EFFECTIVENESS OF PITCHER FERTIGATION ON BUSH PEPPER PLANTS

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ABSTRACT

Pitcher is a bottlelike emitter made of porous baked-clay that is designed to be able to release water through its wall into the surrounding soil. In irrigation practice water level inside the pitcher is maintained by means of a constant water level supplier, or mariotte tube. This research looks at how the pitcher can also release nutrients when filled with dissolved fertilizers. For this purpose, we measured hydraulic and hydro-dynamic properties of the pitcher, and simulated solute transport using the convective-dispersive equation, and observed the effectiveness of fertigation in which NPK fertilizers were used on bush pepper plants. The results showed the pitcher was capable to release dissolved solution. Soil water content played significant roles in distributing the dissolved solution. These three nutrients have different distribution patterns. Nitrogen was well distributed, Phosphor was accumulated close to the pitcher's wall, and Potassium increased gradually with distance. These difference patterns were caused by the difference of hydrodynamic coefficients in which Nitrogen was the largest value among the others. The diffusion coefficient ranged at $1.01 \times 10^{-7} – 4.1 \times 10^{-3}$ cm^2/day for NaCl, and 6.7×10^{-6} - 3.5×10^{-3} cm^2/day for NPK fertilizers. Bush papers planted surrounding a pitcher enabled to extract the nutrients as shown by the progressive growth of the crops: height, branches, leaves and flowers, which were monitored daily. After unearthed, roots of the bush pepper developed only in the wetter soils. This showed the water as well as the dissolved solution were resided concentrically around the pitcher's wall, and were all available to use by the plants effectively.

Keywords: Pitcher, micro-irrigation, fertigation, bush pepper.

BACKGROUND

The use of porous material as an emitter in sub-surface irrigation has been reported elsewhere, *e.g.* to irrigate water melon in India (Mondal, 1974), horticulture in Brazil and Germany (Souza, 1982; Stein, 1997), corns, tomatoes and okra in Zimbabwe (Batchelor *et al.*, 1996), horticultures in Indonesia (Setiawan *et al.*, 1998), in Pakistan (Soomro, 2002). Even though, each technique *e.g.* how to fill and maintain the water inside the pitcher might be different, the main principal is similar that is water flow from the pitcher to the surrounding soil matrices is control by the permeability of the pitcher and soil suction gradient as normally expressed by Darcy law. In practice however the wall of the pitcher is in saturated condition (Saleh, 2000); accordingly the suction gradient is the only driving force to control the water flow. The soil suction itself changes in response to the evapo-

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transpiration process. Thus, it turns out that the evapo-transpiration would regulate released water automatically from the pitcher. In this sense, pitcher irrigation is perceived as self-regulative (Stein, 1997; Saleh, 2000).

Effects of different permeability of the pitcher on soil moisture profiles have been studied for different soil types (Setiawan *et.al.*, 1998; Saleh, 2000). In any cases, advances of the moving water in the soil matrices were laterally restricted in the ranges of 20-25 cm from the wall of the pitcher, and the plants' roots concentrated surrounding the pitcher's wall. In this research, we investigated solute's concentration in the soil matrices when the solution of fertilizers was filled into the pitcher, and its effectiveness to the growth of plants.

MATERIALS AND METHODS

The pitcher used was a bottle-like made from a mixture of clay and sand. Its neck has diameter of 5 cm and height of 7 cm, and its body has diameter of 14 cm and height of 14 cm (Setiawan *et al.*, 1998). The pitcher has different saturated hydraulic conductivity as influenced by the composition of the mixture, which ranges between $7.88 \cdot 10^{-8}$ to $8.78 \cdot 10^{-6}$ cm/s (Saleh, 2000). Here, we used pitchers which have the values of the hydraulic conductivity in the ranges of $6.23 \cdot 10^{-7}$ to $7.25 \cdot 10^{-7}$ cm/s (Hermantoro, 2004). To figure out the ability of the pitcher to release solute, firstly we measured the diffusion coefficient by meant of Fick's law, Equation 1, (Bear and Verruijt, 1987 and Mehta *et al.*, 1995), in which the pitcher was immersed in a container filled with water, and a NaCl solution with known concentration was filled into the pitcher instantaneously. Changes of solute concentration inside and outside the pitcher were measured successively in a certain time interval. The concentration was measured with electrical conductivity meters, which was calibrated before hand. The same procedure was also used to measure the diffusion coefficient of NPK Solution.

$$\frac{\partial C}{\partial t} = D_w \frac{\partial^2 C}{\partial x^2} \quad \text{.......} (1)$$

Where, $\boldsymbol{C}$ is concentration in water (g/l), $\boldsymbol{D_w}$ is diffusion coefficient (cm^2/s), $\boldsymbol{x}$ is distance (cm), and $\boldsymbol{t}$ is time (d).

Secondly, dispersion coefficient of NaCl solution in soil was measured by meant of the inverse problem of the Convection Dispersion Equation, Equation 2, (Noborio *et al.*, 1996; Feyen *et al.*, 1998; Setiawan B.I. and M. Nakano, 1993), in with the pitcher was buried in the soil having water content distribution in a queasy-steady state. Soil samples were taken and measured analytically in laboratory.

$$\theta \frac{\partial C}{\partial t} = D_s \frac{\partial^2 C}{\partial x^2} - \bar{v}\theta \frac{\partial C}{\partial x} \quad \text{.......} (2)$$

Where, **C** is concentration in soil (g/l), $\boldsymbol{D_s}$ is diffusion coefficient (cm^2/s), $\boldsymbol{v}$ is average water flow velocity (cm/s), $\boldsymbol{\theta}$ is volumetric water content in soil (cm^3/cm^3), $\boldsymbol{x}$ is distance (cm), and $\boldsymbol{t}$ is time (d).

Thirdly, simulation of 2-D solute transport in the soil was carried out to see distribution of the solute in the soil matrices. This was done by solving the Equation 3 using Finite Difference Method and applying Alternate Directing Implicit Scheme (Hermantoro, 2004).

$$\frac{\partial C}{\partial t} = -v_x \frac{\partial C}{\partial x} + \frac{D_s}{\theta} \frac{\partial^2 C}{\partial x^2} - v_z \frac{\partial C}{\partial z} + \frac{D_s}{\theta} \frac{\partial^2 C}{\partial z^2} \quad \text{...} (3)$$

Where, **C** is concentration in soil (g/l), $\boldsymbol{D_s}$ is diffusion coefficient (cm^2/s), $\boldsymbol{v_x}$ and $\boldsymbol{v_z}$ are average water flow velocity in ***x***- and ***z***- axes, respectively (cm/s), $\boldsymbol{\theta}$ is volumetric water content in soil (cm^3/cm^3), ***x*** and ***z*** are distance (cm), and ***t*** is time (d).

Fourthly, four bush peppers were planted in the soil surrounding the pitcher in which NPK solution was inserted. Water level in the pitcher was maintained with mariotte tube. Changes of NPK solution in the soil were sampled and measured analytically, and growths of the plants, height, leaf, flowers, etc., were observed. Finally, the soil then excavated to observe the distribution of roots. These experiments were conducted in a green-house.

RESULTS AND DISCUSSIONS

Diffusion and hydrodynamic dispersion coefficients

Figure 1 shows changes of NaCl and NPK solution inside and outside the pitcher when immersed in the container filled with water. The inverse problem to solve Eq.1 with referred to Fig.1 gives $\boldsymbol{D_w}$ in the range of $1.01 \cdot 10^{-7}$~$4.1 \cdot 10^{-3}$ cm^2/d for NaCl solution and $6.7 \cdot 10^{-6}$~$3.5 \cdot 10^{-3}$ cm^2/d for NPK solution, witch were varied with concentration in the form of $\boldsymbol{D_w} = 1 \cdot 10^{-10} \boldsymbol{C}^{\,9.6832}$ for NaCl solution and $\boldsymbol{D_w} = 7 \cdot 10^{-9} \boldsymbol{C}^{\,6.2739}$ for NPK solution. In both cases, the Saturated Conductivity of the pitcher was $1.01 \cdot 10^{-4}$ cm/d.

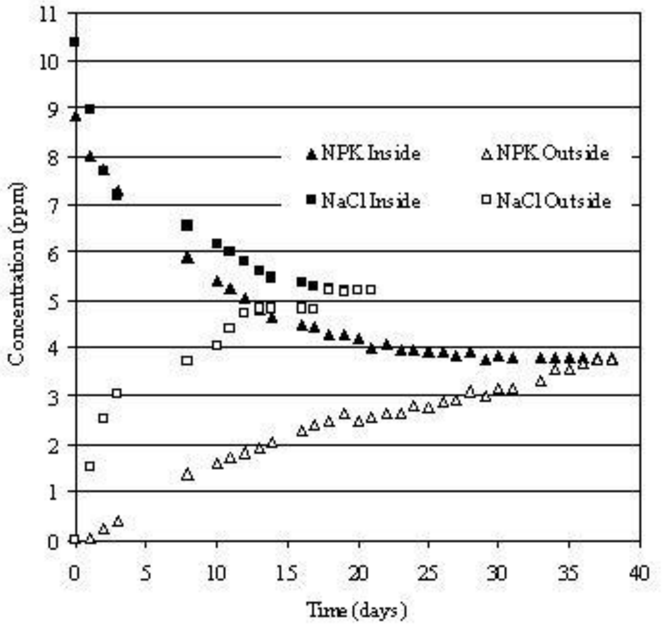

Figure 1. Changes of NaCl and NPK solutions inside and outside the pitcher

Hydrodynamic dispersion coefficient for NaCl solution soil, which was measured with the inverse problem of Equation 2, varied in the range of 0.3 to 0.825 cm^2/d with volumetric water contents of the soil were 0.60 ± 0.04 cm^3/cm^3. However, when Equation 2 was solved numerically, the value of the hydrodynamic coefficient had to be adjusted to get good conformity with the measured concentration of NaCl Solution. The best fitted dispersion coefficient was 0.45 cm^2/d. Figure 2 shows changes of relative concentration of NaCl Solution with distance and time.

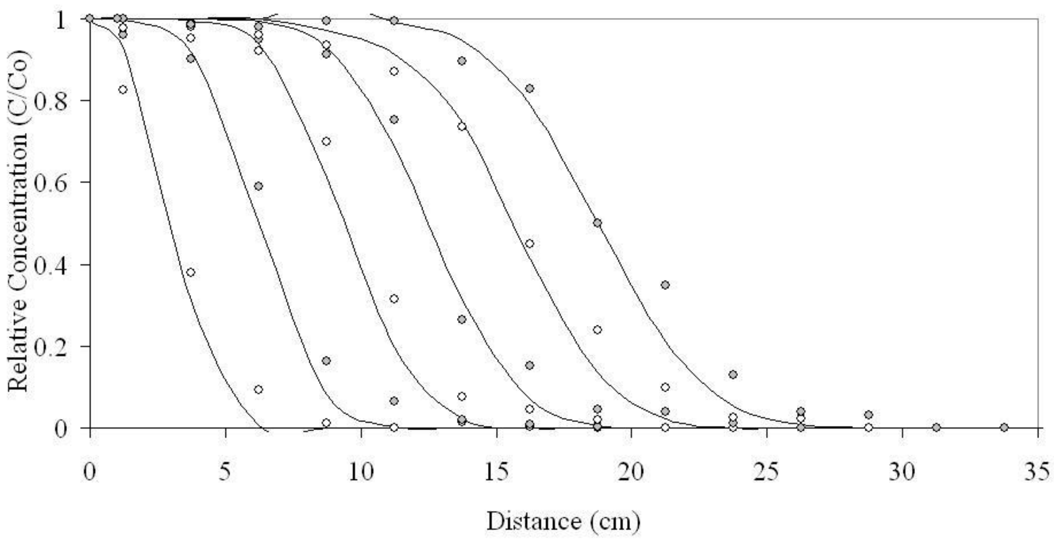

Figure 2. Changes of relative concentration of NaCl solution is soil matrices

Water flow and solute transfer in soil matrices

Profiles of volumetric water content and velocity distribution were obtained by means of solving Darcy and Richards' equation in cylindrical coordinate system. Figure 3a shows a stable distribution of water content in the soil, which was approximately attained 12.74 days after the initiation of irrigation. Water content was gradually distributed along x- and z-axes, where those regions closer to the pitcher are wetter. With the influence of gravity, moving front to z-axes was longer then that to x-axes. It is clear that in all regions the volumetric water content never reached saturated condition, where in the closest region to the pitcher, its value was about 0.67 cm^3/cm^3. These results were not far from those reported earlier (Setiawan, 1998) when the saturated conductivity of the pitcher was less then that of the soil. Velocity of water flow in x-and z-direction was obtained in each grid by means of dividing its related flux with the volumetric water content. The velocity varied with location and direction in the range of 0.18144 to 28.5984 cm/d. Correlation of numerical results (θ_m) and data measured (θ_d) in some points close to the pitcher obtained $\theta_m = 0.913 \cdot \theta_d$ and R^2=0.81. A cluster of data lower than 0.4 cm3/cm3 was overestimated by the calculation, while other data was well represented.

Calculation of solute transfer (Equation 3) was carried out instantaneously after the stable condition of water content was reached as stated before. Figure 3b show concentration profile of NaCl solution in the soil matrices after reaching at a stable condition 8.34 days from the beginning of the application. The similar form of distributions of water content and NaCl concentration was very clear with which it figures out the important of water as the effective medium of the NaCl solution transfer in the soil matrices. Here again, NaCl solution moved farther in z-axes than that in x-axes. The concentration was larger in the regions closer to the pitcher. At 1 cm apart from the pitcher, the relative concentration reached 0.89 while at the moving front was about 0.10. Correlation of numerical results (C_m) and data measured (C_d) in some points close to the pitcher obtained C_m= 0.874·C_d and R^2=0.81. Data was unevenly distributed in two clusters. One cluster was in the range of 0.2-0.4 while the other concentrated at 0.8. There was no data capable to measure between 0.4-0.8.

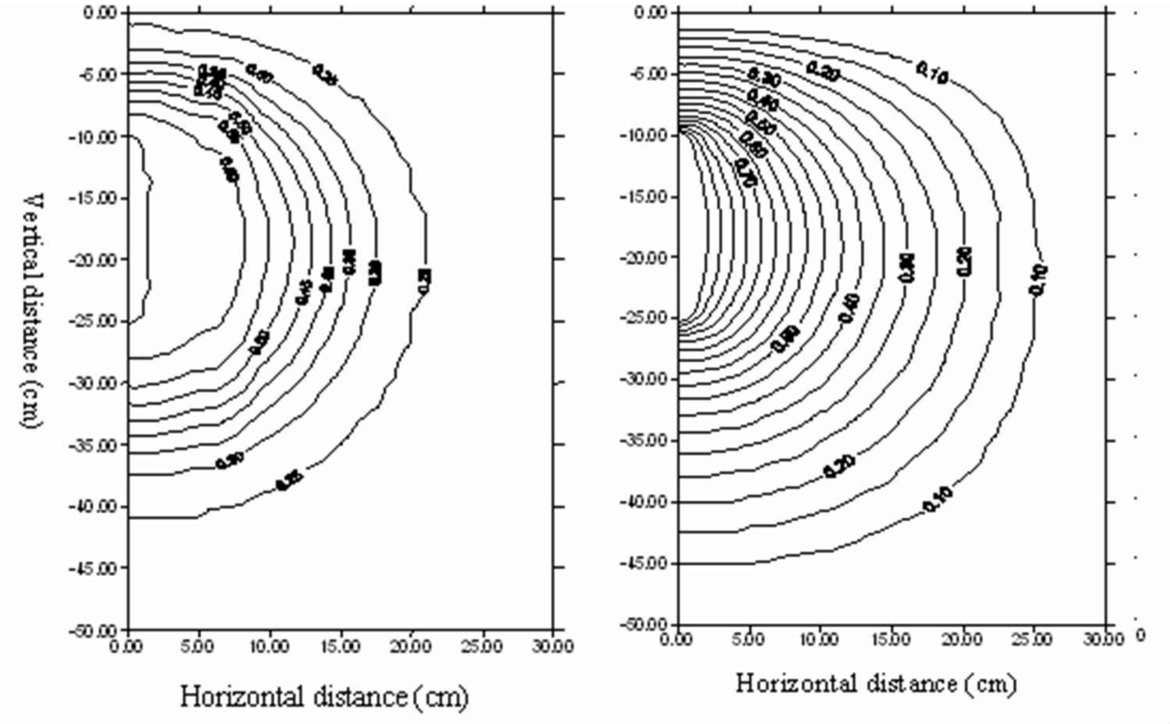

Figure 3. Profiles of volumetric water content (left) and relative concentration of NaCl solution in soil matrices

Application of pitcher fertigation

Figure 4 shows irrigation rate from one pitcher surrounded by four bush peppers. The irrigation rate fluctuated with time. The lowest and highest rates were 0.56 and 1.30 l/d, respectively with the averaged was 0.81 l/d, which is equal to 2.33 mm/d. While, evapo-transpiration rate which was measured independently were 1.9 to 4.3 mm/d with the average was 2.8 mm/d. With these values indicate that the irrigation rates much or less equals to the evapo-transpiration of bush peppers, or could meet the water demand of bush peppers for their growth and developments. Wet regions in the soil matrices formed like a standing oval-ball with a longer radius of 25 cm and vertical length of 70 cm.

Nitrogen content was distributed evenly in the soil matrices at ranges of 0.09 to 0.12%. Farther from the pitcher, Phosphor content decreased significantly, from 27 to 6.3 ppm. Potassium content changed abruptly but tended to decrease with distance, form 4.99 to 4.03 me/100g.

Roots were concentrating up to depths of 15 cm and its density decreased with depth and there were no roots anymore at 65 cm. Up to the depth of 10 cm, cumulative wet roots amounted to 50 gram.

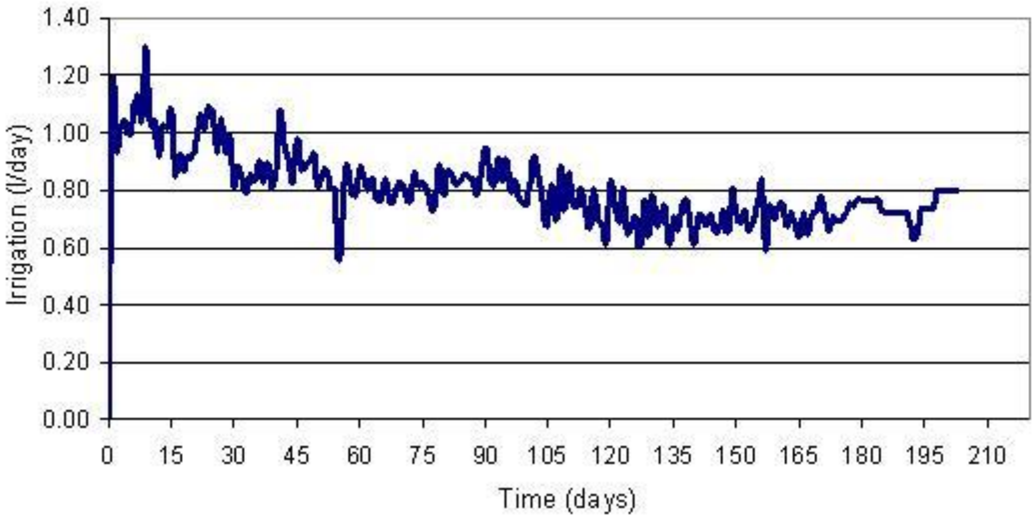

Figure 4. Changes of irrigation rate with time

Bush peppers grew rapidly to 60-70 cm heights in 30 weeks but then slow downed and only reached 65-75 cm in 5 days later. The maximum height was around 90-120 cm. Leaves development also followed these tendencies with the total number of leaves was 60-85 pieces. New branches started from 1 up to 35 weeks amounted to 13-16 branches. Flowers commonly appear when a new braches is coming out but old branches also produce flowers. Here, flowers increased linearly with time amounted to 7 flowers in 12 days but then constant up to 27 weeks, and amounted to 9 in 35 weeks. From these figures, the generative phase of bush peppers was higher than that of conventional farming using spraying irrigation. In another experiment when the dosage of NPK was decreased to 50%, there were no significant differences of bush peppers' growth and developments. Thus, it is possible to save fertilizer that was commonly used conventionally.

CONCLUSIONS

Pitcher fertigation has been examined for cultivating bush peppers in a green house. The pitcher which had saturated hydraulic conductivity $1.01 \cdot 10^{-4}$ cm/d, diffusion coefficient $6.7 \cdot 10^{-6} \sim 3.5 \cdot 10^{-3}$ cm^2/d for NPK solution could meet water demand and supply fertilizer sufficiently for the growth of the bush peppers. Water flow as well as solute transfers in the soil matrices could be determined theoretically using a combination of Darcy and Richards' equation and the convection-dispersion equation. Water as well as fertilizer was concentrated and formed like a ball in the soil matrices surrounding the pitcher where most of the roots of bush peppers resided. Bush peppers could grow well as indicated by the developments of roots, leaves, branches and flowers. It is possible to reduce the dosage of fertilizer application that conventionally applied without the risk of decreasing yields.

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