Discussion

The slope of the curve at each point represented the growth response and yield of the onion per unit amount of water supplied. The shape of this curve was in accordance with the view of Hillel (2004) that the typical response curve of plants to a number of treatment water was identical with quadratic function (*sigmoid in shape*). This view is reinforced explicitly that the response of plants to a treatment is the best when the relationship is quadratic and cannot be determined, if the relationship is linear (Hanafiah, 2014), or parabolic quadratic model (Wibisono, 2013). Such a curve model was also observed by Ukalska and Jastrzeboski (2019) when investigating the dynamics of the emergence of epicotyls from oak trees, This curve model was also observed by Ukalska and Jastrzebowski (2019) when investigating the dynamics of the emergence of epicotyls from oak trees, growing slowly at first, then faster and has a maximum absolute growth and decreases in the final phase. In the case of onions, according to Scherer (2013), at absolute maximum growth, an absolute maximum value is reached or maturity and senescence, after which the soil water content becomes more or waterlogged, then the growth and yield of onion decreased. Aldana *et al*. (2014) reported that waterlogged plants decreased growth of plant height, leaf area, and diameter of the stem base. Even as the soil stays waterlogged, the onion will rot before they have a chance to grow and also will give poor yields (Biswas and Kalra, 2018).

These results indicated that when the soil water contents increased due to water supply, the growth and yield parameters also increased until reaching a maximum value. Conversely, when the soil water contents decreased continuous to a certain amount, the growth and yield parameter decreased. This study examined other ways to measure or estimate soil water content in addition to traditional method. A high degree of correlation of the soil water content was estimated by the numerical method with the soil water content that measured by the gravimetric method (r = 0.96). According to Schober *et al*. (2018), in correlated data, the change in the magnitude of soil water contents estimated by numerical analysis is associated with a change in the magnitude of soil water contents by gravimetric method in the same direction. Coefficient correlation of r = 0.96 represents a good association. The comparison of results between the two methods numerical and gravimetric methods were closely related to 80% in similarity percentage. Thus, a numerical method of estimating soil water content can be used as an alternative method.

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