The relationship between soil nitrate distribution and growth rate of *Capsicum frutescens* in subsurface flow constructed wetland integrated with household septic tank

Y D Prasetyatama*, Ngadisih, R Maftukhah, R E Masithoh, J N W Karyadi and L Soetiarso

Department of Agricultural and Biosystem Engineering, Faculty of Agricultural Technology, Universitas Gadjah Mada, Indonesia

Corresponding author: yudha_dwi_prasetyatama@ugm.ac.id

**Abstract.** Domestic wastewater treatment unit consisted of a single chamber septic tank and Subsurface Flow Constructed Wetland (SFCW) was built in Yogyakarta, Indonesia. SFCW played a significant role as secondary treatment of septic tank effluent. This study aimed to analyze the soil nitrate and its distribution in sand layer of SFCW. The SFCW had a depth of 0.2 m of coral and sand layers with two leach pipes that were installed in the depth of 0.3 m along the garden and planted with chili (*Capsicum frutescens*). Soil nitrate content of SFCW and plant growth were analyzed for 8 weeks of observation. Soil samples were taken in different direction, both vertical and horizontal. In vertical direction, samples were taken with three different depth (10, 15, and 20 cm) from the surface. In horizontal direction samples were taken with three different distance from outlet pipe. Soil nitrate obtained in vertical direction was significantly different ($P<0.005$) with soil nitrate at the depth of 20 cm was higher than 15 cm and 10 cm. However, the soil nitrate obtained in horizontal direction was not significant ($P>0.05$). The soil nitrate has positive correlation with plant growth, the higher soil nitrate will increase the plant growth.

1. **Introduction**

Groundwater pollution of nitrate is one of the most critical and increasing problem worldwide. The main cause of this problem is septic tank effluent which is not treated with secondary treatment process [1]. In several rural area of Indonesia where people do not have proper septic system, high concentrations of nitrate which exceeded the safety level for consumption were detected in the water wells [2,3]. Nitrate is highly soluble in water and when drinking water contains a high concentration of nitrate, a number of health disorder namely methemoglobinemia, gastric cancer, goiter, and birth malformations hypertension can be health problems for human [4].

Subsurface constructed wetland (SFCW) is one of common wastewater technology which is designed to utilize plants, substrates, and their microbes to remove nitrogen contaminants from wastewater. Wetland plants such as *Phragmites australis* are use on constructed wetland to absorb nitrogen contaminants from wastewater as well as to improve the microenvironment of wetland beds [5]. However, there are few published studies on the effect of food plant such as *Capsicum frutescens* growth periods on nitrate removal.
The SFCW consists of a sub-surface irrigation system and a ground-level-garden. A sub-surface outlet irrigation is evenly distributed from the septic tank, through perforated pipes, to the surrounding gravels and soil, where the residual organic matters in the wastewater are gradually removed by aerobic microorganisms. Through this overall process, the cleaned wastewater eventually enters ground water and is fully recycled as safe water, while the harvested economic plants in the garden may compensate for the cost of SFCW maintenance. The quality of treated water produce from SFCW will depend on the filtration that had occurred in the system, the growth of plants and the size of the system [6]. The use of soil as a treatment medium and wastewater as nutrient source was studied as an alternative to the customary discharge of effluents into water bodies [7]. The reuse of wastewater for irrigation may have many beneficial effects as it increases the organic matter (OM) content of the soil thus presenting several advantages for crop production [8].

The organic chemical content of wastewater can be utilized by plants, especially the nitrogen compound in the form of nitrate. Nitrogen is essential for plant growth in each stage, especially at the vegetative stage such as development of stems and leaves. Nitrogen can be absorbed by plants in the form of nitrate (NO$_3^-$) and ammonium (NH$_4^+$) ions [9]. Research done at the Canary Islands showed that banana trees irrigated using secondary effluent could grow better than the conventional cultivation and it was safe to be consumed [10]. The plants absorb pollutants, pathogens, as well as nutrients that has been reacted by microorganisms from the waste aforesaid. Eventually, there will be a gradual increase of plant’s productivity that play a crucial role not only in economic, environmental and agricultural aspects, but also for the welfare of inhabitants. However, a study regarding nitrate concentration in SFCW and growth of Capsicum frutescens has not yet been conducted. It is necessary to investigate relationship between nitrate concentration in vertical and horizontal direction of SFCW with the growth of Capsicum frutescens.

The aims of this study were to: (1) investigate soil nitrate distribution on SFCW in vertical and horizontal direction. This SFCW was built in an open space, treating household septic tank effluent, using two horizontal leach pipes and filled with sand and gravel layer; (2) investigate the growth of chili plant and its relationship with soil nitrate available on SFCW.

2. Materials and methods

2.1. Experimental setup of subsurface flow constructed wetland
The horizontal Subsurface Flow Constructed Wetland (SFCW) with 6 m$^2$ area was built in Piyungan sub-district, Bantul, Yogyakarta. There are four adult members of family who use the toilet. Septic tanks are used to collect wastewater both blackwater and greywater with total flowrate of 140 l/day. The septic tank is watertight and designed with overflow system (Figure 2) so that the effluent from septic tank can be assumed to have the same flowrate with septic tank input flowrate of 140 l/day.

As shown in Figure 1, SFCW consist of 2 (two) different layers (sand and gravel layers). Each layer has 20 cm depth. Sand used in the SFCW have particle size of 0.02–2 mm while gravel have 10–27 mm of particle size as shown in Figure 3. There are two horizontal leach pipes buried in SFCW. Each leach pipe (PVC pipe 3 inch) is perforated with 3 mm holes along the pipe at the bottom side, and located on 10 cm below the bottom of sand layer. Those leach pipes are used to distribute septic tank effluent to SFCW.

2.2. Control garden
As references, one unit of control garden was used and treated using conventional cultivation method. Control garden is located near SFCW so that it can be assumed to have the same rainfall intensity. Latosol soil (Figure 3) was used in the control garden without having any blackwater or greywater irrigation. Both SFCW and control were planted with Capsicum frutescens.
2.3. Soil nitrate and rainfall intensity measurements

Soil sampling was conducted once a week for eight weeks starting from December 2017 to February 2018. The samples were collected from three different location on SFCW (A, B, and C) as shown in Figure 1 and control garden. For each location, soil sample was taken from three different depth (10 cm, 15 cm, and 20 cm). The soil sampling was also conducted in control garden using the same depth. The calcium sulphate extraction method was used to extract nitrate-nitrogen from soil samples and nitrate concentrations were measured spectrophotometrically using LW Scientific model UV-200-RS at 570 nm absorbance [11]. During soil sampling, rainfall intensity data was collected from Balai Pengelolaan Sumber Daya Air (PSDA) Special Region of Yogyakarta.
2.4. Plant growth measurement
On top of the sand layer, *Capsicum frutescens* was planted in three different location (Figure 1). The plants were planted on SFCW and control garden on 51 days after pre-plantation. The plant growth parameters measured during research is stem length [12].

2.5. Data analysis
Soil nitrate and plant growth data was analyzed graphically, as well as descriptive statistical methods. The SPSS 16.0 was used for the statistical analysis. The differences in soil nitrate among different direction (vertical and horizontal) and plant growth were analyzed using one-way analysis of variance (ANOVA).

3. Results and discussion

3.1. Soil nitrate profile
During the observation period (8 weeks), the rainfall rate varies widely with the highest rainfall rate occurred at the 7th week of observation. The soil nitrate of SFCW and control garden are found to be affected by rainfall intensity as shown in Figure 4. The higher rainfall intensity lead to lower nitrate concentration compared to the previous week. That trend can be found in all soil nitrate sampling locations (SFCW and Control Garden). Figure 4 also showed that nitrate concentration in different SFCW was fluctuated during observation. Initially, soil nitrate concentration is observed at high level of concentration, and then it rapidly decreased. This result is obtained because of leaching process occurred when the rainwater infiltrate into sand layer. Nitrate is soluble in water and most of soil nitrate loss occurred during the first 18 minutes of rainfall [13].

![Figure 4. Soil nitrate profile on each sampling location](image_url)

The comparison among three different sampling location indicates that there are soil nitrate differences among three different depth. All sampling location show the deeper sampling has the higher soil nitrate as shown in Figure 4. From statistical analysis, it is found that soil nitrate was significantly different in vertical direction (p<0.05). Nitrate is assumed not to be absorbed by sand particles and therefore leaches easily. Because of that, the nitrate distribution follow the wetting front.
In addition, higher soil nitrate also caused by the position of leach pipe from septic tank which is buried in the depth of 300 mm.

In horizontal direction, soil nitrites are not significantly different (p>0.05) in all three different sampling locations (A, B, and C in Figure 4). This result is obtained because of two horizontal leach pipes used in SFCW. The leach pipes can distribute the septic tank effluent to all area with the same depth. The vertical distance of 1000 mm between each leach pipe is effective to distribute the septic tank effluent.

Compared to soil nitrate of control garden, soil nitrate in all locations in SFCW are lower than soil nitrate of control garden both in vertical and horizontal direction (Figure 5 and Figure 6). Control garden, which was using conventional cultivation method, showed higher soil nitrate due to the use of latosol soil as growth medium while SFCW used sand as growth media. This result is obtained because all type of soil, including latosol soil, has better properties for plant growth compared to sand.

3.2. Plant growth profile
During observation, the stem length growth rate of chili plant in SFCW was only 5.81 cm/week which is lower than stem length growth in Control Garden (3.71 cm/week). This result has positive correlation with soil nitrate concentration difference between SFCW and Control Garden. SFCW has lower soil nitrate concentration in all data measured during observation.
4. Conclusion

Soil nitrates are significantly different in vertical direction with the highest soil nitrate obtained on 20 cm depth for all sampling location. Meanwhile, soil nitrates in horizontal direction are not significantly different because of two horizontal leach pipes used in SFCW. The leach pipes can distribute septic tank effluent to all area with the same depth. Soil nitrate concentration has positive correlation with plant growth. The higher soil nitrate concentration resulted faster plant growth. It also can be concluded that rainfall can decrease soil nitrate concentration because of the increasing water flowrate downward the sand and gravel layers. Rainfall can be seen as critical factor of the availability of nitrate as plant nutrient.

In future studies, the soil nitrates measurements could be done with more sampling location and longer period of observation to obtain more data to study the performance of SFCW. The plant growth could also be monitored until reach the maximum growth and produce fruits.

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